OPPORTUNITIES FOR SAFETY IMPROVEMENTS IN MOTORCYCLE CRASHES IN THE UNITED STATES

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ABSTRACT

Given the steady growth of the crash problem since the late 1990s, a descriptive analysis of motorcycle crashes on U. S. roads was performed to gain insight into crash causation and investigate opportunities for improving rider safety. Data from the 1992-2004 National Automotive Sampling System/General Estimate System (NASS/GES) were studied relative to crash configuration and rider, motorcycle, and environment characteristics. Data trends before and after 1998 were examined. Key findings show that, in addition to the increase in crash risk due to exposure, motorcycle crashes are becoming more deadly. Contributing factors to increased severity and higher fatalities rates were: increased road departures and decreased helmet use for riders, especially those under 19 or 40-49 years of age, increased alcohol involvement for riders ages 30-49; vehicles turning into the path of the motorcycle, and head on crashes; lack of awareness of the impending crash; vulnerability of over 750cc engine size motorcycles in frontal crashes; riding on roads with higher speed limits; crashes away from a junction, and riders over 40 in dark road conditions. Overall, as compared to all crashes, a rider was about two times more likely to be killed in a road departure. Also, riders under age 30 were most vulnerable followed by riders over 50 in all motorcycle crashes. Findings support opportunities in safety strategies such as rider education, grouped by age, relative to speeding, helmet use, and alcohol consumption. Findings also support opportunities in countermeasures such as improved visibility including enhanced lighting, for the motorcycle and/or roadway, and improved performance of larger motorcycles in frontal crashes. Findings highlight the need to study the vulnerability of riders over 50 in motorcycle crashes and the need for a more in-depth study of the growing road departure motorcycle crash problem.

INTRODUCTION

The number of motorcycle riders killed in traffic crashes on United States (U. S.) roads has increased for eight years in a row and has more than doubled since 1997 [1]. This increase recently overshadowed the decrease in passenger car crash fatalities and has led to an overall increase of traffic fatalities in the U. S. In 2005, 4553 motorcycle riders died in U. S. crashes, accounting for 10.5% of all traffic fatalities. Given the recent growth of the motorcycle crash problem on U. S. roads, there is a critical need to gain an understanding of the factors contributing to motorcycle crashes. In this paper, results from a nationally representative descriptive analysis of U. S. motorcycle crashes are presented, including assessment of problem size and examination of recent trends. The goal of the research was to gain insight into crash causation and investigate opportunities for improving rider safety.

STUDY POPULATION AND METHODS

Database Selection - In the U. S., there are two national traffic crash databases: the Fatality Analysis Reporting System (FARS) starting in 1975, and the National Automotive Sampling System (NASS) starting in 1988. FARS is a census of all fatal crashes and, as such, includes motorcycle fatalities. NASS is a stratified sample of police reported crashes of all severities and is composed of two systems: the General Estimate System (GES) and the Crashworthiness Data System (CDS). National estimates are calculated from NASS data by applying a national weight for each case. This national weight is the product of inverse probabilities of selection in a three stage sampling process.

Although CDS includes detailed vehicle, crash scene, and occupant data that allow study of injury mechanisms, the 5,000 tow-away crashes that are investigated per year do not include motorcycles. NASS/GES used for this study samples around 55,000 cases per year with major property damage, injury, or death from the several million police-reported crashes. GES data taken from police reports include motorcycle crashes and incorporates pre-event, rider, vehicle, environment, and limited injury data. NASS/GES was the source of the overall number of crash fatalities.

Crash Population - Weighted NASS/GES data from 1992-2004 of crashes with at least one motorcycle were used for this study. Motorcycles of all engine displacements were included. ATVs (all terrain vehicles) were excluded. The study population involved a national

estimate of 1,003,665 riders (motorcycle operators and passengers) summarized in Table 1.

Table 1. 1992-2004 NASS/GES Motorcycle Population

Crash Types	Sample Size	National Estimates
Single-Vehicle: one motorcycle	**9,993** (291)	**437,261** (9,993)
Two-vehicle	**9,904** (258)	**536,857** (9,904)
Multiple Vehicle	**631** (35)	**29,547** (631)

Fatalities in ()

Motorcycles made up 2.54% of total vehicle registrations in 2005, with a low of 1.86% in 1998 and a high of 3.9% in 1981 [1]. Furthermore, motorcycle traffic exposure is expected to be far lower than registrations. In the landmark study by Hurt et al of on-scene and in-depth investigations of motorcycle crashes in Los Angeles during 1976 and 1977, motorcycles were reported to be 4% of registrations but were only 0.5% of vehicles observed in traffic [2]. In effect, seven out of eight motorcycles were parked at home in the garage. This leads to motorcycle crashes being a small segment of the police reported crashes sampled by GES. The sparse sample size is accentuated when looking at fatal crashes, which occur less frequently. Fatal motorcycle crashes are believed to be under-represented in GES. In the case of motorcycles, GES is more suited to look at trends and problem characterizations using data collected over several years.

In this paper, crash configuration, rider, motorcycle, and environment characteristics were investigated by grouping thirteen years of weighted GES data from 1992 to 2004. The variables investigated variables are listed in Table 2. Although the visual obstruction and speed relation variables for the motorcycle rider were examined, results were deemed to be less reliable.

Table 2. GES Variables Investigated

Crash Configuration: - Accident Type	**Rider Related:** - Injury Severity - Age - Safety Equipment Use - Restraint System Use (helmet) - Police Reported Alcohol Involvement - Driver Maneuvered to Avoid - Vehicle Maneuver - Corrective Action Attempted
Environment Related: - Speed Limit - Relation to Junction - Light Condition - Visual Obstruction - Road Surface Condition	
Motorcycle Related: - Make - Make (engine size) - Vehicle Contribution Factor	

Motorcycle crashes had a downward trend in 1992-1997 followed by an upward trend in 1999-2004 as shown in Figure 1. A trend analysis grouping the two ranges of years was also performed. Crash characteristics were compared between the two ranges of years to study both involvement and severity for motorcycle crashes as shown in the sections below. Injury rates per 100 crash-involved occupants were examined and are presented beginning in Table 5.

Crash Configuration Groupings - The standard GES crash configuration groups were reassigned (Table 3) to better define the role of the motorcycle in the crash. The new assignments specify the crash configuration relative to the motorcycle. For example, in the case of rear-end with a passenger vehicle, the new groups identify if the motorcycle impacted the rear of the passenger car or vice-versa.

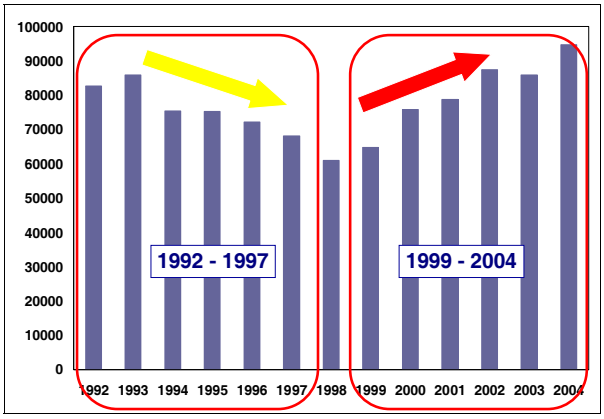

Figure 1. Recent Trends of Motorcycle Crashes (GES)

Table 3.

GES Category	**Study Crash Configuration**: GES ACCIDENT TYPE Codes
Single-Vehicle Crash	**Road Departure**: 01-10 **Frontal Impact:** 11-16
Pair and Multiple Vehicle Crashes	**Frontal Impact:** 20, 24, 28, 34, 36, 38, 40, 50-63, 69, 71, 73, 80, 81, 83, 86, 88 **Sideswipes:** 44-49, 64-67, 76-79 **Side Impact:** 68, 70, 72, 82, 87, 89 **Rollover:** 97 **Rear:** 21, 22, 23, 25, 26, 27, 29, 30, 31, 35, 37, 39, 41 **Other:** 92,93,98,99,00

Note: GES ACCIDENT TYPE codes [3]

Some GES cases were eliminated because the specifics were unknown and the role of the motorcycle could not be

determined. Most of these were multiple vehicle crashes. This resulted in 18,358 cases lost from 1,003,665 or less than 2% of the study population.

Injury Severity Groupings - The GES injury severity codes were grouped as non-severe injury, severe injury, and fatal injures (Table 4).

Table 4. Study Injury Groups

	GES codes
Fatal Injury= K	K : Fatal Injury
Severe Injury = A	A : Incapacitating Injury
Non-Severe Injury = B+C+U	B : Non-incapacitating Injury C : Possible Injury U : Injured, Severity Unknown

OVERALL MOTORCYCLE CRASH TREND AND RISK ASSESSMENT

Motorcycle crashes and resulting rider fatalities have followed a similar trend in the last decade (Figure 2). In fact, since the mid 1980s, both the number of motorcycles on U. S. roads (registrations) and rider fatalities were decreasing until the reversal of trend in the late 1990s (Figure 3). The increase in motorcycle registrations, driven by the rapid increase in sales shown in Figure 3 [4], is a main factor contributing to the increase in motorcycle crashes on U. S. roads.

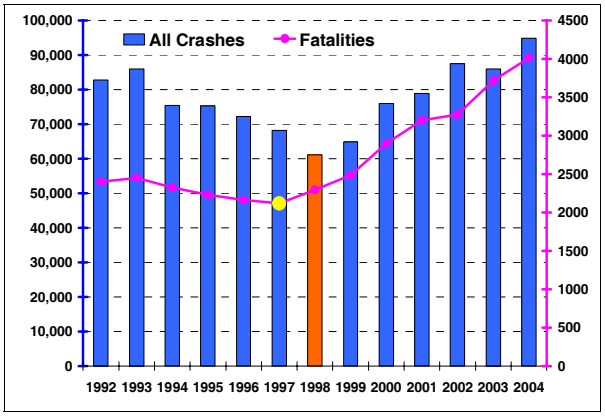

Figure 2. Motorcycle Crashes and Fatalities Trend. Crashes (weighted GES 1992-2004), Fatalities (FARS).

If we account for the increase in the size of the motorcycle fleet by normalizing with the number of registrations from the Federal Highway Administration (FHWA) [5], we find that motorcycle fatality rates per 100,000 registered motorcycles increased from a low of 55 in 1997 to 73 in 2005 (Figure 4).

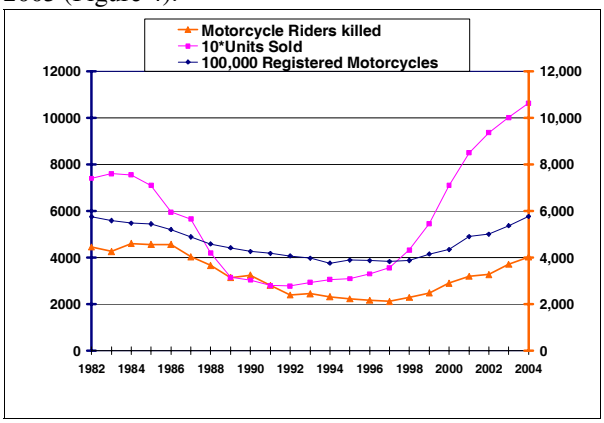

Figure 3. Motorcycle Fatalities (FARS), New Unit Sales (Motor Cycle Industry Council), Registrations (FHWA)

Motorcycle fatality rates have been rising since 1997 while, in comparison, passenger cars fatality rates have been steadily decreasing. Motorcycle riders represent a very vulnerable segment of road users in the U.S. In 2005, riders were 5.4 times more likely to be killed in motor vehicle traffic crashes per registered vehicle than occupants of passenger cars (who had a fatality rate of 13.6 per 100,000 registrations).

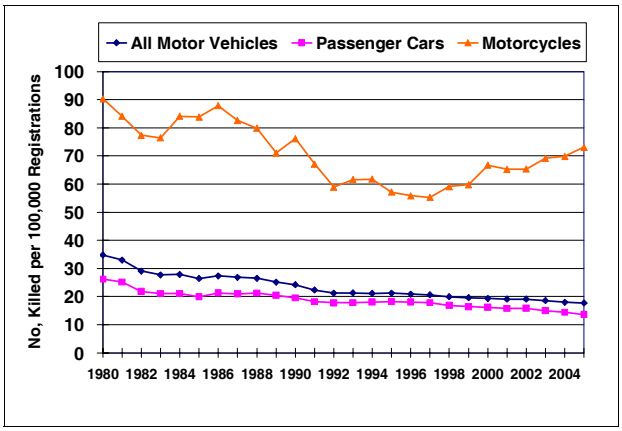

Figure 4. Fatality Rates per 100,000 Registered Vehicles (FARS, FHWA)

Risk Assessment - Are motorcycle crashes just becoming more prevalent and thus resulting in higher fatality rates per registered vehicle or are motorcycle crashes also becoming more dangerous? To obtain some insight into this question, the number of motorcycle crashes with different severity outcome (fatal, severe injury, non-severe injury, and no injury) per 100,000 registered vehicles was used as a relative measure of risk. Fatal risk was the ratio of fatalities from FARS and the injury risks were based on data from GES. The ratio for the total number of crashes was defined as involvement risk. It is worth noting that

miles traveled per registration would be the preferred metric for exposure. However, at this time, there is not much confidence in the miles travel data for motorcycle in the U. S. [6].

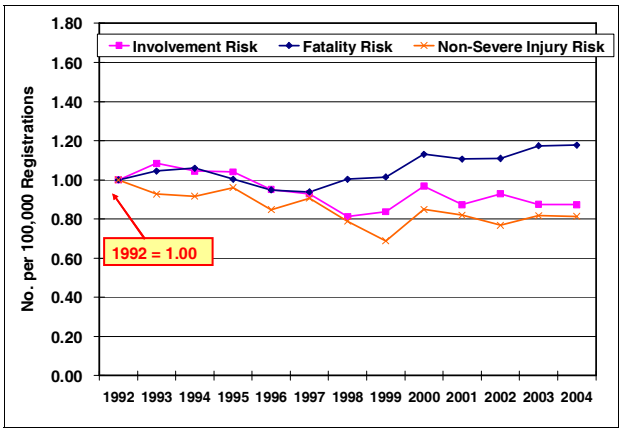

Figure 5. Motorcycle Crashes and Fatalities Risk Trend

In 2004, the risk for crash involvement decreased to 87% and non-severe injury risk decreased to 81% of 1992 levels, while the fatality risk was 18% higher in 2004 than in 1992 (Figure 5). This indicates that, although that there seems to be fewer crashes per registered motorcycle, the crashes tend to be more deadly in recent years.

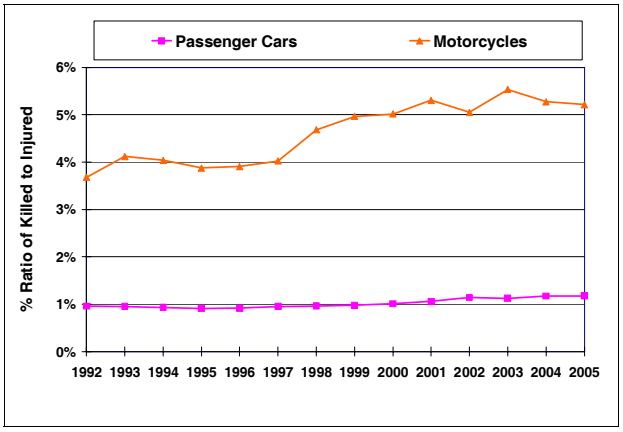

Figure 6. Ratio of People Killed (FARS) to the Number Injured in U. S. Crashes (GES) Trend

As another measure of risk, the ratio of people killed to the number injured people in traffic crashes over the last fourteen years was considered. For motorcycles, this ratio increased from 3.7% in 1992 to 5.2% in 2005 (Figure 6). In contrast, the ratio for passenger cars has more or less stayed in the same range with a relatively small increase (1% to 1.2%). This provides further evidence that, in addition to becoming more prevalent, motorcycle crashes are becoming more severe.

MOTORCYCLE CRASH CHARACTERISTICS

Crash Configuration - Single-vehicle crashes, where only the motorcycle was involved, made up 44.2 % of the 1992-2004 GES population. Crashes with one other vehicle were 52.8% and crashes with multiple vehicles were 3.0%. The percent of single-vehicle crashes has been increasing in recent years to 47.5% in 2004 (Figure 7).

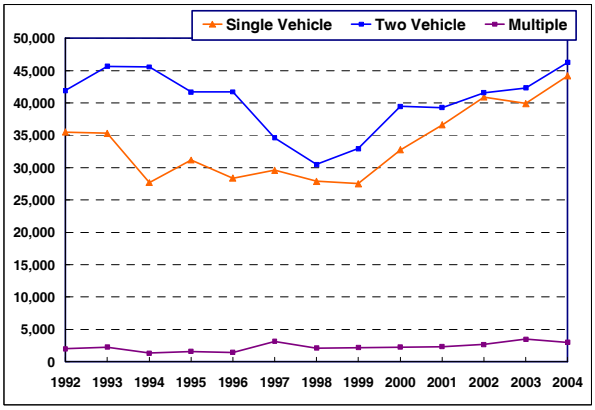

Figure 7. Motorcycle Crash Types (GES)

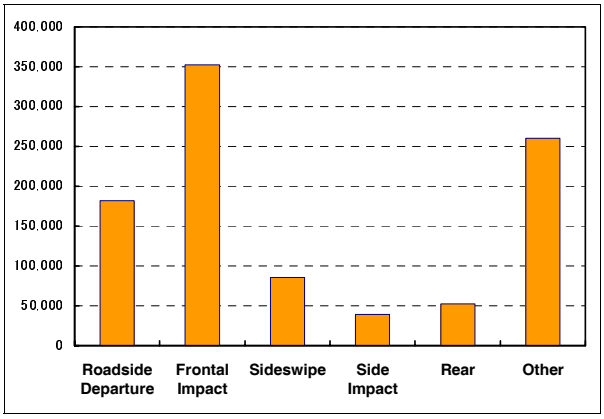

Figure 8. Motorcycle Crash Configurations (GES 1992-2004)

Frontal impact and road departure are the most common U.S. motorcycle crash configurations; both have been increasing in recent years (Figures 8 and 9). They are also the two most common configurations for all injury severities, especially fatal crashes, accounting for 75% of motorcycle riders killed from 1992-2004 (Figure 10).

However, road departures were especially lethal, accounting for 18.7% of all motorcycle crashes but 36.8% of the fatalities in the 1992-2004 GES data (Figures 9 and 10).

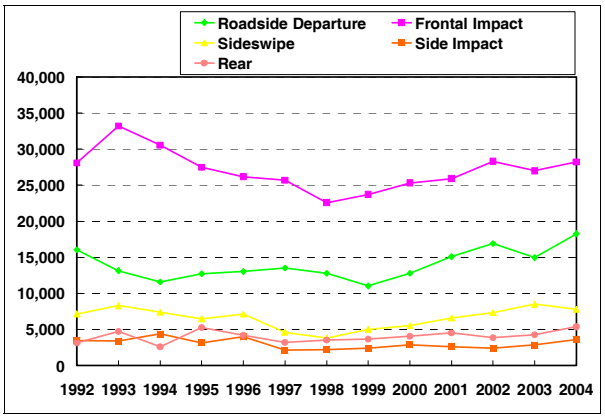

Figure 9. Motorcycles Crash Configurations Trend (GES)

As compared to all motorcycle crashes, a rider was about twice as likely to be killed in a road departure (ratio of 1.97 times). This corresponds to 1675 riders killed in road departures crashes from a total of 4553 fatalities in 2005 based on FARS. Frontal crashes were 36.3% of the GES crashes and resulted in 39.2% of the fatalities (1784 in 2005 based on FARS).

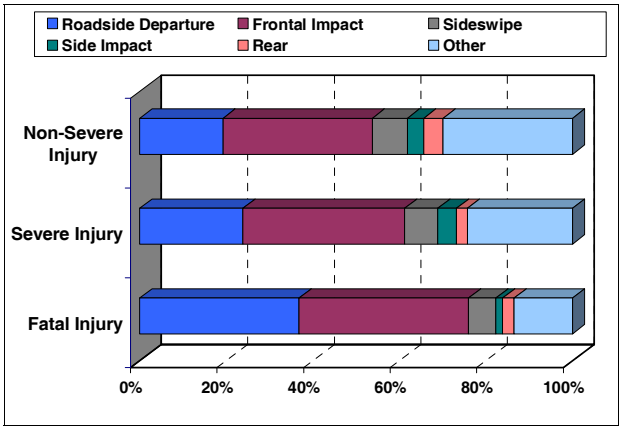

Figure 10. Injury Severity by Motorcycle Crash Configuration (GES 1992-2004)

Table 5.
Injury Rates per 100 Involved Riders in Frontal Crashes

	1992-1997 GES	1999-2004 GES
Fatal	2.5	4.3
Severe Injury	26.2	27.7
Non-Severe Injury	53.2	48.9
No Injury	18.1	19.2

When comparing injury rates per crash before 1998 and after, GES data shows that both frontal and road departure crashes have become more severe in recent years (Tables 5 and 6). Deaths and severe injuries were a bigger percentage of the total crash population after 1998, while the percentage of non-severe injuries declined. Road departures had a higher fatality rate of 6.5 as compared to 4.3 for frontal crashes after 1998.

Table 6.
Injury Rates per 100 Involved Riders in Road Departures

	1992-1997 GES	1999-2004 GES
Fatal	4.5	6.5
Severe Injury	28.4	30.4
Non-Severe Injury	57.9	54.5
No Injury	9.1	8.6

Motorcycle Frontal Crashes - For a more in-depth examination, the frontal crash grouping was subdivided into six configurations outlined in Figure 11.

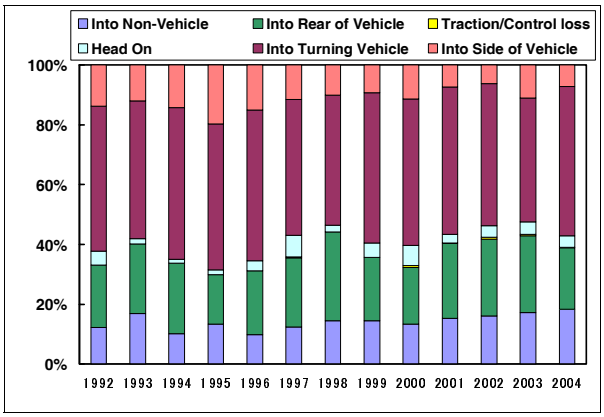

Figure 11. Motorcycle Frontal Crash Configurations

"Into Turning-Vehicle" configuration basically involves another vehicle turning into or across the path of a motorcycle moving straight forward. It is the most prevalent frontal crash configuration from 1992 through 2004, making up at 48.4% of the frontal crashes (Table 7) and 17% of all motorcycle crashes in the GES sample. . "Into Rear of Vehicle" and "Into Non-Vehicle" follow at 23.4% and 13.5% of all frontal crashes respectively in 1992-2004.

Table 7. Motorcycle Frontal Crashes GES (1992-2004)

	% Frontal	% all GES	% Frontal Fatal	% all GES Fatal	Fatality Rate
Into Non-Vehicle	13.5%	4.7%	7.8%	3.0%	1.7
Into Rear of Vehicle	23.4%	8.2%	17.3%	6.7%	2.2
Head On	3.1%	1.1%	20.5%	8.0%	19.2
Into Turning Vehicle	48.4%	17.0 %	45.0%	17.6%	2.7
Into Side of Vehicle	12%	4.1%	9.4%	3.7%	2.4

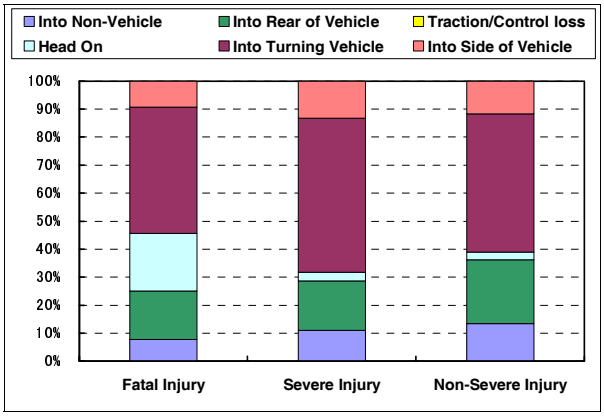

Figure 12. Motorcycle Frontal Crashes by Injury Severity (GES 1992-2004)

Head on crashes were only 3% of all the frontal crashes, but were vastly over-represented in fatalities, accounting for 20.5% of the riders killed. Crashes, where another vehicle turned into or across the path of a motorcycle, resulted in 45% of the fatalities for frontal collisions (Figure 12). Crashes where the motorcycle rear-ended another vehicle accounted for another 17.3% and crashes where the motorcycle crashed into the side of another vehicle resulted in 9.4% of the riders killed in frontal motorcycle crashes.

"Head On" motorcycle crashes have an exceptionally high fatality rate: 22% of head on collisions result in the rider being killed.

Rider Age - In 2004, riders in their twenties were still the largest segment (28%) of crash involved motorcycles riders; however, riders in their forties and fifties increased rapidly while the proportion of teenagers declined (Figure 13). In 2004, riders aged 40-49 were 23% of the GES crash population. Riders under 30 years old were 36% and riders over 40 were 43% of crash involved riders.

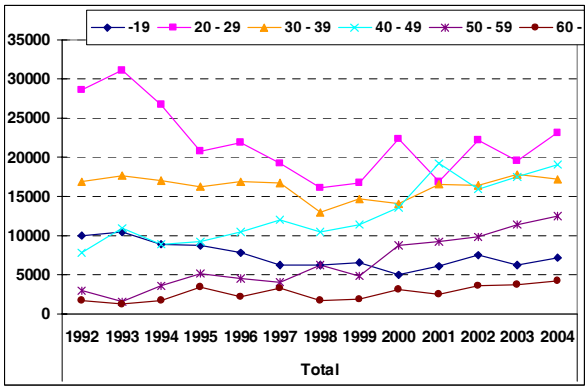

Figure 13. Rider Age in Motorcycle Crashes (GES)

Comparing involvement and fatality rates per crash involvement in the two ranges of years (1992-1997) and (1999-2004), riders under 30 years old were 42% of crash population and 51% of fatalities before 1998 but decreased to 36% of the accident population and 38% of fatalities after 1998. On the other hand, riders over age 40 increased from 24% of the crash population and 23% of the fatalities before 1998 to 38% of crashes and 40% of the fatalities after.

Rider Age in Frontal Crashes: Similar to the overall trend, the proportion of riders aged 40–49 and 50–59 involved and killed has increased in frontal crashes in recent years (Table 8 and Figures 14 and 15). However, while the number of crash involved riders in their twenties has decreased, they were a larger proportion of frontal crash fatalities in later years. Considering the ratio of fatalities to crash involvement, under 30 riders were 1.9 times more likely to be killed in a frontal crash in 1999-2004 than in 1992-1997. Over-50 riders were 1.7 times more likely to be killed in later years.

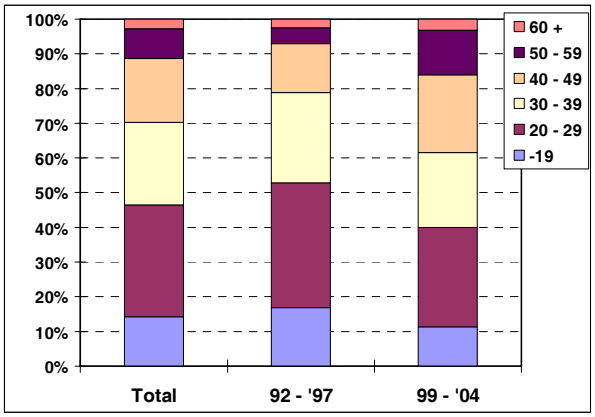

Figure 14. Trend of Frontal Crashes by Rider Age (GES)

Table 8. GES Frontal Crashes by Rider Age

	1992-1997		1999-2004		Fatality Rate	
Rider Age	**All**	**Fatal**	**All**	**Fatal**	**92-97**	**99-04**
-19	17%	12%	11%	6%	1.9	1.8
20 - 29	36%	28%	29%	37%	2.1	4.6
30 - 39	26%	40%	22%	19%	4.1	3.2
40 - 49	14%	13%	22%	20%	2.3	3.2
50 - 59	4%	2%	13%	13%	1.3	3.5
Over 40	21%	19%	38%	38%	2.3	3.6

Rider Age in Road Departures: There were similar trends for over-40 riders in road departures (Table 9). Riders under 30 were also twice more likely to be killed in a road departure in 1999-2004 than in 1992-1997. Riders

aged 40-60 were 1.5 times more likely to be killed in road departures in the later years.

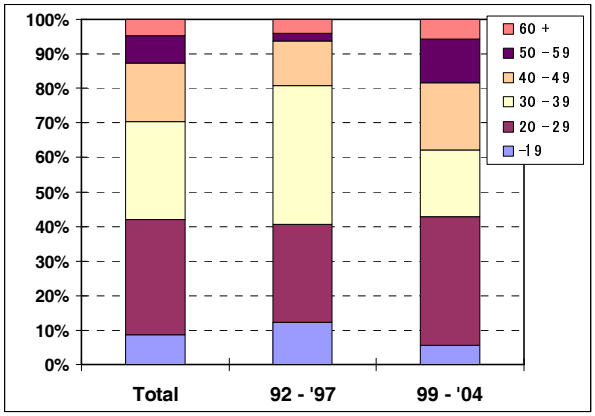

Figure 15. Trend in Fatal Frontal Crashes by Rider Age (GES)

Table 9. GES Road Departures by Rider Age

	1992-1997		1999-2004		Fatality Rate	
Rider Age	**All**	**Fatal**	**All**	**Fatal**	**92-97**	**99-04**
-19	13%	4%	8%	5%	1.5	4.0
20 - 29	38%	36%	29%	36%	4.3	8.0
30 - 39	25%	32%	23%	23%	5.9	6.4
40 - 49	14%	11%	20%	17%	3.3	5.5
50 - 59	6%	9%	14%	18%	6.8	8.4
Over 40	24%	27%	39%	35%	5.2	5.9

Rider Action - In 55% of recent motorcycle crashes, the rider was going straight prior to impact or prior to realizing an impending harmful event; however, in around 15% of the crashes the rider was negotiating a curve (Figure 16).

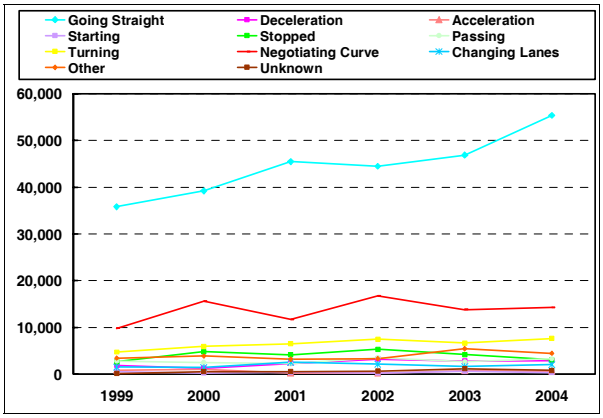

Figure 16. Motorcycle Rider Pre-Crash Action (GES)

As reported by GES, eighty percent of riders took no pre-crash evasive action in 1992-1997 (Figure 17) but this decreased to 73% in recent years. The driver attempted to brake and/or steer in 20% of the crashes after 1998.

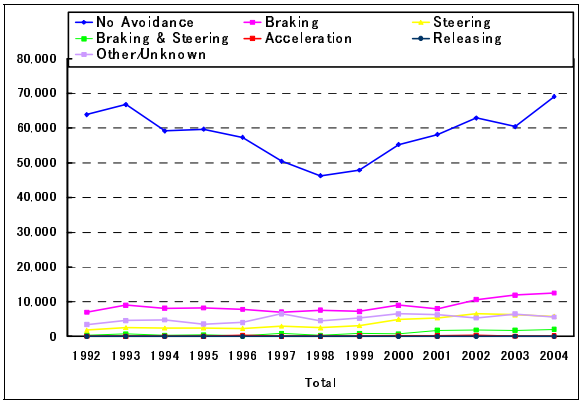

Figure 17. Crash Avoidance Action Taken by the Motorcycle Rider (GES)

In the GES data, in most crashes and at all severity levels, the rider was not able to or did not attempt any avoidance maneuver (Figure 18). In fatal crashes, 71% of all riders killed did not maneuver. The 50-59 age riders did not attempt to maneuver in 77% of fatal crashes. Given the challenges to establishing avoidance maneuvers from reports prepared by police officers who often lack any training or expertise in motorcycle accident investigation, these estimates are suspected to be high.

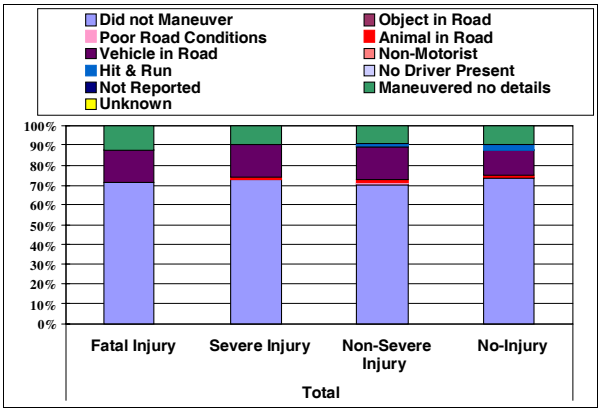

Figure 18. Situation that the Rider Maneuvered to Avoid (GES 1992-2004)

Alcohol Involvement - Most riders who were involved in crashes did not drink (Figure 19). However, alcohol use in fatal crashes increased from 18% in 1992-1997 to 22% in 1999-2004. This is a conservative estimate of alcohol use in fatal crashes because, as shown in Figure 20, alcohol use so often goes unreported by the police, particularly

when the rider survives more than a few hours after the crash.

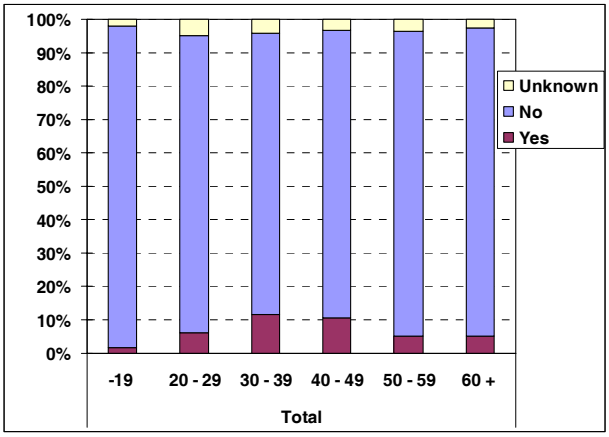

Figure 19. Alcohol Involvement by Age Group in Motorcycle Crashes (GES 1999-2004)

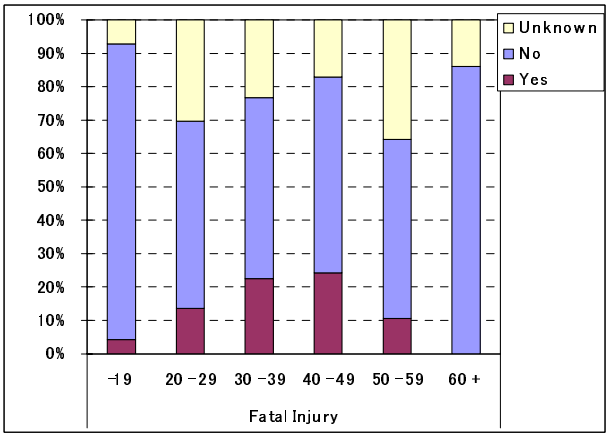

Figure 20. Alcohol Involvement by Age Group for Fatal Motorcycle Crashes (GES 1999-2004)

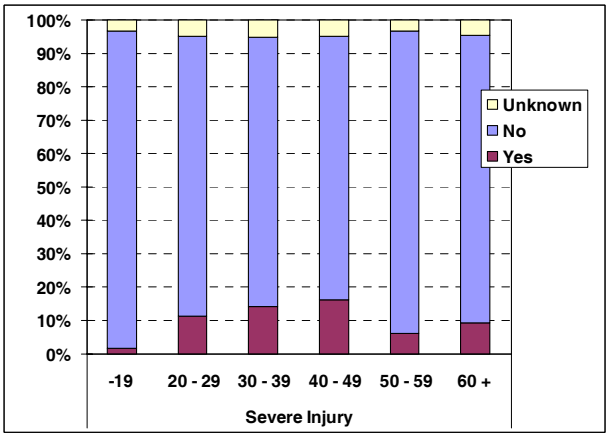

Figure 21. Alcohol Involvement by Age Group for Severe Injury Motorcycle Crashes (GES 1999-2004)

Looking at GES data with known alcohol involvement, there is marked increase in 30-49 year old riders who were drinking in motorcycle crashes at all severity levels relative to other riders (fatalities and Severe Injuries shown in Figures 20 and 21).

Helmet Use - Reported helmet use increased from 52% in 1992-1997 to 57% in the years since 1998 (Figure 22). However, some caution is required in interpreting this data, because of the growing use in the last 15 years of ineffective and unqualified "novelty" head gear that provide no protection in a crash [7]. If users of "novelty" head gear are classified as "helmeted" it can make head protection usage appear higher than it really is.

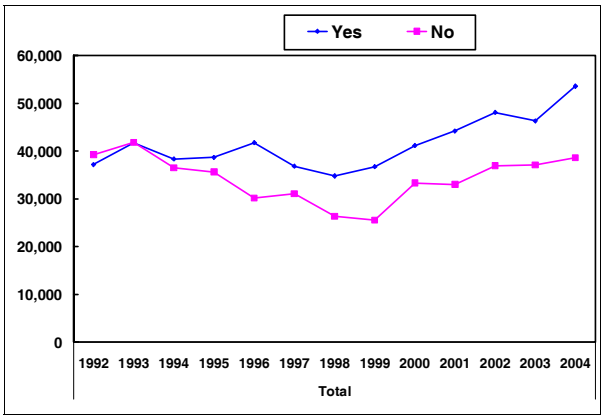

Figure 22. Helmet Use in GES Motorcycle Crashes

Taking a look at fatalities by age group, there is marked decrease of helmet use for the 40–49 and under-20 age groups since 1998, and to a lesser degree in the 20-29 age group (Figure 23). After 1998, fatally injured riders aged 40-49 were 75% as likely to have a helmet on compared to 1992-1997 (45% vs. 61%). Helmet use declined by 22% among fatally injured teenage riders after 1998 (from 54% to 42%).

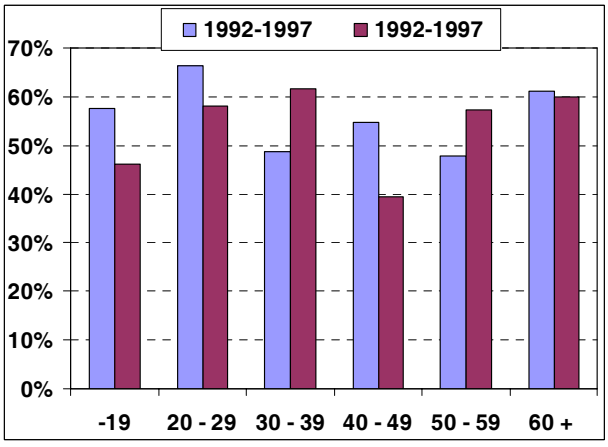

Figure 23. Helmeted Riders by Age Group in Fatal GES Crashes

Speed Relation - A large percentage of fatal GES motorcycle crashes were coded as speed related when compared with crashes with less severe outcomes: 39.5% of fatal crashes, 27.1% of severe crashes versus 13.7% of no injury crashes were coded by police in 1992-2004 with speed being a contributing cause of the crash. Also, a larger proportion of fatal crashes were coded as speed related for the younger riders. Actually, 54% of fatal crashes for rider under 30 are coded as speed related in contrast with 26% of fatal crashes for riders over 40 years old. As a caveat, speeding as reported by the police is approximate and not determined by rigorous speed analysis methods. Given the cursory nature of reporting speeding, it is the judgment of the authors that the type of motorcycle involved (sport bike vs. cruiser) or the severity of rider injuries may play a major role in the investigating officer's conclusion that speed was a factor in the crash. As such, the speed relation data reported in GES is not considered to be very reliable.

Motorcycle Engine Displacement - The motorcycle engine displacement in cc (cubic centimeters), an indication of size, was extracted from the vehicle model variable in GES. The engine size was identified for around two-thirds of the GES motorcycle crash population from 1999-2004 but only for one-fourth of the population in 1992-1997. As such, only GES crashes after 1998 were further examined by engine size.

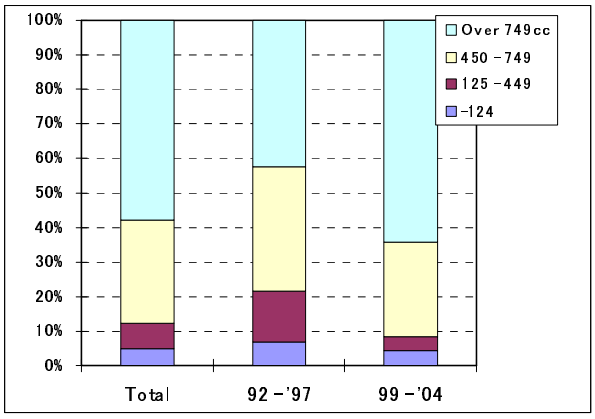

Figure 24. Frontal Crashes by Engine Size in cc

The data indicate a relative increase in bigger bikes in both frontal and road departure crashes in recent years. (Frontal crashes are shown in Figure 24). Motorcycles with engine displacement over 750cc were dominant in both frontal impacts and road departures at all severity levels (Table 10). Larger motorcycles had a higher fatality rate per crash involvement than the 450-749cc in frontal crashes: over 750cc riders were 1.5 times more likely to be killed in frontal crashes than those on 450-749cc bikes. On the other hand, both motorcycle sizes had a similar but high fatality rate in road departure crashes (riders of over 750cc size where 1.1 times more likely to be killed as those on smaller motorcycles).

Table 10. Fatal Crashes by Engine Displacement GES (1999-2004)

		Rate per 100 Crash involved		% Total	
Severity	Engine size (cc)	Frontal	Road Depart	Frontal	Road Depart
Killed	450-749	3.5	6.4	22%	25%
	≥ 750	5.2	6.8	77%	68%
Severe injury	450-749	24	32	24%	30%
	≥ 750	29	31	67%	66%
Non-Severe injury	450-749	51	57	28%	31%
	≥ 750	48	53	64%	63%
All crashes	450-749	-	-	27%	29%
	≥ 750	-	-	64%	64%

Motorcycle Contributing Factor - Motorcycle components, listed in Figure 29, did not have any failures and were not a contributing factor in almost all the crashes (Figure 25).

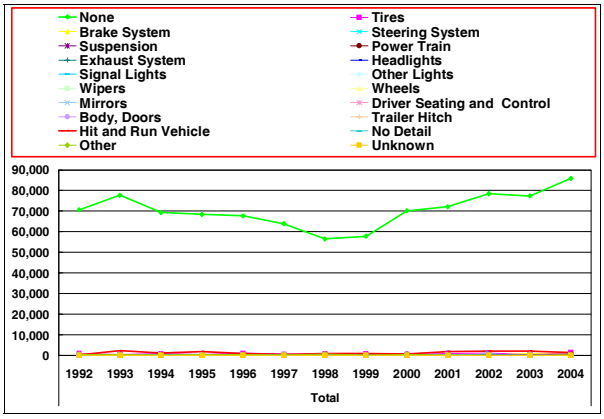

Figure 25. Motorcycle Contributing Factor in GES Crashes

Crash Environment Variables

Speed Limit - Motorcycle crashes from 1992-2004 occurred on roads with all speed limits. However, there is recent increase in number of crashes occurring on roads with speed limits of 65 mph and over (Figure 26).

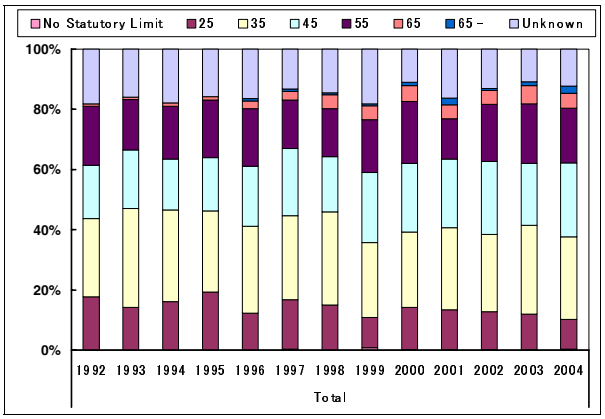

Figure 26. Motorcycle Crashes by Posted Speed Limit in Miles per Hour (mph) (GES)

As expected, there is an increase in crash severity levels on roads with higher speed limits as shown in Table 11. Fatality rates increased from 1.2% on roads with a speed limit less than 25 mph speed limit to 8.1% for roads with a limit over 65 mph.

Table 11. Crashes per Posted Road Speed Limit (mph)

	- 25	26-35	36-45	46-55	56-65	65 +
% crashes	14%	28%	21%	18%	3%	1%
% fatalities	7%	24%	27%	33%	8%	3%
Fatality Rate	1	2	3	5	6	8
Severe Injury Rate	22	23	26	27	26	33
450-749cc fatality rate	1	2	4	6	5	4
750+ cc fatality rate	2	3	5	5	8	9

Motorcycle crashes on roads with 46-55 mph speed limits were 18% of motorcycle crashes but resulted in 33% of the fatalities on roads with known speed limits. Crashes on roads with 45 mph and 35 mph resulted in 27% and 24% of riders killed, respectively (Table 11 and Figure 27).

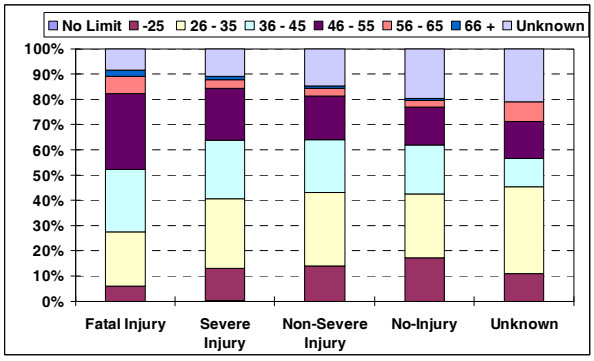

Figure 27. Injury Severity by Speed Limit for GES Motorcycle Crashes (1992-2004)

Motorcycles with engine displacement over 750cc are dominant at all severity levels with percentages increasing at higher speeds limits. However, the 450-749cc size is over-represented on 55 mph speed limit roads, making up 31% of the crashes and 35% of the fatalities (Figure 28).

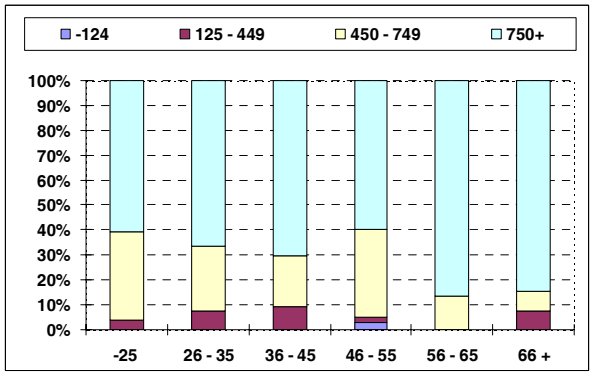

Figure 28. Fatal Crashes by Speed limit and Engine Displacement (GES 1999 - 2004)

Relation to Junction – GES specifies the location of the first harmful event in relation to a road junction. The point of departure is indicated if the first harmful event occurs off the roadway.

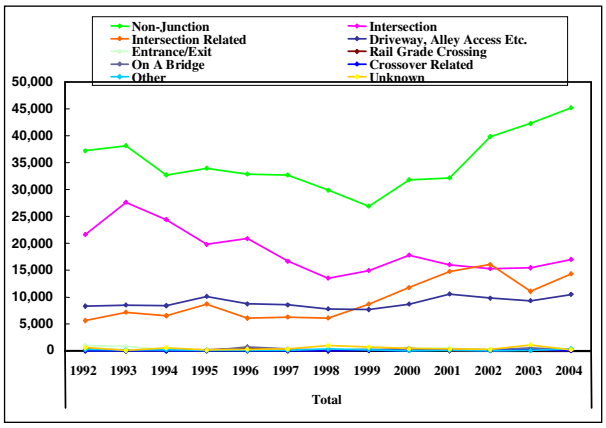

Figure 29. Motorcycle Crashes by Relation to Junction (GES)

Overall, in 1992-2004, 48% of motorcycle crashes occurred away from a junction while 38% percent were within an intersection (Figure 29). However, a disproportionate share of fatalities – about 64% -- occurred in non-intersection crashes, while only 27% happened within an intersection (Figure 30). Crashes away from a junction had a fatality rate of 4.3 over 1992-2004, about 72% higher than crashes within an intersection, which had a 2.5 fatality rate. Crashes away from a junction have also increased steadily in recent years.

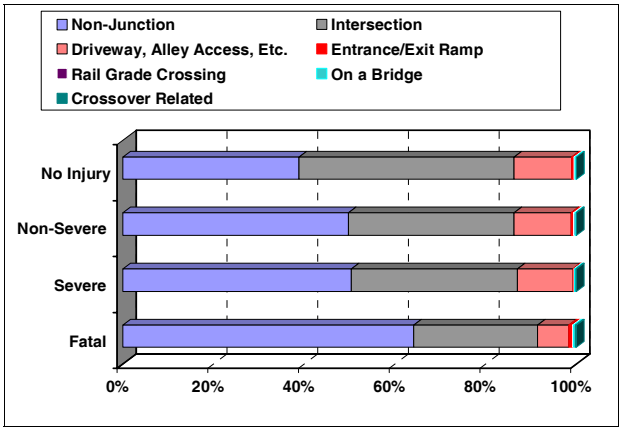

Figure 30. Injury Severity by Relationship to Junction for Motorcycle Crashes (GES 1992-2004)

Road Surface Condition - The great majority of motorcycle crashes in 1992-2004 happened on dry roads. As such, the increase in crashes on dry roads since 1998 simply followed the trend of all motorcycle crashes on U. S. roads (Figure 34).

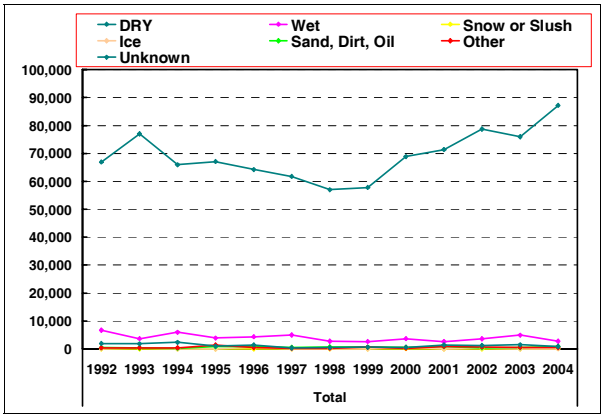

Figure 31. Road Surface Condition for Motorcycle Crashes (GES)

Visual Obstruction – GES identifies visual circumstances that may have contributed to the cause of the crash. In the majority of the motorcycle crashes from 1992-2004 no visual obstruction was reported. However in recent years this variable often was not reported. As such, it was impossible to determine any reliable trends relative to visual obstruction in this study.

Light Condition - GES also identifies the general light condition at the time of the crash, considering the presence of external roadway lighting fixtures.

The majority of motorcycle crashes, 69%, occurred in the daylight in 1992-2004 (Figure 32). The number of motorcycle crashes occurring in the daylight increased in recent years, following the general trend.

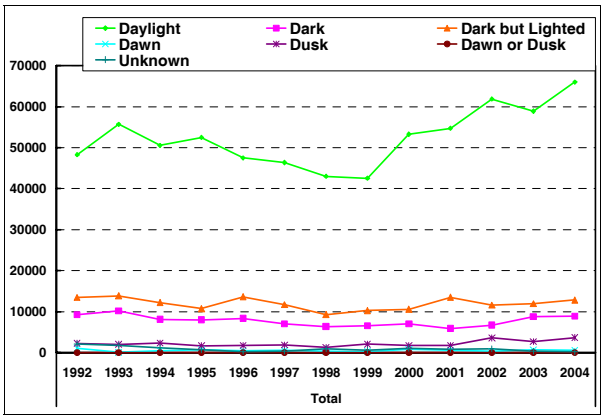

Figure 32. Light Condition for GES Motorcycle Crashes

Although 26% of the crashes occurred during hours of darkness (dark and dark but lighted), those crashes resulted in over 43% of the fatalities (Figure 33). Crashes in unlighted darkness were more likely to result in death than those occurring on lighted roadways at night (5.2 vs. 3.8 per hundred crashes). Also, crashes on unlighted roadways had a lower "no injury" rate than those in the dark but lighted condition (9 vs. 15).

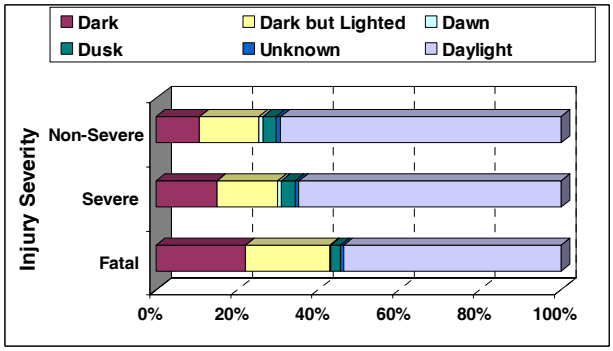

Figure 33. Injury Severity by Light Condition for GES Motorcycle Crashes (1992-2004)

Riders age 40 and older were over-represented in fatal motorcycle crashes that occurred on unlighted dark roads. They were 33% of all crash involved riders but 45% of riders killed on dark unlit roads (Figure 34). In contrast they were not over-represented on lighted roads at night, where they were 29% of crashes and 26% of fatalities (Figure 35). That is, riders over 40 were 1.5 times as likely to die if they crashed on a road that was unlighted at night compared to night crashes on roads that were lighted.

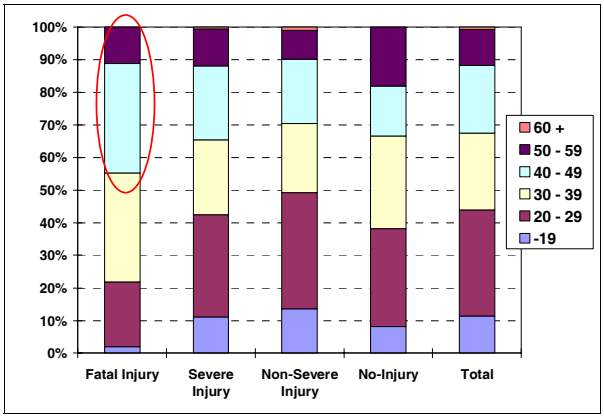

Figure 34. DARK-Unlighted by Injury Severity and Age (1999 - 2004)

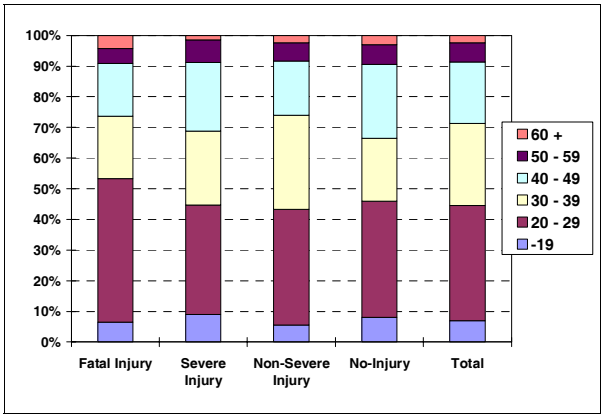

Figure 35. DARK but LIGHTED by Injury Severity and Age (1999 - 2004)

SUMMARY AND CONCLUSIONS

Results from this nationally representative descriptive overview of motorcycle crashes in the U. S. roads are summarized below. Key observations derived in this study are compared with findings from a recent statistical study of motorcycle crashes in the state of Indiana from January 2003 to October 2005 [8] and the landmark study by Hurt et al of on-scene, in-depth investigation of motorcycle crashes in Los Angeles during 1976 and 1977 [2]. The Indiana study, by Savolainen and Mannering, used nested logit and standard multinomial logit probabilistic models to show which variables play significant roles in motorcycle crash injury outcomes in Indiana.

Motorcycle crashes have been on the rise in the U. S. due to increased exposure driven by the rapid increase in sales since the late 1990s. However, motorcycle crashes, when they occur, are becoming more deadly. Relative to 1992 levels, the risks for being in a crash or in a non-severe crash per registered motorcycle decreased by 13% and 19% respectively in 2004 while the risk of being in fatal motorcycle crash increased by 18%. This indicates that, although that there seems to be fewer crashes per registered motorcycle, the crashes tend to be more deadly in recent years. Motorcycle riders also represent a very vulnerable segment of road users in the U.S. Inherently, a motorcycle offers little protection to the rider in a crash. Riders were over five times as likely to be killed in a traffic crash in 2005 as occupants of other motor vehicles.

Crash Configuration: Frontal impacts and road departures were the two most prevalent motorcycle crash configurations. They were also dominant in all injury severities. Frontal impacts were 36% of all crashes and accounted for a proportionate 39% of fatalities. However, road departure crashes were far more lethal, accounting for 19% of all crashes but 38% of all fatalities. These two configurations alone accounted for 75% of motorcycle death in 1992-2004. In the Indiana study, road departure crashes and collisions with roadside objects were found to be much more likely to produce severe injuries, and collisions with trees and poles were the most likely to produce a fatality.

Both frontal and road departure crashes have become more severe in recent years. When comparing injury rates before and after 1998, the fatality rate for road departure increased from 4.3 to 6.5 per hundred crashes while the fatality rate for frontal crashes increased from 2.5 to 4.3 per hundred.

"Head On" motorcycle crashes have an exceptionally high fatality rate of 19.2 of riders killed per hundred head-on crashes – over 5 times the rate of frontal crashes generally. "Head On" frontal crashes accounted for 8% of all riders killed, but only 1.1% of all the motorcycle crashes in this study. Similarly, in the Indiana study, head on crashes greatly increased the probability of fatalities, resulting in a 566% higher likelihood of being killed.

Crashes where another vehicle turned into or across the path of a motorcycle moving straight ahead were the most common frontal crash configuration at 17% of all motorcycle crashes and accounted for 18% of all riders killed. Motorcycles running into rear of other vehicles were 8% of all crashes and 6.7% of rider fatalities.

The most common crash configurations reported by Hurt et al in the Los Angeles study involved another vehicle turning left across the path of a motorcycle coming from the opposite direction (22% of all crashes) and road departure (16%).

Rider Age: The motorcycling population is getting older. The proportion of crash-involved riders age 40 and older has increased considerably in recent years, from 24%

before 1998 to 38% after. The percentage of riders over 40 who were killed in motorcycle crashes nearly doubled after 1998 to 40% of all riders killed. In contrast, Hurt at al reported a median age of 26 for riders killed in their 1976-77 crash population, with riders 17-26 years old accounting for 50% of the fatalities.

The recent increase in age for the crash involved rider follows the trend in motorcycle owner age in the U. S. According to the Motorcycle Industry Council Surveys of Motorcycle Ownership and Usage, the median age of motorcycle owners was 41 years old in 2003 as compared to 27 years in 1985 (a 14 year increase in median age over an 18 year period) [4]. Motorcycle owners over 40 years old were 53% in 2003, steadily increasing from 21% in 1985, 26% in 1990, and 44% in 1998.

Similar to the trend in all motorcycle crashes, riders 40-59 years old have increased in both frontal impacts and road departures in recent years. However, while the numbers of riders 20-29 in motorcycle crashes have decreased in recent years, they were a bigger proportion of the fatalities. Considering the ratio of fatalities to crash involvement, riders under 30 were 1.9 times more likely to be killed in a frontal crash and twice as likely to die in a road departure after 1998 as compared to 1992-1997. The over-50 rider was 1.7 times more likely to be killed in recent frontal crashes and 1.5 times more likely to be killed in recent road departures. In the Indiana study, the results showed that older riders were more likely to be involved in both single- and two-vehicle severe crashes, even when controlling for all other factors.

Rider Pre-Crash Evasive Action: For most crashes at all severity levels, police reported that the motorcycle rider was not able to or did not attempt any avoidance maneuvers. The absence of evasive action was reported in 71% of fatal crashes, and for 77% of all riders aged 50-59. Given the challenges to establish avoidance maneuvers from police reports, these estimates are suspected to be high. Hurt et al reported nearly the opposite: Riders took evasive action nearly 70% of the time, but often made poor choices and executed their chosen action poorly. Part of the problem, according to Hurt, is that riders had little time to react before the crash (a median of 1.9 seconds, and less than 3 seconds to react in over 90% of crashes). Overall, both the GES and Hurt data indicate that motorcyclists and car drivers exhibit a lack of awareness or no expectation of impending danger in motorcycle involved crashes.

One of the principle findings from the Hurt study was that lack of "motorcycle conspicuity" and lack of caution and awareness of both rider and driver were main causes of two-vehicle motorcycle crashes. The driver of the other vehicle who violated the motorcycle right-of-way in 64% of the crashes explained that he/she never saw the motorcycle before the crash. Lack of motorcycle conspicuity is highlighted as a factor contributing to increased motorcycle crash severity by several researchers [9, 10].

Alcohol Involvement: Comparing the years before and after 1998, the percent of riders who died in a motorcycle crash after drinking increased from 18% to 22%. This is a conservative estimate due to large proportion of unknown alcohol involvement in GES fatal crashes. Hurt reported alcohol use in 12% of all crashes and 43% of fatalities. NHTSA reported alcohol use in 34% 2005 fatal motorcycle crashes and a blood alcohol level (BAC) 0.08 g/dl or higher in 27% of motorcycle fatalities [11]. In this study, the GES data showed a marked increase in alcohol use among the 30-49 age groups at all severity levels relative to other riders. According to NHTSA, in 2005 the age group that had the highest percentage of riders with BAC of.08% or higher were those aged 35-50.

Relative to other parts of the world, the ratio of alcohol involvement in 2004 U. S. motorcycle crashes was 6.2 times higher than Japan and 1.8 times that of the European Union (EU). This is based on comparison of data from U. S. GES, EU MAIDS [12], and Japan ITARDA [13].

Studies have shown that alcohol has a pervasive and detrimental effect on motorcycle crash characteristics, including a big increase in road departure crashes (Hurt Study [14], Thailand study [15]) and decreased helmet use [14]. Alcohol crashes also mostly occur at night in non-junction areas (Thailand study [15], Hawaii study [16]).

Helmet Use: Forty-three percent of the 1999-2004 motorcycle crash population in the U. S. did not wear a helmet. Comparing the years before and after 1998, helmet use by riders killed in motorcycle crashes declined from 61% to 45% among riders aged 40-49 and from 54% to 42% among those younger than 20.

In the Indiana study, results showed 50% increase in no injury for helmeted riders in single vehicle crashes. Savolainen and Mannering also report that helmet use significantly increased the probability of "non-incapacitating" injuries in crashes with sport utilities vehicles and pickup trucks in Indiana.

NHTSA reported that use of a qualified helmet was 37% effective in preventing fatalities in motorcycle crashes in 2005 [11]. Similarly, Ouellet & Kasantikul [17] reported that about half of all fatally injured motorcyclists died of non-head injuries, usually to the chest and abdomen. Of those who died primarily from head injuries, helmet use would have prevented nearly 80% of those deaths.

Unfortunately, NHTSA reported that helmet use declined from 71% in 2000 to 48% in 2005 based on their National Occupant Protection Use Survey (NOPUS). States in the U. S. have been repealing laws that require helmet use for all riders. The number of States with mandatory helmet laws has declined from 27 in 1996 to 22 in 2005 [18]. Many studies comparing the effect of mandatory helmet has shown that mandating helmet use for all riders increases use to over 90% and reduces fatalities [19, 20, 21, and 22].

One caveat is necessary in discussing helmet use. Since the early 1990s, the use of "beanie" or "novelty" headgear with no energy-absorbing liner that are incapable of providing crash protection has grown in the U. S. [23] Roadside observational surveys in Florida by Turner at al show that use of "beanie" headgear increased from 15% in 1992 to 40% in 1999 [7]. It is unclear how often the distinction between qualified protective helmets and beanie headgear is made in the police reports that make up the GES data.

It is also worth noting that riding without a helmet is far more common in the U.S. than in Japan or the European Union. The percentage of American riders who crashed without a helmet was 36 times greater than Japan and five times greater than the EU [12, 13].

Motorcycle Factor Related: The motorcycle itself did not have any failures and was not a contributing factor in almost all the GES crashes. Motorcycles with engine displacement over 750cc dominated both frontal impacts and road departures at all severity levels in recent motorcycle crashes. They were involved in 77% of frontal crashes and 68% of road departures in 1998-2004.

Large-displacement motorcycles have been increasing in the U.S. The Motorcycle Industry Council estimates that motorcycles over 749cc increased from 66% of the total motorcycle population in 1998 to 76% in 2003 [4]. In the same years, the 450-749cc motorcycles decreased from 21% to 16.5%. Polk's National Vehicle Population Profile (NVPP) data shows a continued increase in overall motorcycle registration in the U. S., particularly for over-750cc motorcycles (Figure 36) [24].

The over 750cc motorcycles have a higher fatality rate per crash involvement than the 450-749cc in frontal crashes (5.2 vs. 3.5%). Riders on 750+ cc motorcycles were 1.5 times more likely to be killed in frontal crashes than those on 450-749cc motorcycles. However, both motorcycle sizes had a similar but high fatality rate in road departures (6.4% for 450-749cc riders and 6.8% for riders of over 750cc riders). Hurt et al reported the over 750cc motorcycles were under-represented in the crash population compared to their exposure on the street while their involvement in fatal crashes more closely reflected their exposure in street traffic.

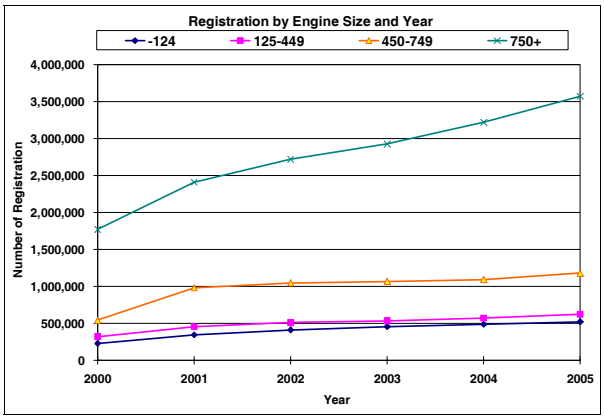

Figure 36. Polk NVPP Motorcycle Registration Data by Engine Displacement

Posted Speed Limit: Motorcycle crashes occur on roads with all speed limits. As expected, there is an increase in crash severity levels on roads with higher speed limits. Thirty percent of the fatal crashes occurred on roads with 46-55 mph speed limits. The Indiana study reported a 32% higher likelihood of a fatality on roads with speed limits over 50 mph. However, 52% of the GES fatal crashes occurred on roads with speed limits less than 45 mph.

Motorcycles with engine displacement over 750cc dominated all severity levels with percentages increasing at higher speeds limits. However, the 450-749cc size was prominent on roads with 45-55 speed limits and was involved in 35% of the fatal crashes.

Relation to Junction: In 1992-2004, 38% of crashes occurred within an intersection and 48% away from a junction. However, crashes away from a junction were 1.7 times more likely to be fatal than crashes within an intersection. Non-junction crashes accounted for 64% of riders killed. In the Hurt study, intersection crashes were also less likely to be fatal than non-intersection: 65% of all crashes but only 33% of fatalities occurred in intersection crashes. Hurt et al reported that fatal crashes were more likely to involve the rider losing control by running off the road, typically on a curve. In the Indiana study, intersection crashes were found to be more likely to result in no injury for single vehicle crashes.
The higher fatality rate for non-junction crashes may be related to alcohol use, since road departure crashes are far more common among drinking riders and are much more likely to be fatal.

Road Surface and Light Conditions: Motorcycle crashes in 1992-2004 occurred primarily on a dry road surface, with almost 70% occurring during daylight. Hurt

et al. reported that motorcycles virtually disappear from the roads when they are wet, an indication of low exposure for motorcycles in inclement weather conditions. Kasantikul [25] reported the same thing in Thailand, where rain is far more common than in Los Angeles and motorcycles tend to be the riders only mode of transportation.

While crashes at night were 30% of all crashes, they accounted for over 43% of the fatalities. Fatality rate per 100 crash involved riders is higher in crashes occurring on dark unlighted roads compared to those on dark but lighted roads (5.2 vs. 3.8). Riders over 40 years old were over-represented in fatal motorcycle crashes on dark, unlighted roads, making up 45% of those killed. In contrast, they were only 26% of riders killed on dark but lighted roads. Riders over 40 involved in a crash at night were 1.5 times more likely to die if they crashed on an unlighted road than on a lighted roadway.

In the Indiana study, crashes occurring in darkness were 95% more likely to result in a fatality in single-vehicle crashes and a twice as likely in multi-vehicle motorcycle crashes. The association of darkness and fatalities may be related to alcohol and crash type. Most alcohol-involved crashes occur at night [15, 16] and alcohol use greatly increases the likelihood of road departure crashes [15].

OPPORTUNITIES FOR SAFETY IMPTOVEMENTS

Key findings of this 1992-2004 NASS/GES motorcycle crash study are that the doubling of motorcycle fatalities is largely due to increasing numbers of motorcycles in use and that motorcycle crashes are becoming more deadly in recent years. Road departure crashes are disproportionately fatal and they have been increasing, possibly because of increasing alcohol use.

Examination of motorcycle crash data trends before and since 1998 show that increased severity and higher fatality rates in recent years can be mainly attributed to:

- Increase in road departures, vehicles turning into the path of the motorcycle, and head-on crashes
- Decrease in helmet use, particularly for riders under 19 and 40-49 years old
- Increase in alcohol use for riders aged 30-49
- Vulnerability of over 750cc engine size motorcycles in frontal crashes
- Riding on roads with higher speed limits
- Crashes away from a junction (possibly related to alcohol use and road departure crashes)
- Riders over 40 in dark road conditions (also possibly related to alcohol use at night and road departure).

Findings support opportunities in safety strategies such as rider education, focused by age groups, relative to speeding, helmet use, and alcohol consumption. Speed risk awareness campaigns can be focused to younger drivers. Alcohol involvement risk awareness education can be focused to rider ages 30-50. Any action that will work to increase the use of qualified helmets will reduce fatalities. As compared to other part of the world, there are considerable opportunities for improvements to lessen alcohol use and increase helmet use for the U. S. motorcycle rider.

Countermeasures to improve visibility would reduce fatalities, in particular for the rapidly growing population of riders over 40 years of age. This includes enhanced lighting, whether for the motorcycle and/or the roadway. Although motorcycles of all engine sizes are vulnerable in road departure crashes, the over 750cc riders were 1.5 times more likely to be killed in frontal crashes than riders of 450-749cc motorcycles. It is not clear what factor or factors might explain the increasing fatality rate on large displacement motorcycles. Crash speed, helmet use or even changes in rider crash motions are possibilities, but on-scene, in-depth crash investigations may be required to resolve this issue.

Findings also support the need to study the vulnerability of riders over 50 in motorcycle crashes, in particular, relative to pre-crash behavior and susceptibility to injury. Finally, findings highlight a critical need for an in-depth study of the growing road departure motorcycle crash problem.

FURTHER STUDIES

Some limitations of this study are as follows. Overall, GES provides a historical perspective of a large number of useful crash, rider, motorcycle, and environment attributes. However, fatal and high severity crashes are believed to be under-represented. Also, GES does not provide sufficient detail to obtain a good understanding of crash causation, injury mechanisms, and crash dynamics.

An examination of injury severities in crashes where the rider attempted braking or steering corrective actions would be useful. A study of injury severity and other attributes in crashes where the rider was negotiating a curve is needed. Also, some rider attributes and crash characteristics are interrelated and their linkage requires further examination; e.g., alcohol involvement, inattention, road departure and pre-crash evasive actions. While this crash study focused on the motorcycle and rider, a study of the attributes of the other vehicle and driver would provide more insights into motorcycle crash involvement and severity in two-vehicle crashes. In particular, investigating the role of visual obstruction, pre-crash actions, vehicle

maneuvers, alcohol involvement, speed relation, and vehicle class would be useful.

Focused studies based on the more comprehensive U. S. state crash data files, such as the Indiana study, can provide better insights to crash attributes such as the influence of roadway features, environmental factors, rider pre-crash actions, and other vehicle characteristics. In-depth studies, such as special crash investigations and crash reconstructions would be very valuable to understand injury mechanisms and crash dynamics. Such studies would also better support the development of engineering countermeasures to the rapidly growing motorcycle crash problem.

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