The Dimensions of Motor Vehicle Crash Risk

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ABSTRACT

A valid assessment of motor vehicle crash risks and the potential impact of safety interventions requires a precise understanding of the types of crashes involved, the types of vehicles likely to be equipped or otherwise affected, the most relevant *referent* to the intervention (e.g., national annual crash total, vehicle mileage, and vehicle life), and the scope of monetary crash costs to be considered. This paper analyzes the U.S. police-reported, motor vehicle crash problem in four dimensions: crash involvement type/role (e.g., single-vehicle roadway-departure, left-turn-across-path); subject vehicle body type (i.e., passenger cars, light trucks/vans, heavy combination-unit trucks, medium/heavy single-unit trucks, and motorcycles); type of metric (i.e., crashes, involved vehicles, persons killed/injured, and monetary cost); and problem size referent (i.e., U.S. annual, per crash, per vehicle, per driver, and per mile traveled).

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INTRODUCTION

Safety interventions to prevent motor vehicle crashes are often characterized by *specificity;* that is, they are designed to prevent a specific type of crash involvement. In the area of Intelligent Transportation Systems (ITS), for example, vehicle-based sensors are being developed to prevent specific crash types, such as the headway/forward obstacle detection system designed to prevent rear-end crashes (Knipling et al. 1993a; Najm and Burgett 1997). Other safety interventions may target a vehicle type; for example, Federal Motor Carrier Safety Regulations focus primarily on large trucks, particularly combination-unit trucks (CUTs), which include tractor- and semitractor-trailers. These vehicles constitute the majority of interstate commercial vehicles. Thus, there is a need to dissaggregate crash statistics along multiple dimensions, including crash and vehicle type. Further, the analysis of crash consequences may focus on different types of measures (most obviously, measures of injuries and lives lost versus measures of monetary loss) and different frames of reference, such as annually for the nation or per miles of vehicle exposure.

In the area of advanced vehicle-based technology, the National Highway Traffic Safety Administration (NHTSA) (Najm et al. 1995) and others (e.g., Fancher et al. 1994) have conducted research to identify and define promising opportunities for crash prevention. One major NHTSA effort was a multidisciplinary project (Najm et al. 1995) to define the principal ITS crash scenarios and identify effective countermeasures. Associated crash data analyses (Knipling et al. 1993a; Wang and Knipling 1994a, b, c, d) have quantified crashes by type, using metrics such as annual numbers of crashes and injuries and rates of occurrence. In addition, the studies documented significant differences in crash involvement patterns among various vehicle body types—in particular, passenger vehicles (i.e., cars and light trucks), CUTs, and medium/heavy single-unit trucks (SUTs)—also known as "straight trucks" (see box 1).

NHTSA has also assessed the overall economic costs of motor vehicle crashes (Blincoe 1996; Blincoe and Faigin 1992). These studies focused on direct economic losses, and provided estimates of the monetary value society places on the human consequences of crashes, including functional impairment due to injury, "pain and suffering," and even loss of life. According to Blincoe, in 1994, the average economic cost of a police-reported (PR) crash was approximately $12,360, and the total economic cost of U.S. motor vehicle crashes (PR plus nonpolice-reported (NPR)) was $150.5 billion. On a comprehensive scale incorporating derived valuations for life and pain and suffering (Blincoe 1996), in addition to direct economic loss, the estimates were $34,490 per PR crash and $379.5 billion (PR and NPR) for the national total.

These monetary studies provided analytical breakdowns of various categories of economic

BOX 1 Abbreviations and Acronyms

C	comprehensive cost
CUT	combination-unit truck
E	economic cost
FARS	Fatality Analysis Reporting System
GES	General Estimates System
ITS	intelligent transportation systems
LC/M	lane change/merge
LTAP	left-turn-across-path
LT/V	light trucks/vans
LVM	lead vehicle moving
LVS	lead vehicle stopped
MAIS	Maximum Abbreviated Injury Scale
NASS	National Automotive Sampling System
NHTSA	National Highway Traffic Safety Administration
NPR	nonpolice-reported
OD	opposite direction
PR	police-reported
PAR	Police Accident Report
RE	rear-end
RE-LVM	rear-end, lead vehicle moving
RE-LVS	rear-end, lead vehicle stopped
SI/PCP	signalized intersection/perpendicular crossing path
SUT	single-unit truck
SV	subject vehicle
SVRD	single-vehicle roadway-departure
UI/PCP	unsignalized intersection/perpendicular crossing path
VMT	vehicle-miles traveled

loss, including property damage, economic losses due to lost production, and medical expenses. They also demonstrated the huge proportion of crash costs associated with alcohol—approximately 30% of all crash costs. Recently, Miller et al. (1997) developed estimates of the economic costs and harm associated with crashes of specific geometries. This analysis was based primarily on Crashworthiness Data System statistics, which include only passenger vehicles.

To date, only limited analyses have been performed of the economic costs of various crash scenarios involving specific vehicle body types, which characterize these costs from the standpoint of the expected "per transportation unit" crash experience of vehicles or drivers. Such per unit statistics are likely to be more meaningful than national statistics to regulators, system developers, vendors, and buyers, because they provide a basis for assessing the potential cost-benefits of new safety interventions applied to some part of the vehicle/crash universe. For example, disaggregation by vehicle type is important because marketing strategies for many vehicle-based devices involve initial deployment in a specific vehicle-type fleet (most frequently CUTs) followed by deployment to other vehicle types.

Accordingly, this paper assesses the U.S. motor vehicle crash problem focusing on a number of major crash involvement types/roles and vehicle body types. Both nonmonetary (e.g., crashes, persons killed or injured) and monetary metrics are employed. In addition, this paper analyzes motor vehicle crashes from the perspective of different problem-size "referents"; that is, the U.S. annual national total as well as various "per unit" referents, including per crash, per vehicle, per mile, and even per driver. All four of these analytical dimensions—crash type, vehicle type, problem-size metric, and problem-size referent—are fundamental to a valid assessment of the potential crash amelioration benefits, and thus market opportunities, of motor vehicle safety interventions.

METHOD

Unless otherwise noted, all crash data were retrieved or derived from the General Estimates System (GES) for the five-year period 1989–93 and are intended to be representative of the population of U.S. PR crashes. Fatalities were adjusted to the 1989–93 levels reported in the Fatality Analysis Reporting System (FARS). Four analytical dimensions—crash involvement types/roles, subject vehicle body type, type of metric, and problem-size referent—are discussed below (see table 1).

TABLE 1 Crash Analysis Dimensions and Categories

Crash involvement types/roles:
- All PR crashes
- Single-vehicle roadway-departure (SVRD)
- Pedestrian
- Rear-end, lead vehicle stopped (RE- LVS), striking vehicle
- Rear-end, lead vehicle moving (RE- LVM), striking vehicle
- Lane change/merge (LC/M)
- Backing
- Opposite direction, encroaching vehicle
- Left-turn-across-path (LTAP)

Subject vehicle (SV) body type:
- All vehicles
- Combination-unit trucks (CUTs)
- Single-unit trucks (SUTs)
- Passenger cars
- Light trucks/vans (LT/Vs)
- Motorcycles

Metrics:
- Crashes (equal to SVs in crashes)
- Crash-involved vehicles
- Crash-involved persons
  - Total
  - Not injured
  - MAIS 1–2
  - MAIS 3–Fatal
- Monetary cost
  - Economic (E)
  - Comprehensive (C)
- Fatal equivalents

Referents:
- U.S. annual total
- Per police-reported target crash
- Per mile traveled (or per 100 million VMT)
- Per vehicle annually (or per 1,000 vehicles annually)
- Per vehicle operational life
- Per driver career

Crash Involvement Types/Roles

Crash involvement[1] types and roles are primarily those that have been analyzed and defined in NHTSA-sponsored studies of crash causation and countermeasure applicability (Najm et al. 1995). Note that, with the exception of "all crashes," each category includes an explicit or implicit definition of the crash subject vehicle (SV). The SV is the vehicle regarded as having the critical precipitating role in the crash, such as the striking vehicle in rear-end crashes. While the SV is generally the vehicle whose driver is "at fault" in the crash, there are many exceptions to this general rule. For example, some single-vehicle roadway-departures (SVRDs) are precipitated by an evasive maneuver to avoid an encroaching vehicle, and some left-turn-across-path (LTAP) crashes are associated with a traffic signal violation by the vehicle going straight. Crash involvement type/role categories examined were:

1. All crashes (the universe).
2. SVRD crashes, including struck parked-vehicle crashes.
3. Pedestrian (first harmful event only—not pedestrian impacts occurring as a result of a prior collision).
4. Rear-end, lead vehicle stopped (RE-LVS) crashes (SV is the striking vehicle).
5. Rear-end, lead vehicle moving (RE-LVM) crashes (SV is the striking vehicle). This category includes crashes where the lead vehicle was coded as traveling more slowly than the following vehicle or coded as decelerating at the time of impact. The differentiation of RE-LVS versus RE-LVM crashes is based on police accident report (PAR) information only. RE crashes not identified as either LVS or LVM were distributed proportionately across the two subtypes.
6. Lane change/merge (LC/M) crashes, not including any rear-end crashes (SV is the vehicle making lane change/merge maneuver).
7. Backing crashes, including both "encroachment" and "crossing path" subtypes (Wang and Knipling 1994a) but not including pedestrian impacts (SV is the vehicle making the backing maneuver).
8. Opposite-direction (OD) crashes, including head-on collisions and opposite-direction sideswipes (SV is the encroaching vehicle). For the small number of OD crashes in which the SV was not identifiable, the SV designation was distributed among vehicle types in proportion to their known roles in other OD crashes.
9. LTAP at intersection crashes (SV is the left-turning vehicle).

With the exception of the "all crashes" category, the above crash types were defined in a manner that ensured mutual exclusivity. For example, the lane change/merge category excluded rear-end crashes resulting from such maneuvers. Similarly, the backing crash category excluded backing-into-pedestrian crashes.

Obviously, not all crash types are addressed here. For example, rear-end crashes could be analyzed from the perspective of the *struck* vehicle to provide insights into the potential benefits of safety enhancements to rear brake light or other rear signaling systems (Knipling et al. 1993b). Two key intersection crash types, signalized and unsignalized perpendicular crossing path crashes (Wang and Knipling 1994c), have not been subjected to detailed analysis because of the difficulty of identifying the SV (i.e., the vehicle violating the right-of-way) based on GES-coded variables alone for the five years under study. Limited, nonvehicle-type-specific statistics for these two crash subtypes are provided, however.

Subject Vehicle Body Type

Six vehicle types were addressed: all motor vehicles, passenger cars, light trucks/vans (LT/Vs), CUTs, SUTs, and motorcycles. These vehicle types were defined as in previous reports (Wang and Knipling 1994a, b, c, d) and as suggested by the taxonomy of the GES body type variable. "Passenger cars" here include standard automobiles and derivatives. LT/Vs include van-based light trucks, pickups, utility vehicles, and other light trucks of less than 4,500 kg gross vehicle weight rating (GVWR). The CUT category includes bobtails. For all crash types/roles, the vehicle type was the SV in the crash; for example, the left-turning vehicle in an LTAP crash.

[1] *Crash involvement* in this context refers to a specific role in a specific type of crash, e.g., the left-turning vehicle in a left-turn-across-path crash.

Type of Metric

"Type of metric" refers to what is actually counted in the statistic. The current analysis counted crashes, SVs, involved vehicles, involved persons (classified by injury severity), monetary cost, and fatal equivalents. The term "crashes" is self-explanatory, although it is worth noting that the number of crashes also equals the number of SVs involved in crashes (except for "all crashes," in which no SV is defined). Two levels of "involved vehicles" are quantified: 1) all of the vehicles *of a particular body type* involved in a crash (e.g., all the light trucks/vans involved in LTAP crashes, regardless of crash role) and 2) all of the vehicles involved in a crash regardless of body type.

Involved persons were classified by injury severity level, and include all persons regardless of vehicle role or type (i.e., *not* just those in the SV). The KABCO injury severity scale values—K, killed; A, disabling injury; B, evident injury; C, possible injury; and O, no apparent injury (National Safety Council 1990)—were converted to Maximum Abbreviated Injury Scale (MAIS) values from 0 to 6 (AAAM 1985) using matrices generated for injuries occurring in crashes involving the different vehicle types based on 1982–86 National Automotive Sampling System data. In addition to a count of all persons involved in crashes we assessed, the following three categories are presented: not injured (MAIS 0), minor-to-moderate injury (MAIS 1–2), and serious-to-fatal injury (MAIS 3–fatal). Fatality counts are not presented separately because unacceptably large sampling errors would be associated with the small fatality estimates for specific crash/vehicle types (USDOT NHTSA 1992) and because GES generally undercounts fatalities. These sources of error are reduced by aggregating injury data across multiple severity levels (e.g., MAIS 3, 4, 5, and Fatal).

The GES data on which this study was based provide estimates of the relative frequency of different crash types. Sampling errors associated with GES crash, vehicle, and person estimates are not provided. For some small estimates, these may be significant (USDOT NHTSA 1992), although the use of five-year averages rather than single-year estimates reduces sampling errors.

This paper also contains a number of monetary metrics of the U.S. crash problem size. Unlike the nonmonetary crash statistics based principally on the GES, most monetary metrics used in this paper were adjusted to account for undercounting of PR and NPR crashes. These adjustments were derived from Blincoe and Faigin (1992).

Monetary assessments of crash problem size may be based on narrow economic loss criteria or comprehensive societal value criteria (Blincoe 1996). This paper provides both economic (E) and comprehensive (C) monetary crash problem-size metrics. Unit costs from Blincoe were adjusted to 1997 price levels using Consumer Price Index statistics. E costs represent the value of goods and services that must be purchased as a result of motor vehicle crashes; they include medical care, legal services, emergency services, vehicle repair services, and insurance administration costs. In addition, economic costs include the value of both workplace and household productivity lost due to death or injury, the value of travel delay to noninvolved motorists, and costs incurred due to workplace disruption when an employee is killed, injured, or delayed.

By contrast, C costs incorporate not only economic losses, but a valuation for less tangible consequences such as "pain and suffering" and loss of life. These values have been derived from "willingness-to-pay" studies that examine marketplace behavior to determine the value that people place on reducing risk. There is far more uncertainty involved with these estimates than those based on direct economic costs. These less tangible impacts, however, are often the most devastating aspects of serious motor vehicle injuries, and they should be incorporated whenever a direct comparison is made of costs and benefits or of the potential benefits of competing safety measures. Failure to consider these aspects could result in a serious underestimation of the true harm caused by motor vehicle crashes or the societal benefits associated with proposed safety measures.

In this paper, both E and C costs are expressed in 1997 dollars using a 4% annual discount rate to reflect the decreased value of future economic losses (e.g., lost wages). A 4% annual discount rate was also applied to calculations of expected monetary cost "per vehicle over operational life" and "per driver over driver career." These metrics are defined and discussed later in this section.

One way to simplify the metrics of motor vehicle crash consequences is to express them as "fatal equivalents."[2] This is achieved by dividing the annual monetary cost of any given crash by the cost of a fatality. For example, the annual C cost of all crashes in 1997 dollars is $431.9 billion and the C cost of a fatality is $3,091,420. The total annual fatal equivalents associated with all crashes equals $431.9 billion/$3,091,420 = 139,699.[3] NHTSA uses C costs and this method to derive a cost per-equivalent-fatality for their analyses of proposed safety regulations. For this study, fatal equivalents provide a convenient single-number basis for comparing crash consequences across crash types and vehicle types.

Problem-Size Referent

Crash problem sizes must be expressed in relation to a *referent*; for example, most traffic crash statistics refer to a particular time (e.g., a year) and place (the United States). Six different referents are used in this paper:

1. U.S. annual total (average of 1989–93).
2. Per PR target crash by type.
3. Per mile traveled. To avoid the use of very high or low numbers, crash involvement rates are expressed as the number of crash involvements per 100 million vehicle-miles traveled (VMT); whereas crash monetary costs are expressed in cents per mile. Passenger car and LT/V VMT were obtained from Walsh (1995). All other VMT statistics were obtained from *Highway Statistics* (USDOT Annual releases 1990–94).
4. Per registered vehicle annually (for numbers of crashes, expressed as the number per 1,000 registered vehicles annually). Passenger car and LT/V registrations were based on Shelton (1995). All other vehicle registration statistics were obtained from *Highway Statistics*.
5. Per manufactured vehicle over its expected operational life.
6. Per driver over his/her expected driving career.

[2] Fatal equivalents are the number of fatalities that would be equivalent in cost to all costs associated with crashes including costs for nonfatal injuries and property damage.
[3] The figure 139,699 was calculated before rounding.

The first four of the above referents are self-explanatory and commonly used in traffic safety research. The fifth (per manufactured vehicle over its expected operational life) is relevant to quantifying a crash problem in relation to the average or expected experience of individual vehicles that may, for example, be equipped at the factory or dealership with a particular safety device lasting the life of the vehicle. The expected number of crash involvements over a vehicle's life is derived by the formula:

Expected number = Average annual number of involvements × Average vehicle life ÷ Average annual number of registered vehicles

The following values were used for average vehicle life by vehicle type: all vehicles, 13.1 years; passenger cars, 11.8 years; LT/Vs, 16.0 years; CUTs and SUTs, 14.7 years; and motorcycles, 7.5 years (Miaou 1990; Wang and Knipling 1994a).

The referent "per driver over his/her expected driving career" attempts to capture the expected lifetime driving experience of the average driver. It is derived by the formula:

Expected number = Average annual number of involvements × Average driving career (years) ÷ Average annual number of registered drivers

The current average life expectancy of a beginning driver (e.g., 17-year-old) is approximately 76 years (USDHHS 1991). Such a person might drive for a total of 55 to 60 years. For example, a person who starts driving at age 17 and stops at age 75 would have driven for 58 years. This "years of driving" value—58 years—is used here although it is an approximation. The extrapolation of five years of crash data (1989–93) across 58 years of driving is also acknowledged to be inexact, since many crash-relevant factors (e.g., driver behavior, road safety, vehicle safety, emergency medicine) may change over such a long time period.

"Per driver over his/her expected driving career" statistics are derived for "all vehicle types" only. Disaggregation by vehicle type would be very difficult, because many drivers operate several different vehicle types during their careers and may drive certain vehicle types (e.g., large trucks, motorcycles) for only a few years.

Statistics: Metric/Referent Combinations

Each metric above could be applied to each referent to constitute a specific crash statistic; for example, crashes (a metric) per year in the United States (a referent). The current analysis includes the statistics listed below. All vehicle, injury, and monetary measures of the crash problem size include all individuals and vehicles involved in the crash, not just those in the SV. All statistics on crashes—involved vehicles and persons, and all "per crash" statistics (monetary value, fatal equivalents)—are based on PR crashes as retrieved from the GES. Monetary and fatal equivalent statistics for the United States, per mile traveled, per registered vehicle, per vehicle over its operational life, and per driver over his/her driving career include both PR and NPR crashes.

1. Annual U.S. number of PR crashes (also equals the number of SVs involved in these crashes)
2. Annual number of vehicles involved (of each body type) in PR crashes
3. Annual number of vehicles involved (regardless of body type) in PR crashes
4. Annual number of persons involved in PR crashes
   - Total
   - Not injured (MAIS 0)
   - Minor to moderate (MAIS 1–2)
   - Serious to fatal (MAIS 3–fatal)
5. Vehicle involvement rate in PR crashes
   - Per 100 million VMT
   - Per 1,000 registered vehicles
6. Expected involvements in PR crashes
   - Per vehicle over its operational life
   - Per driver over his/her driving career ("all vehicles" only)
7. Annual U.S. monetary cost (includes PR + NPR crashes)
   - Economic cost (E)
   - Comprehensive cost (C)
8. Average monetary cost (E and C)
   - Per PR crash
   - Per vehicle-mile (in cents)
   - Per registered vehicle annually (PR + NPR crashes)
9. Expected monetary cost (E and C)
   - Average per vehicle over its operational life (PR + NPR crashes)
   - Average per driver over his/her driving career ("all vehicles" only; PR + NPR crashes)
10. Fatal equivalents
    - Annual national total (PR + NPR crashes)
    - Average per PR crash.

Expected monetary costs over a vehicle's life were calculated using the same vehicle usage-by-vehicle-age projections employed by NHTSA to analyze its safety regulations and, as noted, using a 4% annual discount rate. Motorcycle usage-by-age projections were based on the passenger car pattern, but they were accelerated to reflect the shorter operational life of motorcycles. The "all vehicles" projection was a weighted average of the individual vehicle types. Driver discounting was based on the 1989–93 distribution of crash involvements by driver age. The cumulative discounting for the different vehicle types and for drivers (reflecting their different operational lives) was as follows: all vehicles, 17.45%; passenger cars, 16.73%; LT/Vs, 19.82%; CUTs and SUTs, 18.48%; motorcycles, 11.69%; drivers, 44.56%. For example, the discounted "all vehicles" expected monetary costs over a vehicle's life was derived by first obtaining a gross cost estimate (calculated using the formula shown earlier) and then reducing this gross value by 17.45%.

The "all vehicles" value provided is *not* simply the sum or weighted average of the five specific vehicle types. First, "all vehicles" includes a relatively small number of other vehicle types such as buses. More importantly, for most statistics the crashes, vehicles, injuries, or dollars may be counted under more than one specific vehicle type column. For example, for all crashes (see table 2), those involving *both* a passenger car and an LT/V are counted in both columns. Since many of the statistics provided include all involved vehicles and persons (e.g., injuries to persons in non-SVs), the columns are not additive; such additions would constitute double counting. For all crashes, the per VMT, per registered vehicle annually, and per vehicle over its operational life values for "all vehicles"

TABLE 2 Statistics for All Crashes

Type of statistics		Crashes involving: All vehicles	Passenger cars	Light trucks/ vans	Combin-ation-unit trucks	Single-unit trucks	Motor-cycles
Annual number of PR crashes		6,261,000	5,307,000	2,209,000	214,000	154,000	89,000
Annual number of this vehicle type involved in PR crashes*		10,964,000	7,929,000	2,485,000	221,000	157,000	90,000
Annual number of all vehicles involved in PR crashes*		10,964,000	9,688,000	4,141,000	392,000	287,000	145,000
Annual U.S. number of persons involved in PR crashes*		15,905,000	14,101,000	5,932,000	494,000	376,000	183,000
Not injured (0)*		12,278,000	10,936,000	4,684,000	399,000	307,000	90,000
Minor to moderate (MAIS 1–2)*		3,433,000	3,020,000	1,183,000	85,000	65,000	78,000
Serious to fatal (MAIS 3–fatal)*		194,000	146,000	65,000	9,000	5,000	15,000
Vehicle involvement rate in PR crashes							
Per 100 million VMT		500.41	556.15	415.59	225.52	289.33	927.65
Per 1,000 registered vehicles annually		59.33	64.91	47.87	135.14	36.60	21.54
Expected involvements in PR crashes							
Over vehicle operational life		0.7789	0.7640	0.7684	1.9866	0.5380	0.1615
Per driver over driving career		3.7383					
Annual U.S. monetary cost*	(E)	$164.4B	$146.8B	$57.7B	$9.5B	$5.4B	$6.5B
	(C)	$431.9B	$353.7B	$147.9B	$22.1B	$11.6B	$22.6B
Average monetary cost							
Per PR crash*	(E)	$17,950	$18,650	$17,580	$39,540	$31,870	$57,190
	(C)	$52,610	$50,190	$50,750	$89,400	$66,370	$206,460
Per VMT*	(E)	7.50¢	10.29¢	9.65¢	9.68¢	9.99¢	66.52¢
	(C)	19.71¢	24.81¢	24.73¢	22.57¢	21.50¢	233.05¢
Per registered vehicle annually*	(E)	$890	$1,200	$1,110	$5,800	$1,260	$1,540
	(C)	$2,340	$2,900	$2,850	$13,520	$2,720	$5,410
Expected monetary cost							
Per vehicle over operational life*	(E) d	$9,640	$11,780	$14,310	$69,540	$15,140	$10,230
	(C) d	$25,330	$28,380	$36,660	$162,040	$32,580	$35,830
Per driver over driving career	(E) d	$31,070					
	(C) d	$81,630					
Total annual U.S. fatal equivalents*		139,699	114,423	47,829	7,160	3,763	7,320
Average fatal equivalents per PR crash*		0.01702	0.01623	0.01642	0.02855	0.02120	0.06678

* Inclusive; i.e., includes all crash-involved vehicles and persons, except for the boxed area in "all vehicles" column. For these statistics, a crash or injury may be counted in two different columns (e.g., a crash involving a passenger car and a combination-unit truck). Thus, the columns are not additive.

Key: B = billion; C = comprehensive cost; d = discounted; E = economic cost; PR = police-reported; VMT = vehicle-miles traveled.

are less than any of the individual vehicle types, because the aggregation of all vehicles eliminates the possibility of counting "other" involved vehicles. These all vehicle/all crash statistics (see boxed values within table 2), unlike those in other columns and tables, do not reflect consequences to other involved vehicles and their occupants. Similarly, the table 2 values for all crashes "per driver over driving career" do not incorporate consequences to other involved vehicles and their occupants.

The following rounding rules were applied to all the statistics presented in this paper. For crash and injury statistics, values were rounded to the nearest 1,000 if they are 2,000 or greater, or to the nearest 100 if they are less than 2,000. Monetary costs, except for costs per VMT, were rounded to the nearest $10. Costs per VMT were rounded to the nearest 0.01¢. Other statistics, including rates and expected involvements, have been rounded in a manner to ensure that the smallest value in each row contains at least two, and usually three, significant digits. The total annual national fatal equivalent was rounded to the nearest 1. As a result of rounding, some table entries may not sum to the totals. In addition, percentage estimates and the derived statistics in the tables were calculated before numbers were rounded.

RESULTS AND DISCUSSION

Results are shown in table 2 for all crashes and appendix tables A through H (at the end of this paper) for specific crash types. The statistics provided are too numerous to describe completely. This discussion will focus on major findings, caveats, and clarifications of appropriate interpretations.

"All Crashes" Statistics

At the highest level of analysis are the statistics for all crashes and all vehicles types. Between 1989–93, there were an average of 6,261,000 PR crashes annually involving 10,964,000 vehicles and 15,905,000 persons. There were 500 vehicle involvements in PR crashes per 100 million VMT and 59.3 involvements per 1,000 registered vehicles. Each vehicle can be expected to be involved in 0.78 PR crashes during its operational life and each driver can be expected to be involved in 3.74 PR crashes during his or her driving career.

The average annual total economic cost of motor vehicle crashes (PR + NPR) was $164 billion. Average annual national comprehensive costs were $432 billion. The average PR crash resulted in direct economic losses of $17,950 and had a comprehensive cost of $52,610. Not shown in table 2 are the economic costs of NPR crashes; Blincoe and Faigin (1992) estimated that 22% of all injuries, mostly minor, are not accounted for in PARs. In addition, 48% of all property-damage-only crashes are unreported.

Each mile traveled by a vehicle is associated with crash costs (PR + NPR) of 7.5¢ (E) or 19.7¢ (C). On average, each registered vehicle annually experiences crash consequences with a value of $890 (E) or $2,340 (C). Over the total operational life of the vehicle, these values are extrapolated to discounted values of $9,640 (E) or $25,330 (C). Extrapolation of the 1989–93 statistics across a 58-year driving career (discounted to current value) indicates that each driver would be expected to be involved in crashes with a value of $31,070 (E) or $81,630 (C). As noted earlier, the per VMT, per registered vehicle annually, and per vehicle over its operational life values for the specific vehicle types are all higher than the "all vehicles" value because they incorporate the consequences to other vehicles involved in the crashes (e.g., LT/Vs involved in passenger car crashes and vice versa).

The statistics indicate an annual national average of 139,699 fatal equivalents associated with motor vehicle crashes. Each PR-crash results in an average of 0.0170 fatal equivalents (the total of all involved persons).

The above statistics can be used to assess potential benefits from the application of safety interventions, whether real or hypothetical, to specific vehicle types. For example, a vehicle-based device lasting the life of a passenger car and capable of reducing all its crash involvements by 5% would have a societal economic value of $11,780 × 0.05 = $590 (E) or $28,380 × 0.05 = $1,420 (C) for each equipped passenger car. These represent *time-of-purchase* monetary values because the cost projections were discounted. This monetary benefit would be shared by the occupants of equipped passenger cars and those in other vehicles who would have crashed with the equipped car had the device not been installed.

A new driver education program or similar intervention capable of reducing a driver's lifetime crash involvements by 10% would have a start-of-driving societal economic value of $31,070 × 0.10 = $3,110 (E) or $81,630 × 0.10 = $8,160 (C) for each young driver exposed. This benefit would be shared by the driver, his or her passengers, and any nonmotorists (e.g., pedestrians) who would have been affected by these crashes. In addition to this benefit, there would be benefits to other vehicles and their occupants whose crashes with the subject driver were also prevented.

As noted previously, the "per vehicle over operational life" and "per driver over driving career" monetary cost estimates are discounted to reflect the current economic value of future costs. For drivers, this discounting is substantial (44.56%). The *nondiscounted* value of all expected crash involvements during a typical 58-year driving career is $56,050 (E) or $147,250 (C). Applying the cumulative discount of 44.56% yields the discounted value presented in table 2.

Another way of expressing the nondiscounted driver values presented in the paragraph above is to consider per-driver-per-year crash costs. On an annual basis, the driver on average can be expected to be involved in crashes with a total value (*not* including consequences to other vehicles and their occupants) of $970 (E) or $2,540 (C). The potential cost-benefits of ongoing, continuously applied safety programs, such as public service announcements, might be assessed using these values.

Crash-Type Comparisons

Table 3 provides some comparative all-vehicle-type statistics on the eight specific crash types addressed in appendix tables A through H, plus two additional major crash types, signalized and unsignalized intersection perpendicular crossing path (SI/PCP and UI/PCP) crashes (Wang and Knipling 1994c). For each crash scenario, three summarizing statistics are provided: annual U.S. number of PR crashes, average monetary cost (E) per PR crash, and annual U.S. monetary cost. The three statistics represent comparative measures of PR crash frequency, average PR crash severity, and total societal problem size (PR + NPR). Other statistics could have been chosen from the tables to provide essentially the same comparisons.

Table 3 shows that the most numerous crash categories are rear-end crashes (1.45 million annual PR crashes for RE-LVS + RE-LVM), SVRD (1.31 million annual PR crashes), and intersection crossing path crashes (1.30 million annual PR crashes for LTAP + SI/PCP + UI/PCP). The most severe crash types are OD ($50,770 per PR crash) and pedestrian crashes ($42,340 per PR crash). The highest annual U.S. total monetary costs are associated with intersection crossing path crashes ($39.3 billion for the three subtypes combined), RE crashes ($33.8 billion for the two subtypes combined), and SVRD crashes ($33.2 billion).

A specific caveat relating to the backing crash problem size is that of the crashes shown in tables 3 and appendix table F the majority are *crossing path* backing crashes, where a vehicle backs into traffic and is struck by a another vehicle (Wang and Knipling 1994a). Crossing path backing crashes are probably less amenable to technological solution (i.e., rear object detection) than are *encroachment* backing crashes, in which a vehicle backs into a stationary object.

Vehicle-Type Comparisons

For all crashes and for each of the individual crash types, passenger cars and light trucks/vans dominate the statistics for total number of crashes, associated injuries, and monetary costs. For example, a comparison of the annual national total economic

TABLE 3 Crash Type Comparisons
(All vehicle types combined, 1989–93 average)

Crash type	Annual U.S. PR crashes	Average cost (E) per PR crash	Annual U.S. monetary cost
All crashes	6,261,000	$17,950	$164.4B
SVRD crashes	1,310,000	$19,060	$33.2B
Pedestrian crashes	176,000	$42,340	$9.7B
RE-LVS crashes	974,000	$14,170	$22.3B
RE-LVM crashes	480,000	$15,120	$11.5B
LC/M crashes	234,000	$10,080	$4.1B
Backing crashes	171,000	$7,390	$2.4B
OD crashes	190,000	$50,770	$12.7B
LTAP crashes	396,000	$20,500	$11.9B
SI/PCP crashes	266,000	$21,690	$8.4B
UI/PCP crashes	633,000	$20,490	$19.0B

Key: B = billion; E = economic; PR = police-reported.

cost (E) row in table 2 indicates that total costs for all vehicle types combined were $164 billion. The costs of crashes involving the individual vehicle types were: passenger cars, $147 billion; LT/Vs, $58 billion; CUTs, $10 billion; SUTs, $5 billion; and motorcycles, $7 billion. (The individual vehicle types add up to greater than $164 billion, because each vehicle-type statistic includes all vehicles (and people) involved in the crashes.) Thus, from a national perspective, safety interventions are not likely to have dramatic effects unless they address the huge passenger car and LT/V crash situations.

Passenger cars represented more than three times as many vehicle crash involvements than LT/Vs between 1989–93, but otherwise these two large vehicle populations were similar in their crash profiles. Compared to passenger cars, however, LT/Vs have somewhat lower involvement rates, monetary costs per VMT, and average annual monetary costs per registered vehicle.

CUTs are associated with a very different crash-size profile, however. Although they have very low crash rates, their high mileage exposures, long operational lives, and the severity of crashes (Miaou 1990; Clarke et al. 1991) combine to give them very high per vehicle crash costs. Indeed, for "all crashes" and each of the eight specific crash types/roles, CUTs stand out as having the highest per vehicle crash costs and thus the highest potential crash-reduction benefits on a per vehicle basis. For example, in table 2 it is shown that the per vehicle life monetary costs of all CUT crashes is $69,540 (E) or $162,040 (C). These costs are more than four times as great as those for any other vehicle type. From a percentage cost-benefit standpoint, this means that crash avoidance systems can generally afford to be considerably more expensive and/or less effective for CUTs and still be more attractive than the same device installed on other vehicle types. Still, the national impact of such deployments will be limited; only 3.4% of all crashes and 5.8% of associated monetary costs are associated with CUT crashes.

SUTs have a less dramatic crash picture than do CUTs. SUTs represent 1.4% of all vehicle crash involvements and, compared with other vehicles, they have low involvement rates, both on a per mile traveled and per registered vehicle basis annually. Their crashes are more severe, measured by average monetary cost per PR crash, than those of passenger cars or LT/Vs, but they are less severe than those of CUTs or motorcycles. The per vehicle operational life costs of SUT crashes are about 20% of those of CUTs and are only slightly higher than LT/Vs.

Safety interventions for CUTs applied on an annual basis as well as those lasting the life of a vehicle can be very effective. Annually, on average, each CUT was involved in crashes with a monetary value of $5,800 (E) or $13,520 (C). This is four to five times as great as the values for crashes of other vehicle types. Thus, an annual safety intervention (e.g., vehicle safety inspections) would have four to five times the payoff for CUTs as for other vehicle types, assuming equivalent intervention costs and effectiveness.

An important caveat, which bears repeating, is that the current CUT and SUT monetary cost statistics are based on an assumption of zero unreported crash costs. Since in reality there are some such crashes, the current monetary cost statistics understate CUT and SUT crash costs somewhat. This underestimation, however, is not likely to be more than a few percentage points.

The motorcycle crash picture presents another sharp contrast to that of other vehicle types. Motorcycles represent a relatively small percentage of overall national crashes, but their per crash costs are high; for example, $57,190 per PR crash (E) versus $17,950 for all vehicle types combined. Of course, this reflects the relatively high vulnerability of motorcycle riders to crash injuries. The average PR motorcycle crash is associated with 0.067 fatal equivalents—nearly four times the value of all vehicle types combined. In addition, motorcycles have a rate of involvement in crashes per VMT that is nearly twice that of all vehicle types combined. These two factors have a multiplicative effect in making motorcycle travel 6 to 10 times more costly per mile traveled than other vehicle types.

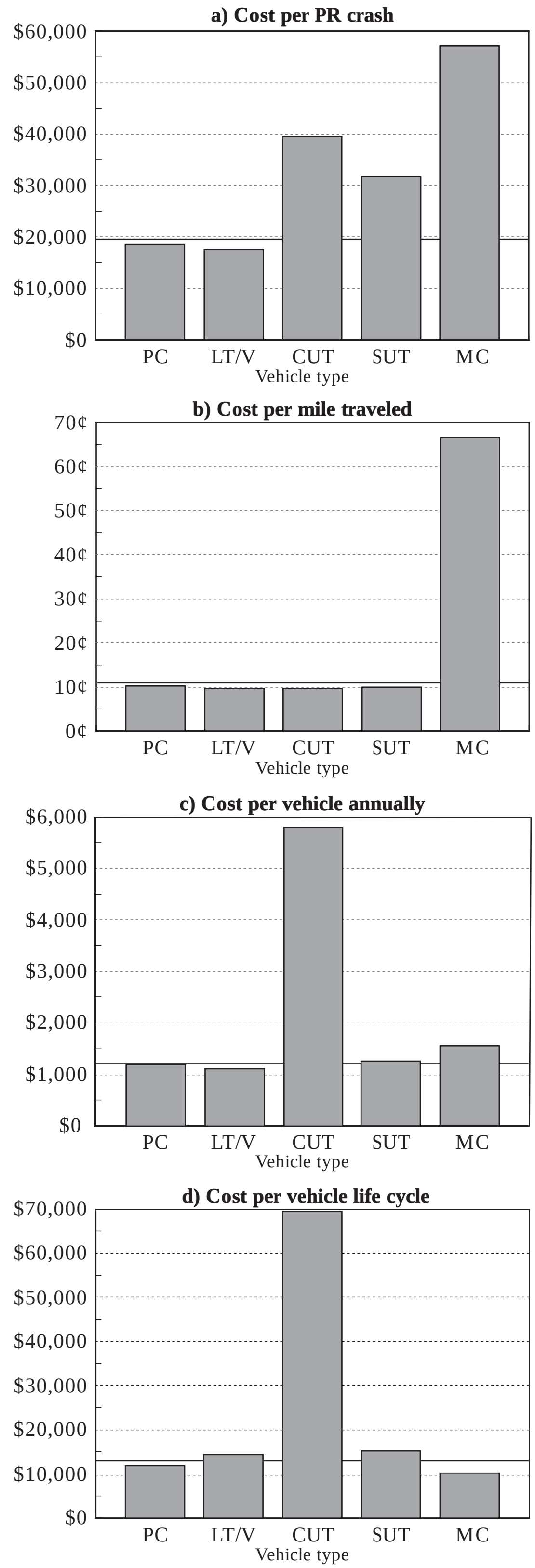
The irony of the motorcycle crash picture—exactly opposite of that of CUTs—is that they have low mileage exposure and relatively short operational lives. These factors make the vehicle operational life crash costs of motorcycles among the lowest of the vehicle types. From a strict per vehicle produced monetary cost-benefit perspective, this makes motorcycles a relatively *unattractive* platform for safety devices lasting the life of the vehicle, assuming equivalent costs and effectiveness levels. On the other hand, this type of vehicle is an extremely attractive platform for safety devices having a limited mileage life. For example, assuming comparable effectiveness, a general safety device (i.e., targeting all crashes) installed for 1,000 miles on an motorcycle would produce more than six times the expected benefit as the same device installed for 1,000 miles on a passenger car.

Figure 1 provides four sets of comparative histograms for four monetary metrics: a) per PR crash, b) per mile traveled, c) per registered vehicle annually, and d) per vehicle life cycle. For each, the horizontal line shows the *weighted average* of the value of the vehicle types, while the vertical bars represent the five specific vehicle types. These relative values are based on the economic (E) monetary values in table 2. Generally, the passenger car and LT/V values are similar to each other and the weighted average across all four comparisons. Since these two vehicle types together represent about 95% of vehicles involved in crashes, they are the principal determinants of the weighted averages for each set. Motorcycles sustain the highest costs per crash, followed by those of CUTs and SUTs, which are also significantly greater than average. In costs per mile of travel, motorcycles are about six times the weighted average; surprisingly, perhaps, both CUTs are SUTs are slightly *lower* than average. In the per vehicle annually set, CUTs are far above the weighted average, while all the other vehicle types are near the average. The per vehicle life cycle set is similar, but not identical since different vehicle types have different average operational lives. In this set, CUTs are again far above average, but motorcycles are now below average reflecting, in part, their short operational lives.

For the individual vehicle types, the current statistics do not provide information to disaggregate "inside" versus "outside" damage, injuries, and associated costs. It is well known, however, that there are major differences across vehicle types in this disaggregation, with CUTs and motorcycles

FIGURE 1 Vehicle-Type Comparisons of Four Monetary (E) Crash Statistics

Weighted costs indicated by reference line



Key: E = economic cost; PC= passsenger car; MC = motorcycle.

representing the extremes. A supplemental analysis (not shown in the tables) indicates that approximately 67.2% of the monetary costs of CUT crashes are associated with damage and injuries outside the truck; for example, occupants of other involved vehicles. In contrast, only 12.5% of the monetary costs of motorcycle crashes are "outside" the vehicle. (The small number of crashes involving multiple CUTs or multiple motorcycles were excluded from this analysis.)

Crash- and Vehicle-Type Interactions

The crash- and vehicle-type statistics provided in appendix tables A through H are too numerous to discuss in detail. For each vehicle type, SVRD and RE crashes (when the RE-LVS and RE-LVM categories are combined) are the most numerous of those shown here. Intersection crossing path crashes are also numerous (Wang and Knipling 1994c), although statistics for only one subcategory of these crashes (i.e., LTAP crashes) are presented here for individual vehicle types.

Comparison of crash statistics across various crash and vehicle types reveals several notable examples of overrepresentation or underrepresentation of particular vehicle types in particular crash types/roles. For example, LT/Vs represent 22.7% of all vehicles involved in crashes but 36.2% of SVs in backing crashes.

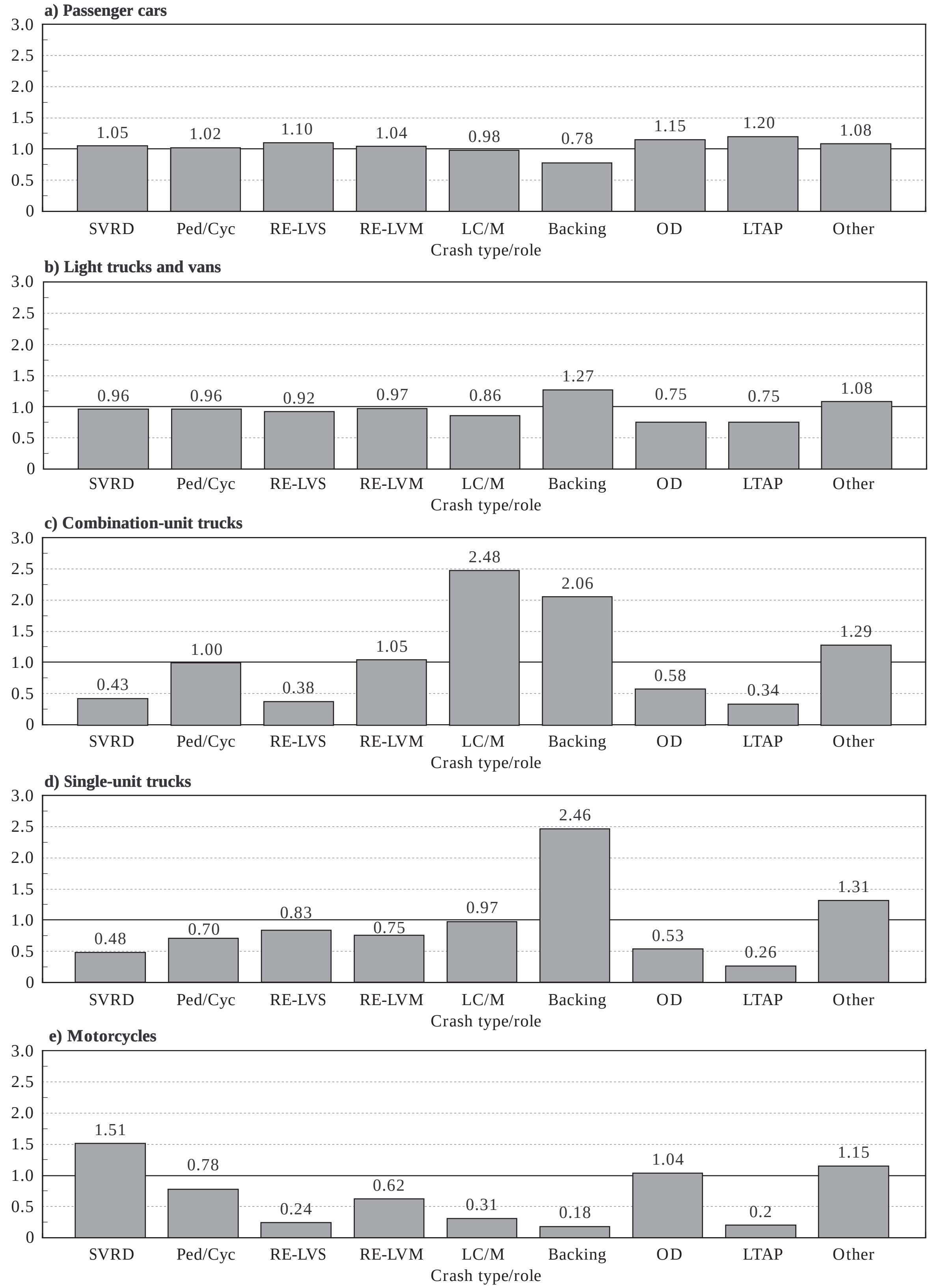
The largest relative overinvolvement of CUTs is in LC/M crashes. CUTs comprise only 2.0% of vehicles involved in crashes, but represent 8.5% of vehicles involved in LC/M crashes as the SV. On a per vehicle life cycle basis, CUT involvements in LC/M crashes are about 12 times as costly as those of SUTs and 14 times as costly as those of all vehicle types combined. CUTs are also relatively underrepresented in certain crash types; for example, they represent only 1.1% of the SVs in RE-LVS crashes and 0.5% of those in LTAP crashes. Nevertheless, for every crash type, CUTs have the highest crash costs per vehicle over the operational life of the vehicle.

The only major overrepresentation of SUTs is in backing crashes; they represent 1.4% of vehicles involved in all crashes, but account for 5.3% of SVs in backing crashes. CUTs and SUTs show a different pattern of SV involvements in RE-LVS versus RE-LVM crashes; CUTs have more RE-LVM crashes, whereas SUTs have more RE-LVS involvements. This likely reflects the different exposure patterns of these two large truck types; CUTs accumulate most of their mileage on highways whereas SUTs accumulate relatively more mileage on secondary/local roads.

Motorcycles are relatively overrepresented in SVRD crashes. They represent 0.8% of all vehicles involved in crashes but 1.2% of SVRD crash involvements. Furthermore, motorcycle SVRD crashes are approximately four times as severe as those of any other vehicle type. On a per mile traveled basis, motorcycle SVRD crashes are an order of magnitude more costly than those of all vehicle types combined. The per vehicle life cycle monetary costs of motorcycle SVRD crashes are actually slightly higher than the "all vehicles" average, an exception to the general rule that motorcycle life cycle crash costs are generally low compared with other vehicle types.

Figure 2 is based on the monetary costs (E) for the different crash type roles and vehicle types. They are shown in terms of *relative* percentage of that vehicle type's crash costs in comparison to a weighted average of all vehicle types combined (the latter statistics are not shown). The horizontal line in each histogram set represents the weighted average across vehicle types for each crash type. The passenger car set (2a) deviates very little from the weighted average of all five vehicle types, since passenger cars dominate these weighted average statistics. LT/Vs (2b) show a relative overinvolvement in backing crashes. For CUTs (2c), there are large relative overinvolvements in LC/M and backing crashes and notable relative underinvolvements in SVRD, RE-LVS, and LTAP crashes. SUTs (2d) show a marked relative overinvolvement in backing crashes. Both CUTs and SUTs show overinvolvements in "other" types of crash roles, since they are very often the non-SV (i.e., nonculpable) vehicle in two-vehicle crashes. For motorcycles (2e), the greatest relative overinvolvements are in SVRD crashes with marked relative underinvolvements in RE-LVS, backing, and LTAP crashes. Recall that the LTAP statistics reflect only SV (left turning) roles in crashes; motorcycles rarely play

FIGURE 2 Relative Distribution of Crash Costs (E) by Crash Type/Role for Five Vehicle-Type Categories



this role in LTAP crashes, but are frequently in the non-SV (going straight), since they are often not seen by other drivers.

"Most-Relevant Referents" for Countermeasure Benefit Assessments

This paper presents crash problem-size statistics that are more specific and heuristic than traditional national annual totals. To perform a meaningful and heuristic benefits assessment, we selected appropriate statistics based on four dimensions of motor vehicle crash risk: crash types/roles, vehicle types, metrics, and referrants. Perhaps the most subtle of these dimensions is problem-size referent. Safety initiatives may vary dramatically in their patterns or "spans" of application and, therefore, in the most appropriate perspective from which to assess their potential benefits. Below are examples of countermeasures with qualitatively different patterns of application and their corresponding most-relevant referents.

For national public information campaigns or other initiatives applied diffusely to the driver/vehicle population, the most-relevant referent would be U.S. annual. Annual program expenditures would be compared with the national annual problem size as measured by various metrics, whether monetary or nonmonetary.

Some safety interventions are applied proportionally to miles traveled; for such interventions, rate-per-mile statistics are most applicable. One example would be improved brake pads with a limited mileage life; benefits would be best assessed by comparing per mile crash rates or monetary cost rates for applicable crash and vehicle types. Another example of a mileage-based safety intervention is roadside inspections for commercial vehicles (primarily CUTs and SUTs). In general, the number of roadside inspections large trucks receive is proportional to their mileage exposure. Recall that CUTs and SUTs have almost identical crash costs per mile of travel (9.7¢ versus 10.0¢ (E), respectively; see table 2 and figure 1b). Assuming that per inspection costs and the crash-reduction effectiveness of inspections are similar for these two vehicle types, the cost-benefits of roadside inspections would also be similar, in spite of the vastly greater per vehicle mileage exposure of CUTs compared with SUTs.

Annual vehicle inspections, in contrast, have a time-based span of application; that is, one year. The most relevant referent would be per vehicle year. From the table 2 per-registered-vehicle-annually monetary cost values and figure 1c, we see that benefits are potentially far greater for CUTs than for other vehicle types. The importance of choosing the most relevant referent is illustrated by the comparison of CUTs with SUTs; unlike the situation above for roadside inspections where the benefits pictures were similar, for annual inspections the per vehicle benefits would be far greater for CUTs than for SUTs.

Most vehicle-based safety devices, whether they are crash avoidance- or crashworthiness-related, are installed at the factory or dealership, or are purchased in the aftermarket for use over the entire life of the vehicle. For example, an ITS crash avoidance device such as a headway/forward obstacle detector would target RE crashes (both LVS and LVM) and would operate over the entire vehicle life cycle. Where the span of application is vehicle operational life, per-vehicle-life-cycle statistics are most relevant to a determination of cost-benefits. Extreme differences among vehicle types are evident in these statistics; for example, assuming equal device cost and effectiveness, a RE-LVM countermeasure installed on a CUT would have 6 times the potential monetary benefits of the same device installed on a passenger car and 12 times that of a motorcycle. As noted earlier, for all crash types studied, the per-vehicle-life-cycle costs for CUTs are higher than for any other vehicle type, even though CUTs generally have low crash rates per mile and are markedly underinvolved in several crash types in relation to their own overall crash picture. The high per-vehicle-life-cycle costs for CUTs reflect their high per vehicle mileage exposure and the great severity of their crashes when they occur.

There do not seem to be any safety interventions with a pure "per crash" span of application. Air bags *deploy* only during crashes (of certain threshold severities), but they are purchased and applied over the vehicle life cycle (albeit they must be replaced after a crash deployment). Costs to government for emergency medical services responding to crashes are not necessarily proportional to the number of crashes to which they respond. Per crash statistics, however, are obviously relevant to any projections of the absolute number of crashes that may be prevented by a safety intervention even if the intervention does not have a per crash span of application.

Finally, there are new driver training/education programs that are conceptualized to affect drivers' entire lifetime driving experience. Here, the intended span of application is the individual driving career. Because drivers are on average involved in multiple crashes over their lifetimes, relatively small reductions in crash risk can be highly cost-beneficial.

CONCLUSION

This paper attempted to dissect the U.S. crash picture in ways that make crash and vehicle type differences more salient and that support realistic assessments of potential countermeasure benefits. Of course, any benefits assessment must include an estimation of the actual crash reduction effectiveness of interventions, which we did not address in this paper, but the above discussion and examples show that identification of the most relevant dimensions of motor vehicle crash risk is even more fundamental to developing a framework for enlightened safety benefits assessment and decisionmaking.

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Appendix Tables

TABLE A Statistics for Single-Vehicle Roadway-Departure (SVRD) Crashes

Type of statistics		Crashes involving: All vehicles	Passenger cars	Light trucks/ vans	Combin- ation- unit trucks	Single- unit trucks	Motor- cycles
Annual number of PR crashes		1,310,000	907,000	323,000	31,000	23,000	16,000
Annual number of this vehicle type involved in PR crashes		1,310,000	907,000	323,000	31,000	23,000	16,000
Annual U.S. number of persons involved in PR crashes		1,791,000	1,277,000	435,000	34,000	27,000	19,000
Not injured (0)		1,190,000	849,000	290,000	27,000	22,000	3,000
Minor to moderate (MAIS 1–2)		553,000	397,000	133,000	7,000	4,000	12,000
Serious to fatal (MAIS 3–fatal)		48,000	32,000	12,000	800	300	3,000
Vehicle involvement rate in PR crashes							
Per 100 million VMT		59.79	63.62	53.97	31.64	41.91	167.65
Per 1,000 registered vehicles annually		7.09	7.43	6.22	18.96	5.30	3.89
Expected involvements in PR crashes							
Over vehicle operational life		0.0931	0.0874	0.0998	0.2787	0.0779	0.0292
Per driver over driving career		0.4466					
Annual U.S. monetary cost	(E)	$33.2B	$22.8B	$8.1B			
	(C)	$62,200	$60,870	$62,650	$40,060	$32,190	$263,040
Per VMT	(E)	1.52¢	1.60¢	1.36¢	0.62¢	0.71¢	14.82¢
	(C)	4.67¢	4.88¢	4.24¢	1.44¢	1.54¢	53.76¢
Per registered vehicle annually	(E)	$180	$190	$160	$370	$90	$340
	(C)	$550	$570	$490	$870	$200	$1,250
Expected monetary cost							
Per vehicle over operational life	(E)d	$1,950	$1,830	$2,020	$4,450	$1,080	$2,280
	(C)d	$6,010	$5,580	$6,280	$10,370	$2,330	$8,270
Per driver over driving career	(E)d	$6,280					
	(C)d	$19,360					
Total annual U.S. fatal equivalents		33,125	22,507	8,190	458	269	1,689
Average fatal equivalents per PR crash		0.02012	0.01969	0.02027	0.01279	0.01028	0.08509

* Inclusive, i.e., includes all crash-involved vehicles and persons. For these statistics, a crash or injury may be counted in two different columns (e.g., a crash involving a passenger car and a combination-unit truck). Thus, the columns are not additive.

Key: B = billion; C = comprehensive cost; E = economic cost; M = million; PR = police-reported; VMT = vehicle-miles traveled.

TABLE B Statistics for Pedestrian/Cyclist (Ped/Cyc) Crashes

Type of statistics		Crashes involving: All vehicles	Passenger cars	Light trucks/ vans	Combin- ation- unit trucks	Single- unit trucks	Motor- cycles
Annual number of PR crashes		176,000	133,000	37,000	1,200	1,500	2,000
Annual number of this vehicle type involved in PR crashes*		178,000	134,000	37,000	1,200	1,500	2,000
Annual number of all vehicles involved in PR crashes*		178,000	134,000	37,000	1,300	1,500	2,000
Annual U.S. number of person involved in PR crashes*		415,000	315,000	85,000	3,000	3,000	5,000
Not injured (0)*		245,000	188,000	50,000	1,400	1,800	1,400
Minor to moderate (MAIS 1–2)*		155,000	117,000	32,000	900	1,300	3,000
Serious to fatal (MAIS 3–Fatal)*		15,000	10,000	3,000	400	200	500
Vehicle involvement rate in PR crashes							
Per 100 million VMT		8.12	9.39	6.15	1.21	2.79	24.07
Per 1,000 registered vehicles annually		0.96	1.10	0.71	0.73	0.35	0.56
Expected involvements in PR crashes							
Over vehicle operational life		0.0126	0.0129	0.0114	0.0107	0.0052	0.0042
Per driver over driving career		0.0607					
Annual U.S. monetary cost*	(E)	$9.7B	$6.5B	$2.4B	$410M	$162M	$218M
	(C)	$31.1B	$20.3B	$7.8B	$1.1B	$427M	$779M
Average monetary cost							
Per PR crash*	(E)	$42,340	$36,850	$51,020	$287,620	$92,180	$74,660
	(C)	$141,480	$121,410	$171,580	$788,970	$240,720	$271,760
Per VMT*	(E)	0.45¢	0.45¢	0.40¢	0.42¢	0.30¢	2.25¢
	(C)	1.42¢	1.42¢	1.30¢	1.15¢	0.79¢	8.03¢
Per registered vehicle annually*	(E)	$50	$50	$50	$250	$40	$50
	(C)	$170	$170	$150	$690	$100	$190
Expected monetary cost							
Per vehicle over operational life*	(E)d	$570	$520	$600	$3,000	$450	$350
	(C)d	$1,830	$1,630	$1,930	$8,250	$1,200	$1,230
Per driver over driving career	(E)d	$1,840					
	(C)d	$5,880					
Total annual U.S. fatal equivalents*		10,065	6,554	2,523	360	136	252
Average fatal equivalents per PR crash*		0.04577	0.03927	0.05550	0.25198	0.07688	0.08791

* Inclusive; i.e., includes all crash-involved vehicles and persons. For these statistics, a crash or injury may be counted in two different columns (e.g., a crash involving a passenger car and a combination-unit truck). Thus, the columns are not additive.

Key: B = billion; C = comprehensive cost; d = discounted; E = economic cost; M = million; PR = police-reported; VMT = vehicle-miles traveled.

TABLE C Statistics for Rear-End, Lead Vehicle Stopped (RE-LVS) Crashes

		Crashes involving vehicle as					
Type of statistics		**All vehicles**	**Passenger cars**	**Light trucks/ vans**	**Combin-ation-unit trucks**	**Single-unit trucks**	**Motor-cycles**
Annual number of PR crashes		974,000	696,000	229,000	11,000	12,000	3,000
Annual number of this vehicle type involved in PR crashes*		2,144,000	1,331,000	319,000	13,000	14,000	4,000
Annual number of all vehicles involved in PR crashes*		2,144,000	1,532,000	504,000	24,000	27,000	7,000
Annual U.S. number of persons involved in PR crashes*		3,107,000	2,020,000	652,000	27,000	34,000	9,000
Not injured (0)*		2,469,000	1,608,000	523,000	21,000	26,000	6,000
Minor to moderate (MAIS 1–2)*		618,000	401,000	125,000	6,000	7,000	3,000
Serious to fatal (MAIS 3–fatal)*		20,000	11,000	4,000	300	300	300
Vehicle involvement rate as SV in PR crashes							
Per 100 million VMT		44.46	48.85	38.30	10.98	22.98	33.51
Per 1,000 registered vehicles annually		5.27	5.70	4.41	6.58	2.91	0.78
Expected involvements as SV in PR crashes							
Over vehicle operational life		0.0692	0.0671	0.0708	0.0967	0.0427	0.0058
Per driver over driving career		0.7308					
Annual U.S. monetary cost*	(E)	$22.3B	$14.6B	$4.8B	$325M	$400M	$140M
	(C)	$48.0B	$30.0B	$9.9B	$613M	$765M	$443M
Average monetary cost							
Per PR crash*	(E)	$14,170	$12,680	$12,620	$28,480	$29,940	$31,400
	(C)	$35,190	$30,260	$30,640	$51,820	$55,410	$107,430
Per VMT*	(E)	1.02¢	1.02¢	0.80¢	0.33¢	0.74¢	1.44¢
	(C)	2.19¢	2.10¢	1.66¢	0.63¢	1.41¢	4.57¢
Per registered vehicle annually*	(E)	$120	$120	$90	$200	$90	$30
	(C)	$260	$250	$190	$370	$180	$110
Expected monetary cost							
Per vehicle over operational life*	(E)d	$1,310	$1,170	$1,190	$2,380	$1,120	$220
	(C)d	$2,810	$2,410	$2,460	$4,490	$2,140	$700
Per driver over driving career	(E)d	$4,220					
	(C)d	$9,070					
Total annual national fatal equivalents*		15,522	9,705	3,215	198	247	143
Average fatal equivalents per PR crash*		0.01138	0.00979	0.00991	0.01655	0.01770	0.03475

* Inclusive; i.e., includes all crash-involved vehicles and persons. For these statistics, a crash or injury may be counted in two different columns (e.g., a crash involving a passenger car and a combination-unit truck). Thus, the columns are not additive.

Key: B = billion; E = economic cost; C = comprehensive cost; d = discounted; M = million; PR = police-reported; SV = subject vehicle (striking vehicle); VMT = vehicle-miles traveled.

TABLE D Statistics for Rear-End, Lead Vehicle Moving (RE-LVM) Crashes

		Crashes involving vehicle as					
Type of statistics		**All vehicles**	**Passenger cars**	**Light trucks/ vans**	**Combin- ation- unit trucks**	**Single- unit trucks**	**Motor- cycles**
Annual number of PR crashes		480,000	329,000	118,000	10,000	7,000	3,000
Annual number of this vehicle type involved in PR crashes*		1,057,000	624,000	165,000	13,000	8,000	4,000
Annual number of all vehicles involved in PR crashes*		1,057,000	724,000	260,000	22,000	15,000	7,000
Annual U.S. number of persons involved in PR crashes*		1,522,000	966,000	341,000	28,000	17,000	8,000
Not injured (0)*		1,212,000	772,000	273,000	21,000	14,000	5,000
Minor to moderate (MAIS 1–2)*		299,000	188,000	66,000	6,000	3,000	3,000
Serious to fatal (MAIS 3–fatal)*		11,000	6,000	2,000	500	200	500
Vehicle involvement rate as SV in PR crashes							
Per 100 million VMT		21.92	23.07	19.76	10.41	12.53	34.14
Per 1,000 registered vehicles annually		2.60	2.69	2.28	6.24	1.59	0.79
Expected involvements as SV in PR crashes							
Over vehicle operational life		0.0341	0.0317	0.0365	0.0917	0.0233	0.0060
Per driver over driving career		0.3603					
Annual U.S. monetary cost*	(E)	$11.5B	$7.2B	$2.6B	$473M	$192M	$187M
	(C)	$25.8B	$15.2B	$5.8B	$1.1B	$361M	$637M
Average monetary cost							
Per PR crash*	(E)	$15,120	$13,390	$13,880	$41,830	$26,800	$43,000
	(C)	$38,960	$32,950	$35,230	$91,530	$48,670	$154,350
Per VMT*	(E)	0.53¢	0.50¢	0.44¢	0.48¢	0.36¢	1.93¢
	(C)	1.18¢	1.07¢	0.97¢	1.09¢	0.67¢	6.56¢
Per registered vehicle annually*	(E)	$60	$60	$50	$290	$50	$50
	(C)	$140	$130	$110	$650	$80	$150
Expected monetary cost							
Per vehicle over operational life*	(E)d	$680	$580	$660	$3,460	$540	$300
	(C)d	$1,510	$1,220	$1,430	$7,810	$1,010	$1,010
Per driver over driving career	(E)d	$2,180					
	(C)d	$4,880					
Total annual U.S. fatal equivalents*		8,347	4,926	1,870	341	115	206
Average fatal equivalents per PR crash*		0.01260	0.01066	0.01140	0.02923	0.01554	0.04993

* Inclusive; i.e., includes all crash-involved vehicles and persons. For these statistics, a crash or injury may be counted in two different columns (e.g., a crash involving a passenger car and a combination-unit truck). Thus, the columns are not additive.

Key: B = billion; C = comprehensive cost; d = discounted; E = economic cost; M = million; PR = police-reported; SV = subject vehicle (striking vehicle); VMT = vehicle-miles traveled.

TABLE E Statistics for Lane Change/Merge (LC/M) Crashes

Type of statistics		Crashes involving lane changing/merging vehicle as: All vehicles	Passenger cars	Light trucks/vans	Combination-unit trucks	Single-unit trucks	Motorcycles
Annual number of PR crashes		234,000	155,000	55,000	20,000	5,000	1,000
Annual number of this vehicle type involved in PR crashes*		476,000	267,000	65,000	20,000	5,000	1,000
Annual number of all vehicles involved in PR crashes*		476,000	315,000	111,000	40,000	11,000	2,000
Annual U.S. number of persons involved in PR crashes*		689,000	464,000	160,000	53,000	13,000	3,000
Not injured (0)*		595,000	400,000	140,000	46,000	12,000	2,000
Minor to moderate (MAIS 1–2)*		91,000	62,000	19,000	7,000	1,500	800
Serious to fatal (MAIS 3–fatal)*		3,000	2,000	600	400	100	100
Vehicle involvement rate as SV in PR crashes							
Per 100 million VMT		10.68	10.85	9.13	20.04	9.93	10.29
Per 1,000 registered vehicles annually		1.27	1.27	1.05	12.01	1.26	0.24
Expected involvements as SV in PR crashes							
Over vehicle operational life		0.0166	0.0149	0.0169	0.1766	0.0185	0.0018
Per driver over driving career		0.1622					
Annual U.S. monetary cost*	(E)	$4.1B	$2.7B	$947M	$443M	$100M	$38M
	(C)	$7.9B	$4.9B	$1.8B	$757M	$148M	$119M
Average monetary cost							
Per PR crash*	(E)	$10,080	$9,680	$9,940	$21,760	$18,300	$27,380
	(C)	$22,880	$20,990	$22,580	$35,840	$26,170	$93,220
Per VMT*	(E)	0.19¢	0.19¢	0.16¢	0.45¢	0.19¢	0.39¢
	(C)	0.36¢	0.34¢	0.30¢	0.77¢	0.27¢	1.22¢
Per registered vehicle annually*	(E)	$20	$20	$20	$270	$20	$10
	(C)	$40	$40	$40	$460	$40	$30
Expected monetary cost							
Per vehicle over operational life*	(E)d	$240	$210	$240	$3,240	$280	$60
	(C)d	$460	$390	$450	$5,540	$420	$190
Per driver over driving career	(E)d	$780					
	(C)d	$1,490					
Total annual U.S. fatal equivalents*		2,542	1,570	585	245	48	38
Average fatal equivalents per PR crash*		0.00740	0.00679	0.00730	0.01145	0.00836	0.03015

* Inclusive; i.e., includes all crash-involved vehicles and persons. For these statistics, a crash or injury may be counted in two different columns (e.g., a crash involving a passenger car and a combination-unit truck). Thus, the columns are not additive.

Key: B = billion; C = comprehensive cost; d = discounted; E = economic cost; M = million; PR = police-reported; SV = subject vehicle (lane changing/merging vehicle); VMT = vehicle-miles traveled.

TABLE F Statistics for Backing Crashes

Type of statistics		Crashes involving backing vehicle as: All vehicles	Passenger cars	Light trucks/vans	Combination-unit trucks	Single-unit trucks	Motorcycles
Annual number of PR crashes		171,000	88,000	62,000	10,000	9,000	300
Annual number of this vehicle type involved in PR crashes*		332,000	150,000	73,000	9,000	9,000	300
Annual number of all vehicles involved in PR crashes*		332,000	170,000	122,000	17,000	17,000	500
Annual U.S. number of persons involved in PR crashes*		456,000	235,000	167,000	21,000	22,000	600
Not injured (0)*		406,000	207,000	151,000	19,000	20,000	400
Minor to moderate (MAIS 1–2)*		49,000	27,000	16,000	2,000	2,000	200
Serious to fatal (MAIS 3–fatal)*		1,000	500	200	100	0	0
Vehicle involvement rate as SV in PR crashes							
Per 100 million VMT		7.81	6.17	10.33	9.39	16.35	2.74
Per 1,000 registered vehicles annually		0.93	0.72	1.19	5.63	2.07	0.06
Expected involvements as SV in PR crashes							
Over vehicle operational life		0.0122	0.0085	0.0191	0.0828	0.0304	0.0005
Per driver over driving career		0.1133					
Annual U.S. monetary cost*	(E)	$2.4B	$1.3B	$800M	$208M	$140M	$12M
	(C)	$3.9B	$2.1B	$1.1B	$365M	$177M	$41M
Average monetary cost							
Per PR crash*	(E)	$7,390	$7,660	$6,280	$21,460	$15,910	$34,300
	(C)	$14,180	$15,000	$10,240	$35,780	$19,630	$125,190
Per VMT*	(E)	0.11¢	0.09¢	0.13¢	0.21¢	0.26¢	0.13¢
	(C)	0.18¢	0.15¢	0.19¢	0.37¢	0.33¢	0.43¢
Per registered vehicle annually*	(E)	$10	$10	$20	$130	$30	$0**
	(C)	$20	$20	$20	$220	$40	$10
Expected monetary cost							
Per vehicle over operational life*	(E)d	$140	$100	$200	$1,520	$390	$20
	(C)d	$230	$170	$280	$2,670	$500	$70
Per driver over driving career	(E)d	$460					
	(C)d	$740					
Total annual U.S. fatal equivalents*		1,262	676	361	117	57	13
Average fatal equivalents per PR crash*		0.00459	0.00485	0.00331	0.01143	0.00627	0.04049

* Inclusive; i.e., includes all crash-involved vehicles and persons. For these statistics, a crash or injury may be counted in two different columns (e.g., a crash involving a passenger car and a combination-unit truck). Thus, the columns are not additive.

** Less than 10 dollars.

Key: B = billion; C = comprehensive cost; d = discounted; E = economic cost; M = million; PR = police-reported; SV = subject vehicle (backing vehicle); VMT = vehicle-miles traveled.

TABLE G Statistics for Opposite Direction (OD) Crashes

		Crashes involving encroaching vehicle as					
Type of statistics		**All vehicles**	**Passenger cars**	**Light trucks/ vans**	**Combin- ation- unit trucks**	**Single- unit trucks**	**Motor- cycles**
Annual number of PR crashes		190,000	137,000	44,000	4,000	2,000	1,800
Annual number of this vehicle type involved in PR crashes*		378,000	230,000	58,000	4,000	3,000	1,800
Annual number of all vehicles involved in PR crashes*		378,000	274,000	87,000	7,000	5,000	4,000
Annual U.S. number of persons involved in PR crashes*		557,000	408,000	127,000	10,000	6,000	5,000
Not injured (0)*		386,000	274,000	91,000	7,000	5,000	3,000
Minor to moderate (MAIS 1–2)*		154,000	121,000	33,000	2,000	1,300	1,600
Serious to fatal (MAIS 3–fatal)*		17,000	13,000	3,000	300	200	700
Vehicle involvement rate as SV in PR crashes							
Per 100 million VMT		8.68	9.63	7.30	3.77	4.47	18.21
Per 1,000 registered vehicles annually		1.03	1.12	0.84	2.26	0.56	0.42
Expected involvements as SV in PR crashes							
Over vehicle operational life		0.0135	0.0132	0.0135	0.0332	0.0083	0.0032
Per driver over driving career		0.1289					
Annual U.S. monetary cost*	(E)	$12.7B	$9.7B	$2.5B	$318M	$165M	$388M
	(C)	$39.9B	$30.6B	$7.6B	$795M	$411M	$1.4B
Average monetary cost							
Per PR crash*	(E)	$50,770	$54,130	$42,490	$74,210	$59,910	$177,420
	(C)	$168,190	$178,200	$139,120	$182,040	$146,120	$630,630
Per VMT*	(E)	0.58¢	0.68¢	0.41¢	0.32¢	0.31¢	3.99¢
	(C)	1.82¢	2.14¢	1.27¢	0.81¢	0.76¢	14.02¢
Per registered vehicle annually*	(E)	$70	$80	$50	$190	$40	$90
	(C)	$220	$250	$150	$490	$100	$330
Expected monetary cost							
Per vehicle over operational life*	(E)d	$740	$780	$610	$2,330	$460	$610
	(C)d	$2,340	$2,450	$1,890	$5,820	$1,150	$2,160
Per driver over driving career	(E)d	$2,390					
	(C)d	$7,550					
Total annual U.S. fatal equivalents*		12,918	9,886	2,461	254	131	440
Average fatal equivalents per PR crash*		0.05441	0.05764	0.04500	0.05814	0.04667	0.20399

* Inclusive; i.e., includes all crash-involved vehicles and persons. For these statistics, a crash or injury may be counted in two different columns (e.g., a crash involving a passenger car and a combination-unit truck). Thus, the columns are not additive.

Key: B = billion; C = comprehensive cost; d = discounted; E = economic cost; M = million; PR = police-reported; SV = subject vehicle (encroaching vehicle); VMT = vehicle-miles traveled.

TABLE H Statistics for Left-Turn-Across-Path (LTAP) Crashes

Type of statistics		All vehicles	Passenger cars	Light trucks/ vans	Combin- ation- unit trucks	Single- unit trucks	Motor- cycles
		Crashes involving left-turning vehicle as					
Annual number of PR crashes		396,000	318,000	71,000	2,000	2,000	900
Annual number of this type of vehicle involved in PR crashes*		792,000	571,000	87,000	3,000	2,000	1,000
Annual number of all vehicles involved in PR crashes*		792,000	637,000	141,000	5,000	4,000	1,900
Annual U.S. number of persons involved in PR crashes*		1,178,000	948,000	209,000	6,000	6,000	3,000
Not injured (0)*		865,000	696,000	155,000	5,000	4,000	1,600
Minor to moderate (MAIS 1–2)*		297,000	241,000	51,000	1,400	1,600	800
Serious to fatal (MAIS 3–fatal)*		16,000	11,000	3,000	200	100	100
Vehicle involvement rate as SV in PR crashes							
Per 100 million VMT		18.07	22.34	11.82	2.44	4.09	9.65
Per 1,000 registered vehicles annually		2.14	2.61	1.36	1.46	0.52	0.22
Expected involvements as SV in PR crashes							
Over vehicle operational life		0.0281	0.0307	0.0219	0.0215	0.0076	0.0017
Per driver over driving career		0.2700					
Annual U.S. monetary cost*	(E)	$11.9B	$9.1B	$2.2B	$163M	$74M	$65M
	(C)	$31.2B	$23.2B	$6.0B	$413M	$149M	$218M
Average monetary cost							
Per PR crash*	(E)	$20,500	$19,290	$21,720	$59,880	$30,940	$53,780
	(C)	$59,910	$54,970	$64,720	$148,190	$60,740	$186,810
Per VMT*	(E)	0.54¢	0.64¢	0.37¢	0.17¢	0.14¢	0.67¢
	(C)	1.42¢	1.63¢	1.00¢	0.42¢	0.28¢	2.24¢
Per registered vehicle annually*	(E)	$60	$70	$40	$100	$20	$20
	(C)	$170	$190	$120	$250	$40	$50
Expected monetary cost							
Per vehicle over operational life*	(E)d	$700	$730	$550	$1,200	$210	$100
	(C)d	$1,830	$1,860	$1,480	$3,020	$420	$350
Per driver over driving career	(E)d	$2,250					
	(C)d	$5,890					
Total annual national fatal equivalents*		10,077	7,496	1,927	134	48	70
Average fatal equivalents per PR crash*		0.01938	0.01778	0.02094	0.04733	0.01940	0.06043

* Inclusive; i.e., includes all crash-involved vehicles and persons. For these statistics a crash or injury may be counted in two different columns (e.g., a crash involving a passenger car and a combination-unit truck). Thus, the columns are not additive.

Key: B = billion; C = comprehensive cost; d = discounted; E = economic cost; M = million; PR = police-reported; SV = subject vehicle (left turning vehicle); VMT = vehicle-miles traveled.