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Assessment of costs associated with deer–vehicle collisions: human death and injury, vehicle damage, and deer loss

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Abstract: Collisions between large vertebrates and vehicles along roadways are an increasing concern, not only because of ecological consequences, but also because of associated economic and social costs. We used a large-scale, long-term data set comprising several databases from Utah to summarize and analyze these costs. The overall cost for 13,020 collisions from 1996 to 2001 in Utah was approximately $45,175,454, resulting in an estimated average per year cost of about $7,529,242 and a mean collision cost of $3,470. These figures include human fatality costs of $24 million (53% of total costs); vehicle damage costs of $18 million (39%); loss of deer, valued at $2.7 million (6%); and human injury costs of $1 million (2%). Cost-benefit analyses have shown that mitigation efforts, which are prioritized based on road-kill data, can produce positive net economic gains and also increase driver safety.

Key words: deer–vehicle collision, economic impact, human–wildlife conflict, *Odocoileus* spp., Utah, mitigation, probablistic linkage

An estimated 6.1 million motor vehicle collisions were reported to police in the United States during 2000; 4% (247, 000) of these involved a motor vehicle hitting a deer (*Odocoileus* spp.) on the roadway (National Highway Traffic Safety Administration 2000). The U.S. Centers for Disease Control (2004) estimated that 26,647 occupants per year during 2001 and 2002 were injured in collisions with animals (mainly deer). In 1980, deer–vehicle collisions (DVCs) were responsible for killing 200,000 deer in the United States (Williamson 1980, Schaefer and Penland 1985). Based on surveys from 36 states, Romin (1994) estimated that 538,000 deer were killed on roads in the United States in 1991. Conover et al. (1995) estimated that actually >1 million DVCs may occur each year in the United States. Even these estimates may be conservative because only about half of DVCs that occur actually are reported to authorities (Romin 1994, Romin and Bissonette 1996).

Collisions between vehicles and large vertebrates, especially white-tailed deer (*Odocoileus virginanus*), mule deer (*Odocoileus hemionus*), elk (*Cervus elaphus*), moose (*Alces alces*), and large carnivores are an increasing concern along roadways throughout the United States, not only because of the ecological consequences for the species involved but also because of the economic costs associated with human injury, death, and vehicle damage (Hussain et al. 2007, Storm et al. 2007, Grovenburg et al. 2008, McShea et al. 2008, Ng et al. 2008).

Although various studies have assessed the number of people who suffer injuries because of DVCs, there is a paucity of information regarding the costs that accrue because of these injuries (Schwabe et al. 2002). Economic analyses of injuries due to DVCs are not easily obtained because of the difficulty associated with assigning monetary value to human injuries and fatalities. For instance, Reed et al. (1982) chose to omit human costs from a cost-benefit analysis of DVC reduction methods, citing the challenges associated with quantifying human injury and death in terms of money. However, to understand the full spectrum of the impacts of DVCs and to put them into a broad and

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applicable perspective, it is both useful and necessary to assign a cost to these damages and losses.

In this paper, we use data from Utah from 1996 to 2001 as a case study example to evaluate economic losses associated with DVCs. To date, no cost analysis of DVCs has included human injury costs. In this paper, we used a unique data set that linked DVC data available from the Utah Department of Transportation (UDOT) with databases from the University of Utah Medical School regarding occupant injuries and associated medical charges available. This enabled us to assign values both accurately and objectively to these outcomes, creating an analysis that fills an existing gap in natural resource economics.

Methods

Study area

The topography of Utah is diverse, consisting of mountains, desert, rangeland, agricultural land, wetlands, and urban areas. Elevations across the state range from 762 m to 4,114 m above sea level. This varied terrain is accessed and divided by 9,500 km of state roads and 56,327 km of city and county roads that are being used by a growing number of drivers. From 1990 to 2001, the number of licensed drivers in Utah increased 43% (from 1,046,000 to 1,496,000), and vehicle miles traveled increased 60% (from 14,000,000 to 23,000,000; U.S. Bureau of Transportation 2004). Additionally, the population of Utah increased by 30% (510,000 people) from 1990 to 2000 and is projected to continue this upward trend, with an estimated increase of 25% (554,000 people) from 2000 to 2010. As the human population increases, the number of licensed drivers and vehicle miles traveled is expected to increase, making the issue of DVCs an even larger safety and conservation priority. These trends are representative of much of the U.S. and many parts of the world. For example, in Portugal, the total mileage of improved and new roads has increased by 20% since 1986 (M. Santos Reis, University of Lisbon, personal communication).

Data description

Our data set came from the Utah Crash Outcome Data Evaluation System (CODES) project, based at the Intermountain Injury Control

Research Center, University of Utah Medical School (Salt Lake City, Ut.). The National Highway Traffic Safety Administration has funded the following states to create CODES databases to link statewide collision and injury data: Alaska, Arizona, Connecticut, Delaware, Georgia, Hawaii, Indiana, Iowa, Kentucky, Maine, Maryland, Massachusetts, Minnesota, Missouri, Nebraska, Nevada, New Hampshire, New Mexico, New York, North Dakota, Oklahoma, Pennsylvania, Rhode Island, South Carolina, South Dakota, Tennessee, Texas, Utah, and Wisconsin.

The Utah CODES data set that we used included the number of DVCs, associated human injuries, fatalities, and costs for collisions occurring within Utah from 1996 to 2001, which was the latest year of available data. The CODES project used probabilistic record linkage, a method for combining multiple databases, to study motor vehicle collisions in conjunction with other healthcare databases. The information for these databases was collected independently from different sources. Comparing numerous common data fields, such as date of birth and gender, in 2 different files leads to the logical conclusion that 2 different records refer to the same patient (or not) and should be linked (or not). Probabilistic record linkage has been used for multiple analyses on a national level (e.g., to assess the effects of seatbelts and motorcycle helmets on medical outcomes). CODES has combined 5 databases: the Utah Division of Transportation (UDOT) motor vehicle collision records, completed by Utah Department of Public Safety Highway Patrol officers at the scene of a collision; records on emergency medical service runs, compiled by the Utah Department of Health, Bureau of Emergency Medical Services; discharge records from emergency departments and hospitals, collected from individual hospital organizations; vital statistics databases (i.e., death certificates); and driver license databases (i.e., moving-vehicle citations and driver medical conditions).

Combining the information found in the CODES databases is necessary to create a comprehensive picture of a DVC and its consequences. For example, the motor vehicle collision database provides a number of variables that are of interest for the analysis of motor

vehicle collisions (e.g., weather conditions, type of collision, and the number of people and vehicles involved). The motor vehicle collision database also includes a police-assessed injury score that is coded on a 5-point scale, ranging from 1 (not injured) to 5 (killed), and assigned to each passenger at the scene of a collision. However, more accurate measures of severity exist in other healthcare databases, including the Glasgow Coma Score that is assessed by emergency medical services, the Abbreviated Injury Score, and the Injury Severity Score that is calculated from emergency department and hospital discharge data sets. While healthcare databases contain more accurate severity rankings and injury mechanisms codes, there are

and emergency department charges for each type of injury, we used individual occupant data (n = 20,873) sorted by injury code. Injury codes are assigned to each occupant of a vehicle by the reporting officer at the site of the collision. The codes include no injury, possible injury, bruises or abrasions, broken bones or bleeding, and fatal (see criteria in Table 1). If vehicle occupants incur a charge from the hospital, that charge is linked to their record, making it possible to correlate costs with the severity of injury. Because the fatal criteria was included as an occupant injury class within the CODES database, we included these collisions and occupants in our assessment of number of collisions and injuries. The cost of a human

TABLE 1. Criteria for assigning injury codes used by the reporting officer at the site of a motor vehicle collision in Utah.

Injury code	Criteria
No injury	No signs of bodily harm, confusion, excitement, anger, or internal injuries that are known to the individual.
Possible injury	Reported or claimed injury that is neither incapacitating nor fatal, including momentary unconsciousness, claims of non-evident injury, limping, complaint of pain, nausea, hysteria.
Bruises and abrasions	Nonfatal and non-incapacitating injuries apparent to others at the scene, e.g., lump on the head, abrasions, minor lacerations.
Broken bones and bleeding	Nonfatal injuries that prevent individuals from continuing activities they were capable of before the collision, e.g., walking, driving. These include severe lacerations, broken limbs, skull fractures, crushed chest, internal injuries, and unconsciousness.
Fatal	Individual died as a result of the accident.

no collision characteristics documented within them.

We used these linked data sets to develop our analysis of the economic costs associated with DVCs in Utah. Our analysis excluded large domestic animal collisions (e.g., livestock). The U.S. Centers for Disease Control (2003) reported that deer are the most common large animals involved in vehicle collisions. Most DVCs reported in Utah involve mule deer, with only a few involving elk, moose, or pronghorn (*Antilocapra americana*). For this reason, and given the nature of the Utah CODES database, we focused on identifying patterns, trends, and costs associated with motor vehicle collisions involving mule deer.

Estimate of human injury and death

To calculate the total and average inpatient

fatality, however, has been determined by the U.S. Department of Transportation (USDOT). To guide public policy and health and safety regulations, governmental agencies have attempted to define the value of a life for >30 years (U. S. Department of Transportation 2002). In preparing economic evaluations, USDOT has defined value of a "statistical" life as the value for safety measures that reduces the statistically predicted number of accidental fatalities by one. In 2001, adjusting the value of life by the Gross Domestic Product (GDP) implicit price deflator, USDOT recommended the use of a value of $3.0 million (U.S. Department of Transportation 2002). The GDP implicit price deflator is an economic metric that accounts for inflation by converting output measured at current prices into constant-dollar GDP. The GDP deflator shows how much a change in

the base year's GDP relies upon changes in the price level. Because only 3 fatalities had dates associated with them, we used this value in our analysis for all 8 fatalities to coincide with the last year of data available in the CODES database (i.e., 2001).

We did not adjust values by the Consumer Price Index when comparing total and average costs by injury severity. Rather, we showed the distribution of injuries across injury classes as reported in the CODES database from 1996 to 2001. To compare costs by year and injury class, we used reported values adjusted for inflation by the Consumer Price Index for 2001 to reflect costs. Standardizing these values allowed us to differentiate between changes due to inflation and actual increases in medical charges.

Estimates of vehicle damage

Romin (1994) reported that DVC damage claims averaged $1,200 per incident in Utah in 1992. In a mitigation cost-benefit analysis, Bissonette (unpublished data) adjusted this vehicle damage claim amount to a 1998 value ($1,320/DVC) using the Consumer Price Index adjustment multiplier. Based on a review of the literature, we chose to use the same conservative estimate of $1,320 as an average value for vehicle damage costs associated with each DVC in Utah. To take inflation into account and to accurately reflect the cost of vehicle damage during each year, we adjusted the 1998 cost per collision value for each year (1996–2001) using the Consumer Price Index adjustment multiplier. Using this adjusted cost per collision and the total number of collisions per year, we calculated the overall costs of vehicle damage per year, allowing a comparison of vehicle damage values across all 6 years.

## Estimating value of deer loss

To calculate the number of deer killed per year in Utah from 1996 through 2001, we estimated that 92% of collisions result in the death of at least 1 deer (Allen and McCullough 1976). To calculate the monetary losses associated with animals killed, we assigned a value to each deer. Assigning value to deer and other wildlife, however, is surrounded by a history of controversy and debate (Langford and Cocheba 1978). Difference in the deer's age, sex, and condition can affect how humans value it.

Schwabe et al. (2002) explained that a variety of methods have been used within DVC and natural resource economics literature, resulting in a range of values, with $35 as a minimum (Livengood 1983) and $1,313 as a maximum (Romin and Bissonette 1996). Even though both of the latter estimates were derived from costs associated with hunting, a wide range in values still exists because prices have been estimated for different deer species. In distinct parts of the United States varied market valuation techniques have been used (Schwabe et al. 2002). Schwabe et al. (2002) argued that estimating the impacts of deer loss due to collisions should involve measuring the true value of deer, not just the expenditures associated with hunting. They suggested that economic analyses should focus on the benefits received from a successful hunt instead of the costs incurred to bag a deer. They stated that such benefits are represented by costs reported in literature using nonmarket valuation techniques. For example, Loomis et al. (1989) used contingent valuation based on the value of a deer, rather than the cost to a hunter of obtaining a permit and traveling to the site, to estimate the value of an average mule deer at $236 (our Consumer Price Index adjustment to 2001 dollars). This value reflects the consumer surplus, or individuals' net willingness-to-pay, and is a measure of what hunters gain by being able to hunt. We used this value because it was conservative and appeared to accurately represent the value that humans place on deer, not the costs associated with hunting one. To accurately represent and compare the changes in deer value over the years, we adjusted this value for each year of our data using the Consumer Price Index multiplier.

Results
Patterns and trends of DVCs in Utah (1996–2001)

The Utah CODES database contained a total of 13,020 recorded DVCs (4.0 % of all collisions) occurring over 6 years. In Utah, DVC rates remained fairly constant, with a mean annual cost of 2,170 collisions (Figure 1). Non-DVC rates were also constant over time with a mean of 51,431 collisions per year. Higher numbers of DVCs occurred from October through December; 4,220, or 33% of all collisions occurred within this 3-month period.
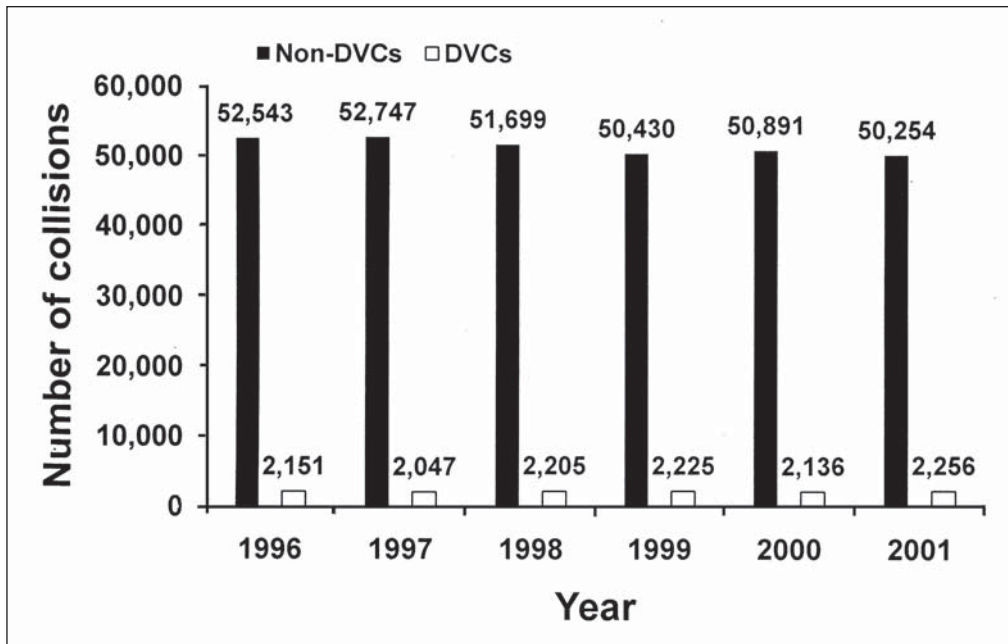
Figure 1. Number of DVCs and non-DVCs in motor vehicle collisions in Utah from 1996 to 2001. Source of data, Utah CODES.

Additionally, there was a smaller increase from May to July, with 3,399 collisions, or 26% of the total collisions. The rest of the collisions were spread more consistently over the remainder of the year, ranging from 791 to 978 collisions per month.

Most DVCs (7,079 collisions, or 54.4%) occurred from 1900 hours to 2400 hours. An increased number of collisions (2,261, or 17.4%) occurred in the early morning between 0600 hours to 0800 hours. The greatest number of collisions during any hour (1,557, or 12%) occurred between 2200 hours and 2259 hours, while the lowest number (99, or 0.8%) occurred between 1400 hours and 1459 hours.

Human injury and death

The CODES database revealed that 20,873 people were involved in DVCs in Utah from 1996 to 2001. The resulting human injuries were classified as follows: 94.7%, no injury; 2.2%, possible injury; 1.8%, bruises and abrasions; 1.2%, broken bone or bleeding; and 0.04%, fatal. Of the 20,873 people involved in DVCs, 448 (2.1%) incurred an inpatient hospital or emergency department charge, resulting in a total cost of $1,002,401. Forty-four (0.2%) of those injured in DVCs were hospitalized for at least 1 night, accruing charges of $781,324,

while 404 (1.9%) injured people visited the emergency department, resulting in total charges of $221,077. Most of those involved in DVCs (97.9%) did not visit a hospital.

Utah CODES distribution of injury classes did not correlate with cost due to the disparity in charges associated with certain types of injuries (Figure 2). After the fatal injury class, the broken bone and bleeding injury class was least common (1.2%), but this injury class contributed 28% of all emergency department visits and 80% of all inpatient hospital visits. Overall, the broken bone and bleeding injury class was the most costly, with $90,112 (41%) of total emergency department costs and $733,481 (93.9%) of total inpatient costs (Figure 2). Those individuals in the bruises or abrasions class accounted for 29% of emergency department visits, 11% of inpatient visits; they accrued 24% of emergency department costs and 4% of inpatient costs. Occupants classified as "Possible Injury" were responsible for 22% of emergency department visits and 2% of inpatient visits, totaling 18% of emergency department costs and 1% of inpatient costs. Those with "No Injury" accounted for 19% of emergency department visits, 6% of inpatient visits and contributed to 15% of emergency department costs and 2% of inpatient costs. Occupants classified as "Fatal"

had no inpatient costs and contributed to 2% of all emergency department costs (Figure 2).

We reported the average charges across injury classes to illustrate the impact that injury severity and type of treatment (inpatient or emergency department) can have on charges incurred. For the no-injury class to the broken-bone or bleeding class, emergency department average costs ranged from $437 to $790, with costs increasing as the severity of injury increased, while inpatient average charges ranged from $4,351 to $20,957.

An analysis of injury class costs by year adjusted to 2001 values allowed for a comparison across years and injury classes (Figure 3). Because costs were adjusted, we expected that the total costs within an injury class would be proportional to the number of people included within that injury class per year. However, we did not always find this result. An analysis of adjusted total and mean costs revealed that there was a great deal of variation within the inpatient "broken bone and bleeding" class, independent of the number of people within a class (Figure 3).

There were 8 reported fatalities due to DVCs in Utah from 1996 to 2001. The Utah CODES database reported only 3 fatalities, with emergency department charges totaling $4,270 (adjusted by the Consumer Price Index to 2001). To provide a more complete and accurate assessment of costs associated with DVC fatalities, we used the USDOT statistic for the value of a human life ($3.0 million; U.S. Department of Transportation 2002) to estimate that fatalities in Utah from 1996 to 2001 carry a value of $24.0 million (2001 adjusted dollars).

Estimates of vehicle damage

From 1996 to 2001, we calculated an increase of $163 (13%) in the average adjusted per collision value (AAPCV) with a minimum in 1996 of $1,271 and a maximum in 2001 of $1,434. The AAPCV is the mean per-year cost adjusted by the Consumer Price Index. The AAPCV associated with vehicle damage correlated with the number of collisions occurring per year. For example, 1997, the year with the lowest number of collisions, had the lowest total cost in vehicle damage ($2,661,100), while 2001, the
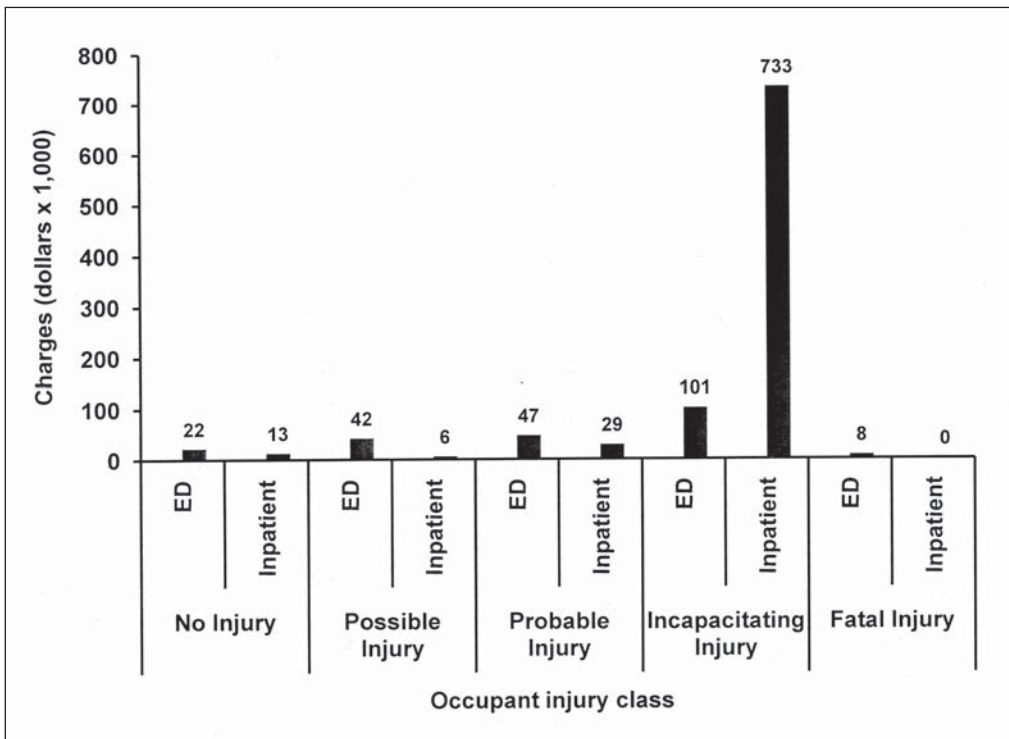
FIGURE 2. Summary of medical charges resulting from DVCs, sorted by injury class, Utah, 1996–2001 (*n* = the number of occupants accruing the charges within each injury class, ED = emergency department, IP = inpatient (≥ 1 night in hospital). Source of data, Utah CODES.
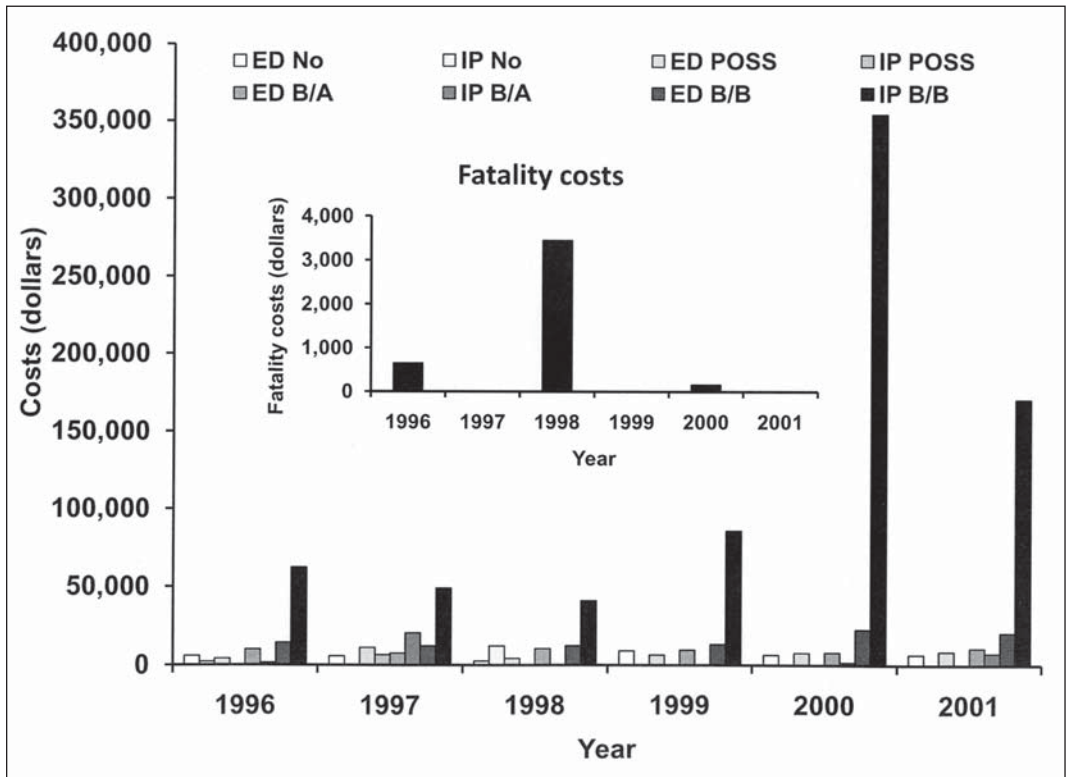
FIGURE 3. Summary of medical charges ($U.S.) due to DVCs, sorted by year and by injury class, Utah, 1996–2001 (ED = emergency department; IP = inpatient (≥1 night in hospital); No = no injury; BA = bruises and abrasions; POSS = possible injuries; BB = broken bones).
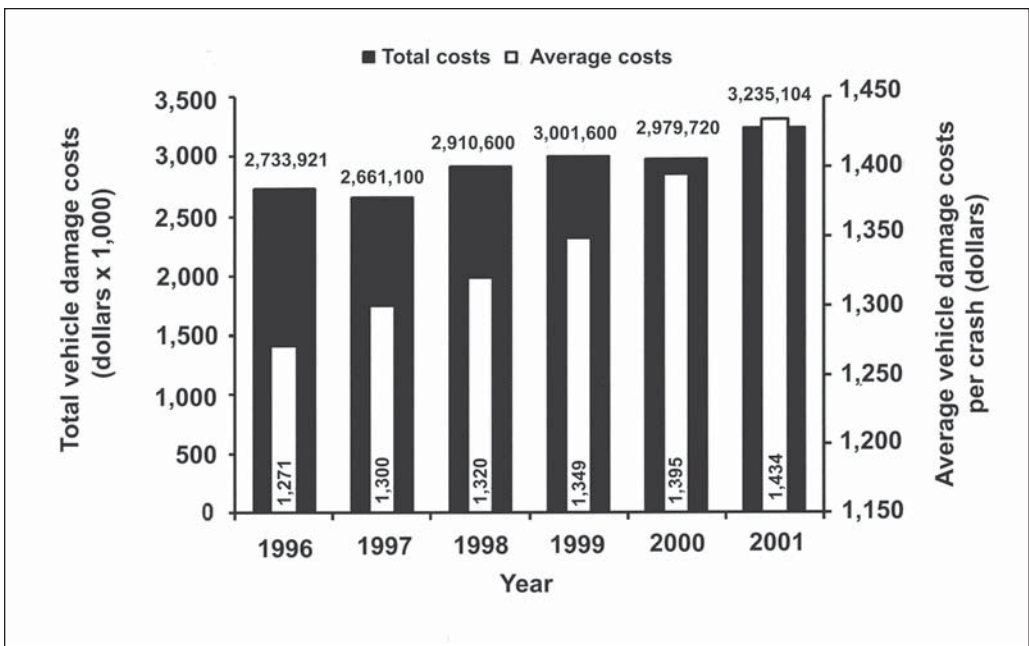
FIGURE 4. Costs of damage to vehicles due to DVCs in Utah, 1996–2001. The average adjusted per collision value has been made to accurately represent the value for each year.

year with the highest number of collisions, had the highest total costs ($3,235,104) in vehicle damage (Figure 4). From 1996 through 2001, the mean total annual cost of vehicle damage was $2,920,328 per year, while the total over 6 years was $17,521,970.

Estimated deer loss

We assumed that 92% of the reported DVCs resulted in a deer fatality. From 1996 through 2001, a total of 11,978 deer, or a mean of 1,996 deer per year, were killed. The number of deer killed remained fairly constant from year to year, with a maximum of 2,076 in 2001 and a minimum of 1,883 in 1997 (Figure 5). We found that the adjusted value of a deer increased each year from $209 in 1996 to $236 in 2001 (Figure 5). From these values, we calculated the yearly monetary costs of deer loss. We found that yearly costs were fairly constant, ranging from a minimum of $403,013 during 1997 to a maximum of $489,823 during 2001. The overall total dollar cost of deer loss for 6 years in Utah was $2,651,083, with a yearly mean of $441,847 (Figure 5). This is a conservative estimate; many DVCs are never reported.

Value synthesis

Considering each of these components in total, the overall cost for 13,020 collisions over 6 years in Utah was $45,175,454, resulting in an estimated average cost per year of $7,529,242 and a mean cost per collision of $3,470. Con-

tributions to total costs varied widely, including the total cost of human fatality at $24 million (53% of total costs), vehicle damage costs at $17,521,970 (39%), deer loss at $2,651,083 (6%), and human injury costs at $1,002,401 (2%).

Discussion

Our analyses confirm that costs associated with human injuries and death, vehicle damage, and loss of wildlife resources are significant aspects of DVCs that require attention and justify mitigation. Conover et al. (1995) and Conover (1997) estimated that >1 million DVCs occur annually each year in the United States, resulting in 211 fatalities, 29,000 human injuries, and vehicle damage costs in excess of $1.1 billion per year. Four percent, or 2,170, of collisions that occurred between 1996 and 2001 in Utah were DVCs. When property damage, human injury, human death, and deer loss are included, we estimated overall costs of $7,529,242 per year in Utah. However, if only 17% (Decker et al. 1990) to 50% of all DVCs are actually reported (Romin 1994), the impacts of DVCs could be greater than what we calculated. Our data are also conservative because accidents in which the driver swerved to avoid hitting a deer but collided with something else (e.g., another vehicle or a tree) would not be classified as a DVC.

The Utah CODES database we used included statistics on crash vehicle occupants who were treated in either a hospital or the emergency
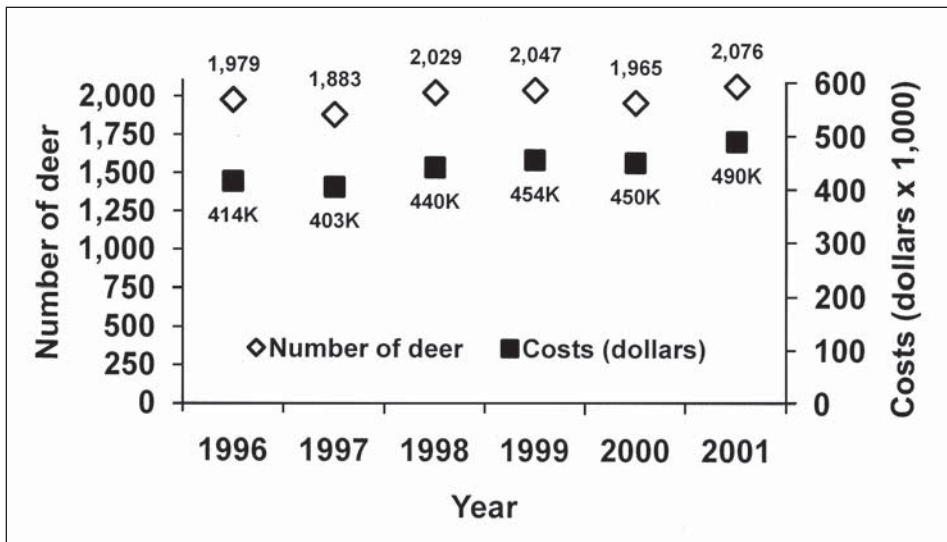
FIGURE 5. Summary of costs associated with deer losses due to vehicle collisions in Utah, 1996–2001.

room. However, there may be costs associated with occupants who did not require immediate treatment but experienced latent effects (e.g., whiplash). Additionally, there could be long-term, after-care issues involved that we were unable to address in our analyses. The inclusion of current insurance claim databases may add to the economic costs of DVCs.

Mitigation to reduce DVCs is expensive, but it can be practical and cost-effective (Mastro et al. 2008). Most DVCs in Utah (58%) are concentrated on 11% of the available roadway (Bissonette and Kassar, unpublished data). In Utah, a small percentage of the people (2.1%) involved in DVCs are responsible for 100% of the costs associated with injuries ($1,002,401). We suspect that other states may show similar patterns. Cost-benefit analyses have shown that mitigation efforts can have positive net economic gains while also increasing safety (Wu 1998, Schwabe et al. 2002). Research suggests that the collisions might be mitigated best by the installation of underpasses or overpasses with associated exclusion fencing and right-of-way escape ramps at certain key travel or migration corridors (Reed et al. 1975, Ward 1982, Foster and Humphrey 1995). Placing crossings based on the analysis of collision data should increase the efficacy of the crossing structures, thereby decreasing DVCs and increasing public safety. There are few, if any, circumstances where fencing should be installed without also in-stalling crossings and right-of-way escape ramps.

Our data analyses support the findings of the U.S. Centers for Disease Control (2004) that more people were injured in DVCs both during the fall season and the dawn and dusk hours when deer are more active. We suggest that mitigation measures, including driver education and outreach, should take into ac-count the temporal patterns associated with DVCs.

Nonfatal DVC-related injuries accounted for <1.0% of the 3 million people treated in U.S. emergency departments annually (U.S. Centers for Disease Control 2003, 2004). However, DVCs and associated consequences, including property damage, deer loss, and human injury and death, are important concerns in rural locations with large deer populations. It is clear that the ecological, social, and economic consequences of DVCs make this an important issue in Utah and across the country. These consequences have caused municipalities and state agencies to seek methods to reduce local deer populations (Curtis et al. 2008, DeNicola and Williams 2008, Miller et al. 2008, Rutberg and Naugle 2008).

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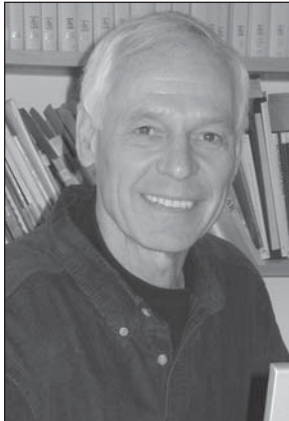
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