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Wildlife-Vehicle Collisions in Utah: An Analysis of Wildlife Road Mortality Hotspots, Economic Impacts and Implications for Mitigation and Management

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WILDLIFE VEHICLE COLLISIONS IN UTAH:

AN ANALYSIS OF WILDLIFE ROAD MORTALITY HOTSPOTS, ECONOMIC IMPACTS, AND IMPLICATIONS FOR MITIGATION AND MANAGEMENT

by

Christine A. Kassar

A thesis submitted in partial fulfillment
of the requirements for the degree

of

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in

Wildlife Biology

Approved:

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ABSTRACT

Wildlife-Vehicle Collisions in Utah:
An Analysis of Wildlife Road Mortality Hotspots, Economic Impacts and Implications for Mitigation and Management

by

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Utah State University, 2005

Major Professor: Dr. John A. Bissonette
Department: Forest, Range and Wildlife Sciences

In the US, the roaded landscape has had serious ecological effects. We studied wildlife-vehicle collisions occurring on the 248 state routes in Utah from 1992 to 2002. We tracked trends and patterns in deer-vehicle collisions, evaluated all routes for frequency of deer kills, and identified "hotspots" (segments of road with high concentrations of collisions per mile). We found pronounced patterns: e.g., 61.15% of all collisions occurred on only 10 routes. We studied the effects of posted speed limit and annual average daily traffic flow and found that no relationship existed between traffic volume and/or posted speed limit and the number of wildlife-vehicle collisions that occurred. We put the economic costs associated with wildlife vehicle collisions into a public safety perspective and confirmed that associated costs, damage, injuries, and loss of resources are significant aspects of DVCs that require attention and justify mitigation.

(215 pages)

DEDICATION

I dedicate this thesis to Mom and Dad; my sisters, Angele, Helen, Shauntel, and Felicita and my brothers, Kim, Phil, Bob, and Ken. Thank you for always having time to talk and for all of your encouragement. Without your continued moral and emotional support, I never would have made it. This is also dedicated to my nieces and nephews, Emily, Nick, Kelley, KJ, Joey, John, and Tia. Hearing tales of your trials in day care, your exploits on the playground, your successes in grade school and your perserverance on the many sports fields that you dominate, have continually served to give me perspective and to make me laugh. I will do what I can to help you explore this amazing world so that you will respect its wonder, enjoy its beauty and learn to treat it kindly and protect it.

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Chris Kassar

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CHAPTER 1

INTRODUCTION

The United States has 6.4 million kilometers of public roads that are used by over 200 million vehicles (Federal Highway Administration 2003). Road corridors cover approximately 1% of the United States; however, the ecological impacts of these roads are not restricted to this area alone. It is estimated that 19% of the land surface in the United States is directly affected by roads and associated vehicular traffic, while in total, 22% of the United States may be ecologically altered by the road network (Forman 2000). Roads are responsible for a suite of indirect effects that impact species dynamics, soil characteristics, water flow regimes, and vegetation cover (Bashore et al. 1985; Reijnen et al. 1996; Forman et al. 2003). The degree of indirect effect varies in relation to the distance from a road, extending to what is known as the "road effect zone," or the outer limit of a significant ecological effect (Forman 2000).

The indirect effects of roads, road networks, and accompanying infrastructure are often not obvious despite the fact that they can extend well beyond the physical area of these structures. Thus, it is important to realize that at large landscape extents, roads and associated networks can have major ecological impacts on landscape processes and biodiversity because roads disrupt natural processes (e.g., animal movement) and alter ecosystem functions (e.g., hydrologic surface flow) (Forman & Deblinger 1998; Forman & Alexander 1998). Thus, the cumulative effects of road systems can be extensive. It is important to realize a continuity of ecological process and function across landscapes to achieve long-term ecological integrity. The concept of continuous ecological flow is important when we consider that in addition to landscape fragmentation and ecosystem disturbance, transportation networks are also a direct threat to individual animals.

Roads and vehicles directly affect wildlife in a number of ways and can have profound impacts on wildlife species abundance, community diversity, habitat availability and ecosystem health and integrity. Animal mortality, or road kill, is the most significant direct effect of roads on wildlife. There is a large body of literature on this subject because wildlife-vehicle collisions date back to the origin of vehicles and continue to be an issue of concern to this day (Stoner 1925; Forman et al. 2003). Forman (1998) implied that this problem is growing in scope; he estimated that one million vertebrates per day are killed on roads in the United States, placing vehicle-animal collisions above hunting as the leading cause of deaths to terrestrial vertebrates.

Despite the fact that vehicles may not hit larger animals most frequently, statistics regarding the number of animals killed on roads may be skewed because large animals are more readily noticed by the public. For this reason, data in the U.S. tend to be more available and complete for large animals that are killed on roads. Scientists first documented road mortality of deer (*Odocoileus* sp.) in the early 1920s, yet as the following numbers show, this is still a great nationwide concern (Stoner 1925). Based on the 35 states that responded to her survey, Romin (1994) reported that vehicles hit 538,000 deer during 1991. By extrapolating from this data and increasing it by 26% to account for the area of the 14 states with deer that did not respond to the survey, Conover (1995) suggested that an estimated 726,000 deer are killed on U.S. roads each year.

For most areas, however, road kill statistics only take into account reported collisions or those dead deer that are found on the side of the road. This is problematic because it is thought that 50 % of deer that are involved in vehicle collisions may not be counted because they leave the area after they are hit to find cover (J.A. Bissonette, unpublished data). In addition, because only half of all deer-vehicle collisions are reported or documented by state authorities (Decker et al. 1990; Romin 1994), Conover et al. (1995) estimated that actually over 1.5 million deer-vehicle crashes occur each year in the United States. Therefore, the data on road kills collected by public road authorities and police and hunter associations are minimum estimates. It is probable that deer road mortality may actually be a larger problem than the current numbers suggest.

Although much of the deer-vehicle literature focuses on the number of animals killed per year and the number of humans injured in these collisions, Lehnert (1996) emphasized the impact that these collisions may have on deer populations. He found that 5.6% to 17.4% of a mule deer population in northern Utah was removed each year due to highway deaths. Thus, loss due to vehicle collisions may have implications for deer populations as highway mortality can significantly alter trends and characteristics of these populations over time (Lehnert et al. 1996). These impacts may be seen whether losses are compensatory or additive and may have enough of an effect on low populations to cause significant declines. In turn, loss of deer can affect the dynamics of an entire natural community and may have implications for harvest rates.

Collisions between deer and vehicles are an increasing concern along roadways throughout the United States because of not only the ecological implications and the associated increase in anthropogenic impacts on the environment, but also due to the potential for resulting human injury and death, vehicle damage and accompanying economic costs.

There is a great deal of variation in the literature regarding the costs associated with deer-vehicle collisions. Romin and Bissonette (1996) used 10 years of data consisting of 24, 884 deer-vehicle collisions to estimate that the average cost of vehicle damage per accident was ~$1,881 (Consumer Price Index adjustment:[1] ~$2,288.61). Conover et al. (1995) used the mean of value ranges as reported from various studies in Michigan, New York, Pennsylvania, and West Virginia. From this range of values reported in a review of economic losses caused by wildlife in the United States, Conover et al. (1995) estimated that the average cost for vehicle repair due to deer-vehicle collisions was ~$1,577 per accident (CPI adjustment: ~$1,975.39), resulting in a total damage to vehicles in excess of ~$1 billion per year (CPI adjustment : ~$1,252,600,000). Other approaches involve obtaining cost estimates by surveying drivers who have submitted accident reports and compiling data from accident reports or insurance claims (Reed et al. 1982; Hansen 1983). Hansen (1983) surveyed drivers in Michigan to determine that the average cost of

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[1] The CPI inflation calculator uses the average Consumer Price Index for a given calendar year. This data represents changes in prices of all goods and services purchased for consumption by urban households. This index value has been calculated every year since 1913. For the current year (2004), the latest monthly (December) index value is used.

property damage for a deer-vehicle accident in 1978 was ~$569 (CPI adjustment: ~$1,665.98), including costs associated with repairs, substitute automobile costs and towing. Reed et al. (1982) surveyed vehicle repair costs from state patrol reports and claims to insurance companies, resulting in an average rounded value of ~$500 (CPI adjustment: ~$1,463.96) in vehicle damage for collisions in Colorado in 1978. In this instance, only collisions that resulted in enough damage to warrant filing a police report were included in the survey. Although adjusting these vehicle damage amounts using the Consumer Price Index allows for a comparison across years, it highlights the degree of variation found in vehicle damage costs associated with wildlife collisions. It is probable that differences in monetary figures result from the use of varied definitions, study designs, data collection methods and variables that were included in studies. Also, costs change with each year and different cars do not cost the same to repair.

Vehicle collisions with deer and other larger animals cause not only damage to vehicles, but also injury to drivers and passengers. Although collisions with vehicles involve many species, larger wildlife species (deer, elk, moose, caribou, and large carnivores) pose the most risk to driver safety and result in higher human injury rates.

Although various studies have assessed the number of people who suffer injuries because of deer-vehicle collisions, there is very little information regarding the costs that accrue due to these injuries. Rue (1989) reported a 4 % human injury rate nationwide for deer-vehicle collisions and reported that 0.029% of deer vehicle collisions resulted in human fatality. Based on the conservative estimate of ~726,000 deer-vehicle crashes per year, Conover et al. (1995) used the above rates to conclude that these collisions result in ~29,000 human injuries and ~211 human fatalities annually. In 2001, there were 37,795 human fatalities resulting from all highway-related causes. Paired with Conover's estimate of 211 fatalities, this suggests that animal-vehicle collisions resulted in approximately one-half of 1% of total annual highway fatalities (Forman et al. 2003).

Economic analyses of injuries due to deer-vehicle collisions are not easily obtained because of the difficulty associated with assigning monetary values to human injuries and fatalities. Reed et al. (1982) chose to omit these from a cost-benefit analysis of deer-vehicle accident reduction methods because of the challenges associated with quantifying injury and death in terms of money. However, to understand the full spectrum of the impacts of animal crashes and put them into a broad and applicable perspective, it is both necessary and useful to assign a price to these damages and losses.

Deer-vehicle collisions not only cause injury to humans and damage to vehicles, but also often result in a deer fatality, causing a further economic loss. Allen and McCullough (1976) reported that 92% of deer-vehicle collisions result in the death of the animal. Assigning value to deer and other wildlife is surrounded by a history of controversy and debate (Langford & Cocheba 1978). Despite this fact, estimates have been made and used to aid in management decisions. Similar to estimates of vehicle damage, there are varied methods and philosophies used to ascertain the values that should be assigned to individual animals.

Conover (1997) states that the value of a wildlife species is derived from the impact that it has on a "person's economic state, sense of well-being, or quality-of-life." Thus, he acknowledges that there are not only monetary values associated with a species, but also intangible values. Although economists cannot assign a dollar value to intangible values as they can for monetary values, Conover (1997) argues that intangible values are as important and need to be considered in order to explore fully the net value of wildlife resources for society. Based on their impacts on people, deer can have both negative and positive values that contribute to their net value and to the loss assigned when one is killed.

In a market system, the economic value of an entity is determined by the amount that an informed and willing buyer will pay in an open and competitive market to an informed and willing seller. However, the value of a deer is not this straightforward because these observed measures of value, or market prices, do not exist in this situation. Thus, because deer are not owned by individuals and are the property of the collective society, it is difficult to establish monetary values for deer using traditional market system approaches (Conover 1997).

However, many approaches have been employed to estimate the positive monetary values associated with deer. Often, an analysis of the amount that individuals spend on activities related to the species of interest is used to provide an estimate of the positive monetary value of an animal. For instance, Adamowicz et al. (1991) found that deer in Alberta were worth $53 million based on a per person value of $119-210 of the benefits derived from hunting. In another instance, Reed et al. (1982) used damages that were awarded to the State of Colorado for $350 as an estimate of the value of a deer. Most recently, Bissonette estimated deer valuation to be $2,274 based on Utah hunting expenditures and harvest rates for 1996 (U.S. Fish and Wildlife Service 1997; Utah Division of Wildlife Resources 1997). Adjusting this deer valuation to 2004 values using the CPI adjustment resulted in a deer valuation of ~$2,667. Combined with the adjusted value of monetary losses due to insurance claims for vehicle damage of ~$1,574 per collision, total monetary losses associated with each deer-vehicle collision in Utah averaged ~$4,214, not including costs associated with human deaths or injury.

Schwabe et al. (2002) explained that a variety of methods have been used within deer-vehicle collision and natural resource economics literature, resulting in a range of values with a minimum of $35 (Livengood 1983) and a maximum of $1,313 (Romin & Bissonette 1996). Despite the fact that each estimate was derived from costs associated with hunting, there is still a wide range in values. This exists because prices have been estimated for different deer species in distinct parts of the United States, using varied market valuation techniques (Schwabe et al. 2002). Other studies have not focused on hunting, but have instead determined an associate economic value by evaluating the subjective values that people place on a resource (Fausold & Lilieholm 1999).

Clearly, there is an important economic component related to deer-vehicle collisions. By acknowledging the estimated costs associated with these crashes, we understand why managers seek to increase efforts to minimize them. Despite the fact that in some areas road mortality may not have a large impact on the abundance or survival of ungulate populations, this problem is of economic importance, is a significant safety concern, and is an issue that is clearly important to conservation (Groot Bruinderink & Hazebroek 1996). The following chapters address this important issue by providing an analysis of deer wildlife road-kill patterns throughout the state of Utah.

The study area varies because the topography of Utah is extremely diverse, consisting of mountainous, desert, rangeland, agricultural, wetland and urban regions. Elevations across the state span a large range. The lowest area is the Virgin River Valley in the southwestern part with elevations between 762 m and 1,067 m (2,500 and 3,500 feet), while the highest point, Kings Peak in the Uinta Mountains, rises to 4, 144 m (13, 498 feet). This varied terrain is accessed and divided by ~9,500 km (~5,900 miles) of state roads and ~ 56, 327 km (~35,000 miles) 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 the state showed an increase of 43%, increasing from 1,046,106 to 1,495,887. Vehicle miles traveled have increased more rapidly than the number of licensed drivers, increasing from 14, 646 million to 23, 452 million; an increase of 60.1% over the same time period (Bureau of Transportation Statistics 2004). In addition, the population of Utah increased by 29.6 % (510,319 people) from 1990-2000 and is projected to continue this upward trend with a projected increase of 24.8% from 2000 to 2010 (554, 501 people). As the population increases, it is expected that licensed drivers and vehicle miles traveled will also grow, making the issue of animal vehicle collisions an even larger safety and conservation priority.

Chapter 2, *Wildlife-Vehicle Collision Hotspots and Implications for Mitigation and Management: Feel the Heat*, summarizes our analysis of 11 years of data to identify the road segments on state routes in Utah that have a concentrated number of wildlife-vehicle collisions. This identification and analysis of consistently collected data, which is grouped into deer-vehicle collision 'hotspots' will allow the Utah Department of Transportation and Utah Division of Wildlife Resources to tailor mitigation efforts to high road-kill highway segments. This chapter also includes an analysis of the temporal patterns of deer-vehicle crashes in relation to the influence of seasonality and time of day on collisions. Chapter 3, *Data Issues in Describing Road Mortality Hotspots and Creating Predictive Models: A Case Study of Utah,* describes the difficulties associated with drawing conclusions from correlations between roadway characteristics and concentrations of wildlife-vehicle collisions. We argue that if the objective is to *define hotspots of road kill for mitigation action*, then existing data with an accuracy of the nearest road mile marker is sufficient and provides reliable results. However, if the objective is to develop a *predictive model* of animal-vehicle crashes using explanatory environmental variables, then the spatial accuracy of GPS locations of animal-vehicle crashes is necessary. We discuss problems with using data at different scales when describing factors contributing to hotspots and identify ways to address these issues. Chapter 4, *An Assessment of Costs Associated with Deer-Vehicle Collisions: It's More than Just Road Kill,* summarizes the costs associated with deer-vehicle collisions in terms of vehicle damage, human injury, human death and the loss of deer.

In most regions, wildlife-vehicle collisions are increasing in frequency in conjunction with more commuters, human development, urban and suburban sprawl, and expanding road networks. Clearly, direct effects, including the associated ecological and economic impacts, as well as costs to citizens, e.g., loss of human life and loss of deer, will continue to increase if wildlife-vehicle collisions follow their current trend. Knowing where to concentrate mitigation efforts may help in curbing wildlife-vehicle collisions and thus, decrease their negative impacts. However, in order for more effective mitigation techniques to be implemented, it is necessary to not only identify the road segments that are most susceptible to wildlife-vehicle collisions, but also to analyze what it is about these areas and their relationship to deer that result in a larger amount of deer-vehicle collisions. Romin and Bissonette (1996) suggested the need for further studies that explore the spatial and temporal components of why deer vehicle collisions occur. Broadly, this study will provide the opportunity to explore long-term trends in deer-vehicle collisions on state routes in Utah in terms of their spatial and temporal distribution. The research explained here will lead to an increased understanding of deer movements in relation to highways in Utah by identifying where collisions are concentrated and by discussing the difficulties associated with drawing correlative links between these areas of concentration and contributing factors. Locally, synthesis of this information will allow us to derive implications for mitigation and management, thereby creating a useful resource for managers across the state. Information presented in the following chapters will be used in the deer-hit plan that the Utah Department of Transportation is creating (D. Anderson, personal communication). This will allow the Utah Department of Transportation and Utah Division of Wildlife Resources to tailor mitigation efforts to high road-kill highway segments, thereby increasing their efficacy.

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CHAPTER 2

WILDLIFE-VEHICLE COLLISION HOTSPOTS AND IMPLICATIONS FOR MITIGATION AND MANAGEMENT: FEEL THE HEAT

Abstract: We studied deer-vehicle collisions occurring on the 248 state routes in Utah from 1992 to 2002 using the Utah Department of Transportation (UDOT) vehicle crash database. The data originates from accident forms filled out by law enforcement officers and provided to UDOT by the Utah Department of Public Safety. We tracked trends and patterns in deer-vehicle collisions for these 10 years, evaluated all routes for frequency of deer kills, and identified "hotspots" (segments of road with high concentrations of collisions per mile.) We found that although the number of deer-vehicle collisions did not vary much from year to year, seasonal patterns were pronounced, with one-third of total collisions occurring from October through December. We found a daily pattern with 55.7% of all collisions occurring between 1800 to 2400 hr. A small number of routes had a disproportionately high concentration of the collisions; 61.15% of all collisions occurred on 10 different routes. Hotspot collisions were concentrated in short length, specific areas; 57.74% of all collisions occurred within a cumulative, ~1001 km (622 mi), range, or 10.5% of total analyzed highway miles (~9,500 total km, ~5,900 mi). Long route core hotspots ranged in length from 2 to 19 miles, with a mean of ~6.3 miles, while short route core hotspots ranged in length from 2 to 11 miles with a mean of ~3.7 miles. Overall, core hotspots averaged 5.3 miles in length. Animal-vehicle collisions could be

significantly reduced and road safety enhanced if mitigation were prioritized based on hotspot data. We argue that hotspots should consist of two parts: (1) a core area, the road segment where collisions per mile are most concentrated; and (2) a mitigation zone, buffering segments on each side of the core where appropriate mitigation actions can account for animal movement and behavior and help avoid the "end of the fence" problem. By "end of the fence problem" we refer to the movement of deer beyond the core fenced area. When only a core hotspot is fenced (without associated crossings and right-of-way (ROW) escape structures) deer and other large animals are prone to move along the fence and cross at the end of the fence. Locally, knowledge of the location of deer-vehicle collision hotspots and associated temporal patterns will allow the Utah Department of Transportation and Utah Division of Wildlife Resources to prioritize areas for mitigation and to tailor mitigation efforts to high road-kill routes and highway segments, thereby increasing their efficacy. Globally, this analysis has broader implications; an analysis of wildlife-vehicle collision data can be useful to managers in addressing human safety issues and conservation concerns, including restoring connectivity and minimizing fragmentation.

Introduction

Animal-vehicle collisions and their associated ecological impacts have been reported since at least the early 1920s (Stoner 1925) and continue to be of national and international concern today (Groot Bruinderink & Hazebroek1996). During the 20th century, as the world's dependence on the automobile grew and traffic volumes and speed on roads increased, wildlife-vehicle crashes have also increased (Puglisi et al. 1974; Danielson & Hubbard 1998). Today, the number of wildlife-vehicle collisions continues to grow with increasing urban and suburban development, growing numbers of vehicle miles traveled per year (VMT) and an expanding road network. Increasing development is evident by the fact that in the 1990s, Americans increased the rate of conversion of open space to developed land by 50% from the 1980s leading to a conversion rate of 0.89 million ha (2.2 million acres) per year (Forman et al. 2003). In the United States, over 200 million vehicles use the 6.3 million km of roads that are open to the public (Bureau of Transportation Statistics 2004). Through road widening and lengthening (88,000 new km from 1987 to 1997), the direct and indirect ecological effects of the road network are growing and impacting the interactions between humans and the environment. The direct environmental effects associated with roads, (e.g., deer mortality) and the corresponding human and economic impacts (e.g., loss of human life, injury, and vehicle damage) will continue to increase along with the expansion of the transportation network (Conover et al. 1995; Groot Bruinderink& Hazebroek 1996; Forman et al. 2003).

Lalo (1987) estimated that 1 million wildlife vertebrates are killed each day on roads within the United States, placing vehicle-animal collisions above hunting as a cause of death in terrestrial vertebrates. More road mortality data in the United States is available for larger rather than smaller animals due in large part to large carcass sizes which are most noticed by the public, and the higher vehicle and personal damage caused when these animals are hit. In 1980, vehicle collisions were responsible for ~200,000 deer deaths in the United States (Williamson 1980; Schaefer & Penland 1985). Based on survey returns from 36 states, Romin (1994) estimated ~ 538,000 deer killed on roads in the United States in 1991. Conover et al. (1995) estimated that actually over 1 million deer-vehicle crashes may occur each year in the United States. Reported numbers of deer-vehicle collisions may be conservative because only about half of the deer vehicle collisions that occur are actually reported to authorities (Romin 1994; Romin & Bissonette 1996). Decker et al. (1990) suggested that actually only one-sixth of deer hit may be counted. Deer-vehicle collisions account for the second highest number of deer kills observed by wildlife personnel and are apparently increasing. However, few state agencies keep consistent and accurate records of deer-vehicle collisions, much less the smaller animal road mortalities (Forman et al. 2003).

Road mortality and the possibility of human injury can be significantly reduced by mitigation activities consisting of deer fences, road crossing structures, such as overpasses and underpasses, and earthen ROW escape ramps (Clevenger & Waltho 1999, 2000). However, without accurate data showing trends and patterns related to spatial locations and temporal occurrence of kills, it may be difficult for managers to prioritize areas and implement mitigation measures most effectively.

Despite the high number and increasing frequency of vehicle-wildlife-vehicle collisions and the resulting cost to citizens, only a few complete and accurate analyses based on multi-year data sets have been conducted to evaluate the spatial patterns of animal-vehicle collisions (Clevenger & Waltho 2000). In an effort to fill the gap between the information that exists and it's potential to aid in identifying priority areas for collision mitigation, we analyzed the Utah Department of Transportation collision database to identify routes and segments of routes within Utah that have high wild animal-vehicle collision rates. Most reported large animal wildlife-vehicle collisions in Utah involved mule deer (*Odocoileus hemionus*); only a few involved elk or other larger animals (J.A Bissonette & D. Anderson, personal communication).

In this paper we highlight spatial and temporal patterns and trends associated with motor-vehicle deer collisions. We used 11 years of consistently collected data to track trends in Utah collisions across the years (1992-2002) and within each state route. We expected an increase in collisions over the 11 years in conjunction with an increase in population and vehicle miles traveled (Forman et al. 2003). We also hypothesized that there would be certain road segments and routes with concentrated numbers of deer-vehicle collisions. Thus, we defined, identified, and ranked deer-vehicle collision "hotspots" for all of the Utah state routes. We also analyzed the temporal variation in these collisions, including time of day and month of the year. We expected patterns similar to those reported by Groot Bruinderink and Hazebroek (1996) and Elzohairy et al. (2004). We predicted that a large peak in collisions would occur in October, November, and December in conjunction with breeding, migration and hunting seasons, while a smaller peak would occur in late May and June because of migration. We also expected a larger number of collisions to occur at dawn and dusk when animals tend to be more active.

Locally, this analysis of Utah will aid managers in addressing safety concerns and conservation issues by helping them to prioritize high risk areas for mitigation. Globally, this study can serve as an example for conservation agencies and transportation departments of how long-term data can be used to set priorities for mitigation that can improve public safety. Additionally, this type of analysis can be linked to ecological connectivity analyses to prioritize mitigation that can increase permeability, maintain landscape connectivity and minimize fragmentation.

Methods

Study Area. The study area includes the entire state of Utah (Appendix A, Figure A-1).. Its topography is diverse, consisting of mountainous, desert, rangeland, agricultural, wetland and urban regions. Elevations across the state range from 762 m (2,500 feet) in the Virgin River Valley in the southwest to 4,114 m (13, 498 feet) at Kings Peak in the Uinta Mountains. This varied terrain is accessed and divided by ~9500 km (~5,900 miles) of state routes and ~ 56, 327 km (~35,000 miles) of city and county roads that are being used by a growing number of drivers. From 1990 to 2001,[1] the number of licensed drivers in the state increased 43%, from 1,046,106 to 1,495,887. Vehicle miles traveled (VMT) increased from 14, 646, 000 to 23, 452, 000 (60.1%) over the same time period (Bureau of Transportation Statistics 2004). In addition, the population of Utah increased by 29.6 % (510,319 people) from 1990-2000 and is projected to continue with an estimated increase of 554, 501 people (24.8%) from 2000 to 2010. As the population increases, it is expected that licensed drivers and vehicle miles traveled will also grow, making the issue of animal vehicle collisions an even larger safety and conservation priority. These data are representative of many parts of the world which show increases in motor vehicle use.

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[1] This represents the latest data available.

For example, since 1986 the total mileage of roads in Portugal has increased by ~ 20% (M. Santos Reis, personal communication).

Data Description. The Utah Department of Transportation (UDOT) maintains a database of reported vehicle crashes from 1992 to 2002. The data originate from collision reports prepared by law enforcement officers and provided to UDOT by the Utah Department of Public Safety. The database contains information for all types of collisions, including those involving wildlife. A wildlife-vehicle collision is included in the database only if an animal was actually hit, if the estimated vehicle damage exceeded $1,000, and/or if a person was injured. Collisions included in the database do not account for crashes that occurred as a result of swerving to miss an animal. Due to these constraints and because collisions are underreported, the number of collisions reported within the database are conservative and should be considered minimum estimates (Jahn 1959; Groot Bruinderink & Hazebroek 1996). This analysis does not deal with large domestic animal collisions (e.g., livestock). Smaller wild animals are also not reported. Hence, we focus on motor vehicle collisions involving almost exclusively mule deer.

The database allows queries based on variables of interest. It is possible to perform a simple collision analysis or do more advanced analyses based on any combination of existing variables. Each record in the UDOT database consists of three sections: (1) Accident Information; (2) Vehicle Information; and (3) People Information.

The ‘Accident Information’ category contains 37 variables, including route, milepost, date, time, locality, road characteristics, weather conditions, severity of the collision, traffic volume, and posted speed limit. The 'Vehicle Information' section contains 18 variables, including the estimated travel speed, the number of occupants in each vehicle, and the number and type of vehicle(s) involved. The 'People Information' component provides details about each person involved, including their age, what type of seatbelt they had on (if any), injuries sustained, and results of an alcohol test (if one was done).

Although not all of these options and variables are used directly in the procedures outlined in this paper, we have included a brief description of them because of the possibilities that the Utah database and other similar state databases provide opportunities for further research into the spatial relationships involved in deer-vehicle collisions.

Database Analysis. In our analysis, we tracked trends and patterns in deer-vehicle collisions for an 11 year period, evaluated entire routes for frequency of deer kills, and identified "hotspots," or segments of road with a high concentration of collisions per mile.

Within the collision database, we searched each route individually for wildlife-vehicle collisions that occurred from 1 January 1992 to 31 December 2002 (Fig. 2-1). This resulted in data sets consisting of every wildlife-vehicle collision recorded to the nearest milepost that occurred from 1992 to 2002 on each of the 248 state routes in Utah (Table 2-1).

To explore trends and patterns in the occurrence of deer-vehicle collisions we classed the data by year and calculated the frequency of collisions for each year. We also evaluated the temporal patterns in these collisions by calculating the frequency of crashes by month and by hour of the day. We adjusted for daylight savings time.

To evaluate and compare trends across routes in the state of Utah, we analyzed each route individually and then ranked all of them accordingly. We analyzed and ranked each route in two different ways: (1) by determining the number of collisions per mile for each route and (2) by determining the total number of collisions for each route. We calculated the overall collision per mile rate for each route by the following equation: $N_{RC}{}^{-MR}$ where N_{RC} = total number of collisions on a route and –MR= route mileage. This rate allowed for a comparison across routes despite their varying lengths.

Identifying and Ranking Hotspots of Deer-Vehicle Collisions in Utah. To evaluate each route, we performed a 'fixed segment analysis,' in which a segment or fixed length is used to query collision records for locations with a certain number of crashes. For each route, we used a one mile fixed segment length and searched for all one mile intervals that had one collision or more. This analysis resulted in collisions that were grouped by the mile segment within which they occurred, enabling an assessment of trends along each route (Fig. 2-2).

The 'fixed segment analysis' tool made the data more useful by allowing us to identify individual road segments and groups of consecutive road segments with a significant amount of kills. Hotspots consisted of one to several mile segments. We defined a mile of road as being 'significant' if it had at least 11 collisions (1 collision/mile/year). Thus, mile segments with less than 11 collisions were not included in the following analysis of hotspots.

We identified segments of road that had 11 or more collisions per mile over the 11 years (at least one collision per year). This process was repeated for each of the 284 state routes that exist in Utah. For standardization and comparison purposes, these routes were divided into long routes (total length > than 80.5 km or ~ 50 mi) and short routes (total length ≤ 80.5). The routes were classed this way to ensure that hotspots were ranked in comparison to others found on routes of similar length and to ensure that results portrayed an accurate picture of the true danger associated with certain routes. We wanted to prevent the effects of outliers and the possibility of skewed results due to those very short routes with an abnormally high number of collisions per mile (see example in Discussion: Analysis of State Routes).

For each of the long and short routes, we then divided the hotspots into two categories: those consisting of only 1 mile with 11 collisions or more, termed "isolated" hotspots and those consisting of segments of at least two consecutive miles or more, termed "core" hotspots. Here we use the English measuring system because all US road segments are identified to the milepost.

Each high concentration road segment was assigned an identifying hotspot code (the route number and a letter, i.e., #89A, 89B) and then hotspots on all routes were ordered by collisions per mile; allowing comparison between routes of varying lengths and with varying numbers of collisions. Hotspots were identified by natural breaks in the data, i.e., no reported collisions or collisions did not exceed 1/year. A consistent intensity-ranking was then determined based on the number of collisions (Fig. 2-3, 2-4, 2-5, 2-6; Table 2-2, 2-3, 2-4, 2-5). Intensities for core hotspots on long and short routes were classified as follows: low = 11-14.9 collisions per mile, moderate = 15 -19.9, high =20-29.9, and very high intensity = 30 or more collisions per mile. The intensities for isolated hotspots on long and short routes were classified similarly as follows: low = 11-14.9 collisions per mile, moderate = 15-19.9, and high intensity = 20 or more collisions per mile. Ranking intensity classes were based on the natural breaks in data because it is not expected that collisions will follow a normal distribution in terms of their spatial distribution on the landscape or their distribution across intensity categories.

Results

Trends and Patterns in Deer-vehicle Collisions in Utah (1992-2002). In total, we identified 24,299 wildlife-vehicle collisions over 11 years. Of these, 24,210 (99.6%) had dates and years associated with them. In Utah, collision rates remained fairly constant over 11 years with a median value of 2,202 collisions per year, a maximum of 2,577, and a minimum of 2,025 collisions per year (Fig. 2-7).

Higher numbers of deer-vehicle collisions occurred from October through December (Fig. 2-8); during that one-quarter of the year, there were 7,933 collisions, totaling one-third of all collisions. November had the most collisions of any month with 2,961 collisions, totaling 12.23 % of the total crashes. In addition to a pulse of crashes in the fall, there was a smaller increase in the month of July with 2,379 collisions or 9.83% of the total collisions. The rest of the collisions were spread more consistently over the other eight months ranging from 1,538 (6.35%) to 1,899 (7.84%) collisions. In the database, there were 24,189 collisions where a time of occurrence was recorded. Most deer-vehicle collisions occurred from 1800 to 2400 hr

(Fig. 2-9). In these seven hours, there were 13,475 collisions, totaling 55.70 % of all crashes. An increase in crashes was also noticeable in the early morning hours (0500 to 0800 hr) with 4,017 collisions or 16.60% of the total. The most crashes within an hour (3,100) occurred from 2000 to 2059 hr while the least collisions (218) occurred during the noon hour from 1200 to 1259 hr.

Analysis of State Routes. We examined the state routes in Utah and found that 12 routes had a high deer-vehicle collision rate over their length (≥ 10 collisions per mile) while 16 routes were rated as having a moderate deer-vehicle collision rate (≥5≤9.99 collisions per mile) (Fig. 2-10, 2-11). There were 148 routes with low collision rates (>0≤4.99), while 65 had no reported deer-vehicle collisions (Table 2-6). Within the database, data was unavailable for seven existing routes: 8, 42, 76, 159, 178, 196, and 666. Collision frequency rates ranged from a maximum of 21.27 crashes per mile to a minimum of zero crashes per mile.

Of the 12 routes classified as having high deer-vehicle collision rates, 11 were short routes (≤ 80 km or ~50 miles) while 1 was a long route (>80km or ~ 50 miles) (Fig. 2-10). Similarly, out of the 16 routes with a moderate rate of deer-vehicle collisions, 12 were short, while 4 were long (Fig. 2-11).

When we analyzed state routes according to the overall number of crashes occurring on a route, totals ranged from 0 to 3,360 collisions from 1992-2002. Of the 10 most dangerous routes as identified by total number of collisions, only Route 91 is a short route (Fig. 2-12).

Hotspot Analysis. We identified the segments of roads in Utah with considerable deer-vehicle collision rates for both long routes and short routes. We defined a hotspot as a segment of road in which each mile had 11 or more collisions occur within it over 11 years. In our hotspot analysis, we included segments of road consisting of isolated mile segments and those consisting of multiple consecutive mile segments that each fulfilled the collision rate criteria. Overall, given our criteria, we found a total of 183 deer mortality hotspots in Utah. Long route core hotspots ranged in length from 2 to 19 miles long, with a mean of 6.3 miles, while short route core hotspots ranged in length from 2 to 11 miles with a mean of 3.7 miles. Overall, core hotspots averaged 5.3 miles in length; all isolated hotspots were 1 mile in length.

Long Routes. - - There were 122 hotspots on long routes, with 53 core and 66 isolated segments of road (Table 2-7). The core hotspots had collision rates ranging from 11.33 to 34.85 collisions per mile (Fig. 2-3, Table 2-2). Core hotspots fell into our intensity classification scheme (described in methods) as follows: Low: 15, Moderate: 21, High: 11 and Very high: 6 (Table 2-9). We found that isolated hotspots on long routes had a maximum of 23 crashes in one mile and a minimum of 11 crashes in one mile (Fig. 2-4, Table 2-3). Isolated hotspots were less evenly distributed across classes with four of high intensity, four moderate and 58 in the low category (Table 2-9).

Short Routes. - - There were 61 hotspots on short routes, with 36 core and 25 isolated road segments (Table 2-7). The core hotspots had collision rates ranging from 11.50 to 40.80 collisions per mile (Fig. 2-5, Table 2-4). On short routes, core hotspots fell into our intensity classification scheme as follows: Low: 9, Moderate: 10, High: 12, and Very high: 5 (Table 2-8). We found that isolated hotspots on short routes had a maximum of 33 collisions in one mile and a minimum of 11 crashes in one mile (Fig. 2-6, Table 2-5). Isolated hotspots were less evenly distributed across classes with five falling into the high intensity category, four into the moderate and 16 in the low category (Table 2-9).

Discussion

Trends and Patterns in Deer-vehicle Collisions in Utah (1992-2002). Mule deer (*Odocoileus hemionus*) are found throughout Utah. Early research has shown that deer activity patterns influence the distribution and frequency of deer-vehicle collisions (Jahn 1959; Arnold 1978). Several authors have associated an increased number of crashes with seasonal changes because of breeding activities, migration, dispersal, and hunting activity (Case 1978; Feldhamer et al. 1986; Jaren et al. 1991). Certain species may be more vulnerable to highway mortality as a result of their behavior patterns and life histories. We analyzed 11 years of data and found that the largest number of deer-vehicle crashes occurred from October through December. There are at least three contributing factors. First, adult bucks move more during the rut in October and November and cross the highway more frequently than at other times of the year (Jahn 1959). Second, hunter activity during fall results in greater movement by deer. Third, seasonal migratory routes from high elevation summer ranges to lower elevation winter ranges often cross highways.

Driver behavior also changes with the seasons and impacts temporal patterns in deer-vehicle crashes. As daylight savings time ends on the last Sunday of October, working daylight hours shift and become more limited, forcing commuters onto the roads during darker periods of dawn and dusk (Elzohairy et al. 2004). Increased traffic volume and decreased visibility, combined higher animal exposure appears to explain the overall increase that occurs from October through December.

Does normally give birth to fawns in June; Robinette et al. (1977) reported an average fawning date of 20 June in Utah. It is possible that the smaller peak in collisions in July may be due to increased fawn movement during their second month of life. As forage quality declines in summer in Utah, deer may search for better foraging opportunities nearer the road.

Higher frequencies of road kills are also correlated with variations in animal activity patterns throughout the day. When it is dark, many ungulates become more active, increasing the risk of a vehicle collision (Reed & Woodward 1981; Waring et al. 1991; Groot Bruinderink & Hazebroek 1996). Most deer-vehicle crashes in this data set occurred from 1800 to 2400 hr (6 pm to 12 pm) and 0500 to 0800 (5 am to 8 am). These peaks probably occurred because of a convergence of factors affecting both deer and drivers, including increased foraging, increased traffic volumes and poorer visibility.

Although number of collisions showed significant fluctuations across months, comparison across years shows a consistent number of crashes per year. We expected an increase in the number of kills over the years as the human population and vehicle miles traveled increased from 14,646,000 to 23,452,000 from 1990 to 2001.[2] The fact that our data do not support a corresponding increase may be explained by the dramatic decrease in deer population numbers in Utah over the past 11 years. The

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[2] This represents the most recent data available.

Utah Division of Wildlife Resources (2003) estimates that the mule deer population has decreased from ~ 340,000 in 1992 to ~280,000 in 2002 (~17.65 %) due to a combination of severe winters, years of drought and habitat loss. The population estimate of ~280,000 is well below the 2008 objective of 320,000 and the long term management objective of 426,000 deer (Utah Division of Wildlife Resources 2003).

Continued under- reporting of collisions as suggested by Romin (1994) and Decker et al. (1990) and increased effectiveness of mitigation structures in decreasing wildlife –vehicle collisions in Utah may serve as alternative or linked explanations for the consistent number of crashes found per year. We expect that underreporting has remained consistent. There is little evidence to suggest that mitigation structures placed in Utah over the last 11 years (e.g., deer warning signs and one-way gates) have had a large enough effect to nullify the impacts of more drivers and higher vehicle miles traveled. The decrease in the Utah deer population may explain why wildlife-vehicle collisions do not appear to have increased over the last 11 years.

Analysis of State Routes. The primary objective in this study was to identify routes of high priority or concern in terms of wildlife mortality. Our attempt to identify the most "dangerous" routes for wildlife-vehicle collisions consisted of two types of analysis: (1) a comparison of the total number of collisions across state routes, and (2) a comparison of the number of collisions per mile across state routes.

The analysis of the total number of collisions occurring on state routes demonstrated that, as expected, wildlife-vehicle collisions were not distributed evenly along routes (Fig. 2-12). Fifty-five percent of the total number of collisions occurring on all routes was concentrated on 10 routes.

Many routes with high overall collision occurrence did not have a high collision per mile rate. On the other hand, certain short routes with an unusually high number of collisions per mile did not have a high total number of collisions. For example, with greater than 21 collisions per mile, Route 146 ranked highest among all routes analyzed in Utah. However, from 1992-2002, there were only 113 collisions in total on this ~5.3 mile route. In contrast, with 3,360 total collisions, Route 89 ranked highest among all routes, however, this route ranked 16th with only ~8.1 collisions per mile. When we compared the number of collisions per mile across routes, short routes dominated the "dangerous"routes. This may be because shorter routes with equivalent total number of crashes had a higher frequency per mile than other longer routes. Routes 40 and 91 were the only long routes characterized as having a high deer-vehicle collision rate despite the fact that hotspots were numerous on many other long routes (Fig. 2-10). For this reason we differentiated between long and short routes in our analysis.

Few research projects have identified specific areas, or hotspots, where wildlife-road mortality is concentrated. Our analysis of wildlife-vehicle collision hotspots in Utah supports the idea that these collisions are grouped together in their occurrence; 57.74% of all collisions occurred within 10.5 % (~1001 km , 622 mi) of highway out of ~9,500 total km (~5,900 mi) that were analyzed. Identification and ranking of these hotspots will aid managers in prioritizing those areas that need mitigation.

Conclusion

Addressing Conservation and Safety. The roaded landscape in Utah and elsewhere impacts interactions between wildlife and vehicles. Although much of the deer-vehicle literature focuses on the number of animals killed per year and the number of humans injured in these accidents, Lehnert (1996) emphasized the impact that these accidents may have on deer populations. Lehnert (1996) found that 5.6% to 17.4% of the mule deer population in Utah was removed each year due to highway deaths. Thus, loss due to vehicle collisions may have implications for deer populations as highway mortality can significantly alter trends and characteristics of these populations over time (Lehnert 1996). These impacts may be seen whether losses are compensatory or additive and may have enough of an affect on low populations to cause significant declines. In turn, loss of deer can affect the dynamics of an entire natural community and may also have implications for harvest rates. In certain areas, the impacts of collisions on wildlife populations may be insignificant or deemed as positive (viz., nuisance deer herds). However, given that deer-vehicle collisions will still occur, these areas may still be prioritized for mitigation to avoid human injury, human fatality, and vehicle damage and associated costs.

State transportation departments have a mandate to protect public safety; state conservation organizations focus on environmental issues. Effective mitigation planning will address both conservation issues and safety concerns by finding ways to maintain connectivity and avoid fragmentation of wildlife habitat. If wildlife and transportation agencies work together, a decreased number of wildlife-vehicle collisions, a lessening of wildlife mortality of animal populations and positive safety benefits will result.

Collecting Spatially Explicit Data. Continued data collection that includes wildlife as a variable should continue on a statewide scale. We argue that data to inform mitigation efforts to reduce wildlife-vehicle collisions would benefit from the inclusion of information on species, sex, age, and more accurate spatial location. Accurate location of carcass data and/or animal vehicle collisions data by GPS location would enable the development of reliable models that attempt to correlate environmental variables with areas of high road kill. This type of data collection would be more costly, requiring GPS units and training to gather added information correctly. However, significant improvement in recording spatial location and animal information for wildlife-vehicle crashes would greatly enhance the utility of the data base. Currently, animal-vehicle collisions with damage to the vehicle < $1,000 and with no human injury are not recorded. Inclusion of these data in the database would significantly improve any analysis of hotspots of wildlife kill.

Mitigating for the "End of the Fence Problem." Mitigation to reduce wildlife-vehicle collisions is not inexpensive, but may be practical and cost effective in Utah; the majority of crashes are concentrated on 10.5 % of the available roadway (1000 km of ~9500 km). Mitigation can be prioritized based on the hotspots that we have identified. We argue that mitigation will be most effective if managers recognize that hotspots actually consist of two components: (1) a core area and (2) a mitigation zone. We define the core area as the section of the route where collisions per mile (or deer kills) are most concentrated. The mitigation zone is the additional area bordering the core that we suggest is needed to address the "end of the fence problem" by creating a buffer to account for animal movement and behavior (Fig. 2-13). By "end of the fence problem" we refer to the movement of deer beyond the core fenced area. When only a core hotspot is fenced (without associated crossings and right-of-way (ROW) escape structures) deer and other large animals are prone to move along the fence and cross at the end of the fence. If mitigation includes the "mitigation zone" and the installation of crossing and ROW escape ramps, the "end of the fence" (EOF) problem can be largely eliminated. The length of this mitigation zone on the actual landscape will vary based on the characteristics of the hotspot, the surrounding terrain and the input of managers and biologists within the region.

Focusing on Connectivity and Permeability. Research suggests that the collisions might be best mitigated by installing underpasses or overpasses at certain key travel or migration corridors, thereby providing animals an opportunity to bypass the road and decreasing habitat fragmentation (Reed et al. 1975;Ward 1982; Foster & Humphrey 1995). The use of deer-proof fence in conjunction with deer escape ramps has also been proven to reduce deer-mortality by providing an effective way for animals to exit the right of way (Hammer 2001). There are few, if any circumstances, when fencing should be installed without crossing and ROW escape ramps. Placing crossings based on the analysis of road kill data that we have provided should increase the efficacy of the crossing structures, thereby decreasing wildlife-vehicle collisions while restoring connectivity and preventing further fragmentation of habitat. Road kill and crash data can be used in a connectivity analysis based on an integration of GIS and satellite imagery that shows animal migration routes and distribution ranges in relation to hotspots. Studies that put hotspots into an ecological context by exploring environmental and roadway characteristics that may be contributing to making certain areas more susceptible to wildlife-vehicle collisions would be most helpful.

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Table 2-1. State routes searched (n=248) for deer-vehicle collisions within the Utah Department of Transportation database, 1992-2002.

State Route Number	Route Mileage	Presence of Hotspots on the Route?	Total Collisions on the Route	Total Collisions per Route Mile
6	288.71	Y	1419	4.91
8	8.718	Data unavailable	Data unavailable	Data unavailable
9	44.876	Y	121	2.70
10	68.885	Y	204	2.96
11	2.995	N	3	1.00
12	123.174	N	125	1.01
13	32.876	N	70	2.13
14	40.507	N	146	3.60
15	401.21	Y	2204	5.49
16	29.187	N	30	1.03
17	6.04	N	19	3.15
18	50.872	Y	186	3.66
19	4.57	N	0	0.00
20	20.611	N	92	4.46
21	107.31	Y	118	1.10
22	6.867	N	3	0.44
23	29.917	N	71	2.37
24	160.913	Y	496	3.08
25	10.01	N	22	2.20
26	3.744	N	14	3.74
28	38.98	Y	291	7.47
29	21.738	N	37	1.70
30	136.099	Y	162	1.19
31	47.71	N	59	1.24
32	29.056	Y	142	4.89
34	2.169	N	0	0.00
35	61.906	N	100	1.62
36	67.581	Y	241	3.57
37	12.321	N	1	0.08
38	19.1	Y	230	12.04
39	68.041	Y	208	3.06
40	175.138	Y	1858	10.61
41	4.755	N	12	2.52
42	7.392	Data unavailable	Data unavailable	Data unavailable
43	10.554	N	16	1.52
44	27.958	N	87	3.11

45	39.929	N	31	0.78
46	21.615	N	42	1.94
48	12.691	Y	75	5.91
50	59.107	N	125	2.11
51	3.396	N	12	3.53
52	4.476	Y	82	18.32
53	1.957	N	0	0.00
54	1.26	N	0	0.00
55	2.991	N	2	0.67
56	61.387	Y	118	1.92
57	10.634	N	4	0.38
58	1.557	N	0	0.00
59	22.159	N	0	0.00
60	6.922	N	6	0.87
61	7.284	N	14	1.92
62	42.918	N	54	1.26
63	2.641	N	10	3.79
64	2.018	N	0	0.00
65	28.254	Y	43	1.52
66	14.98	N	27	1.80
68	71.082	Y	252	3.55
70	231.69	Y	894	3.86
71	22.47	Y	40	1.78
72	35.501	N	26	0.73
73	41.201	Y	237	5.75
74	5.687	Y	28	4.92
75	2.045	N	10	4.89
76	2.434	Data unavailable	Data unavailable	Data unavailable
77	9.11	N	4	0.44
78	9.417	N	6	0.64
79	4.904	N	2	0.41
80	193.86	Y	938	4.84
81	2.473	N	0	0.00
82	3.128	N	0	0.00
83	31.65	N	155	4.90
84	80.846	Y	459	5.68
86	2.119	N	0	0.00
87	38.11	N	66	1.73
88	16.95	N	21	1.24
89	417.759	Y	3360	8.04
90	1.662	N	8	4.81
91	45.591	Y	584	12.81
92	27.234	Y	247	9.07
93	0.368	N	0	0.00

94	0.957	N	1	1.04
95	121.139	N	54	0.45
96	22.756	N	35	1.54
97	5.355	N	0	0.00
99	4.195	Y	54	12.87
100	16.925	N	12	0.71
101	21.77	N	17	0.78
102	20.093	N	60	2.99
103	0.209	N	0	0.00
104	3.02	N	1	0.33
105	0.695	N	1	1.44
106	9.416	Y	84	8.92
107	4.511	N	1	0.22
108	12.816	N	3	0.23
109	2.958	Y	22	7.44
110	3.488	N	0	0.00
111	10.591	Y	187	17.66
112	8.585	N	20	2.33
113	7.145	N	15	2.10
114	10.771	N	11	1.02
115	8.265	N	1	0.12
116	7.052	N	22	3.12
117	12.195	N	3	0.25
118	24.173	Y	118	4.88
119	8.78	N	17	1.94
120	3.906	N	6	1.54
121	40.194	N	106	2.64
122	8.793	N	1	0.11
123	11.422	N	19	1.66
124	7.958	N	3	0.38
125	21.869	N	35	1.60
126	21.544	N	18	0.84
127	2.511	N	0	0.00
128	44.555	N	26	0.58
130	42.3	Y	170	4.02
132	63.133	Y	327	5.18
133	7.17	N	4	0.56
134	12.41	N	1	0.08
137	11.374	N	26	2.29
138	20.451	N	9	0.44
139	1.416	N	3	2.12
140	2.565	N	4	1.56
141	6.607	N	1	0.15
142	17.323	N	21	1.21
143	50.576	N	61	1.21

144	2.378	N	2	0.84
145	0.498	N	3	6.02
146	5.313	Y	113	21.27
147	18.121	N	0	0.00
148	2.513	N	2	0.80
149	4.217	N	10	2.37
150	54.842	N	117	2.13
151	5.56	N	4	0.72
152	3.013	N	2	0.66
153	40.64	N	24	0.59
154	24.337	N	13	0.53
155	10.729	N	6	0.56
156	1.383	N	0	0.00
157	5.034	N	10	1.99
158	11.671	N	46	3.94
159	8.01	Data unavailable	Data unavailable	Data unavailable
160	3.824	N	1	0.26
161	3.082	N	1	0.32
163	56.018	N	6	0.11
164	2.736	N	0	0.00
165	10.728	N	61	5.69
167	11.075	N	50	4.51
168	1.158	N	0	0.00
171	15.68	N	5	0.32
172	9.276	N	11	1.19
173	9.822	Y	30	3.05
174	8.135	N	0	0.00
178	1.2	Data unavailable	Data unavailable	Data unavailable
180	1.046	N	2	1.91
181	6.897	N	0	0.00
184	1.942	Y	21	10.81
186	12.411	Y	59	4.75
189	29.216	Y	396	13.55
190	19.921	Y	81	4.07
191	253.322	Y	1066	4.21
193	5.689	Y	41	7.21
195	2.568	N	6	2.34
196	36.856	Data unavailable	Data unavailable	Data unavailable
197	1.087	N	0	0.00
198	15.728	Y	41	2.61
199	21.944	N	42	1.91
200	1.57	N	1	0.64

201	18.034	Y	181	10.04
202	1.955	N	7	3.58
203	6.145	Y	84	13.67
204	5.414	N	2	0.37
208	10.192	N	15	1.47
209	14.57	Y	26	1.78
210	13.642	Y	120	8.80
211	18.956	N	35	1.85
212	1.288	N	0	0.00
215	28.968	Y	101	3.49
218	8.202	N	21	2.56
219	1.664	N	1	0.60
224	14.248	Y	106	7.44
225	0.523	N	0	0.00
226	3.003	N	2	0.67
227	0.707	N	6	8.49
228	1.824	N	0	0.00
232	2.421	N	1	0.41
235	4.869	N	1	0.21
237	4.813	N	12	2.49
238	4.69	N	2	0.43
239	1.047	N	2	1.91
240	1.218	N	0	0.00
241	0.386	N	0	0.00
243	1.412	N	0	0.00
244	0.91	N	0	0.00
248	14.507	Y	167	11.51
256	5.591	N	7	1.25
257	69.152	N	27	0.39
258	2.025	N	0	0.00
260	4.184	N	15	3.59
261	32.629	N	10	0.31
262	39.991	N	0	0.00
264	15.407	N	3	0.19
265	4.332	N	4	0.92
266	8.118	N	0	0.00
268	0.631	N	0	0.00
269	1.806	N	1	0.55
270	0.75	N	0	0.00
271	5.579	N	8	1.43
273	3.049	Y	15	4.92
274	1.245	N	0	0.00
275	3.813	N	2	0.52
276	70.929	N	2	0.03
279	15.176	N	2	0.13

280	0.404	N	0	0.00
282	2.957	N	12	4.06
284	1.716	N	1	0.58
285	0.37	N	0	0.00
286	1.19	N	0	0.00
287	0.77	N	0	0.00
288	0.98	N	2	2.04
289	1.886	N	0	0.00
290	1.165	N	0	0.00
291	0.47	N	0	0.00
292	1.69	N	0	0.00
293	1.05	N	0	0.00
294	0.38	N	0	0.00
295	0.65	N	0	0.00
296	1.5	N	0	0.00
298	1	N	0	0.00
299	1.03	N	0	0.00
301	2.04	N	0	0.00
302	3.6	N	1	0.28
303	1.28	N	0	0.00
304	0.26	N	0	0.00
306	0.18	N	0	0.00
308	2.14	N	0	0.00
309	0.33	N	0	0.00
310	0.34	N	0	0.00
311	3.91	N	0	0.00
312	0.58	N	0	0.00
313	22.519	N	8	0.36
314	0.76	N	0	0.00
315	1.744	N	0	0.00
316	3.512	N	0	0.00
317	1.62	N	0	0.00
318	2.215	N	0	0.00
319	1.202	N	0	0.00
320	2.19	N	0	0.00
666	17.058	Data unavailable	Data unavailable	Data unavailable

Table 2-2. Core wildlife road mortality hotspots (≥ 2 miles) on long state routes > ~ 80.5 km (50 mi) in Utah, 1992-2002 listed by hotspot identification code.

Code	Route	Mileposts of Hotspot	Collisions per Mile
89A	89	336-348	34.85
89B	89	231-236	34.17
6A	6	221-227	31.57
68A	68	34-39	31.17
15A	15	120-127	30.63
191A	191	60-75	30.44
89C	89	362-373	29.67
40A	40	001-13	27.92
89D	89	283-288	27.67
89E	89	216-218	27.67
36A	36	50-53	26.75
80A	80	131-143	26.15
70A	70	1-7	23.86
89F	89	38-42	23.25
36B	36	48-53	21.50
6B	6	229-234	21.17
80B	80	151-154	20.75
89G	89	102-107	19.67
70B	70	72-77	19.40
40B	40	88-89	19.00
40C	40	122-123	19.00
40D	40	96-106	18.82
6C	6	200-203	18.50
15B	15	120-143	18.46
40E	40	74-81	18.13
6D	6	188-198	17.82
40F	40	33-36	17.75
15C	15	36-47	17.58
6E	6	177-178	17.50
80C	80	163-167	17.20
6F	6	181-185	17.00
89H	89	394-396	17.00
70C	70	56-63	16.75
70D	70	72-86	15.80
15D	15	142-143	15.50
6G	6	206-210	15.20
40G	40	50-68	15.16
70E	70	79-86	15.13
6H	6	170-210	15.12

6I	6	218-219	15.00
15E	15	134-140	14.57
24A	24	6-8	14.33
6J	6	170-175	14.00
6K	6	165-167	14.00
132A	132	37-45	13.89
89I	89	109-114	13.50
89J	89	79-84	13.33
15F	15	130-132	13.00
40H	40	146-148	13.00
89K	89	127-128	13.00
89L	89	69-70	12.00
24B	24	1-2	11.50
40I	40	109-110	11.50
84A	84	78-79	11.50
89M	89	245-247	11.33

Table 2-3. Isolated wildlife road mortality hotspots (=1 mile) on long state routes > ~ 80.5 km (50 mi) in Utah, 1992-2002 listed by hotspot identification code.

Code	Route	Mileposts of Hotspot	Collisions per mile
80D	80	123-124	23.00
40J	40	85	22.00
89N	89	118	22.00
84B	84	45	20.00
40K	40	28	18.00
191C	191	202	17.00
24C	24	37	16.00
40L	40	43	15.00
24D	24	24	14.00
24E	24	29	14.00
40M	40	22	14.00
40N	40	45	14.00
40O	40	92	14.00
80E	80	159	14.00
84C	84	16	14.00
89O	89	155	14.00
89P	89	180	14.00
89Q	89	222	14.00
89R	89	263	14.00
89S	89	375	14.00
89T	89	334	14.00
89U	89	122	14.00
21A	21	94	13.00
30A	30	98	13.00
40P	40	112	13.00
80F	80	99	13.00
89V	89	94	13.00
89W	89	176	13.00
89X	89	212	13.00
89Y	89	253	13.00
191D	191	45	13.00
191E	191	55	13.00
191F	191	127	13.00
10A	10	28	12.00
24F	24	26	12.00
36C	36	48	12.00
39A	39	15	12.00
39B	39	16	12.00

39C	39	18	12.00
40Q	40	48	12.00
56A	56	48	12.00
80G	80	126	12.00
84D	84	3	12.00
84E	84	6	12.00
89Z	89	102	12.00
89AA	89	190	12.00
89BB	89	226	12.00
89CC	89	238	12.00
89DD	89	266	12.00
6M	6	141	11.00
10B	10	48	11.00
18A	18	18	11.00
18B	18	26	11.00
21B	21	92	11.00
24G	24	46	11.00
24H	24	64	11.00
40R	40	38	11.00
40S	40	153	11.00
70F	70	23	11.00
80H	80	150	11.00
84F	84	54	11.00
89EE	89	57	11.00
89FF	89	88	11.00
89GG	89	90	11.00
89HH	89	255	11.00
89II	89	259	11.00

Table 2-4 .Core wildlife road mortality hotspots on short state routes ≤ ~ 80.5 km (50 mi) in Utah, 1992-2002.

Code	Route	Mileposts of Hotspot	Collisions per mile
118A	118	0-4	40.80
92A	92	0-4	40.80
52A	52	2-3	40.00
130A	130	3-5	34.67
146A	146	2-4	33.67
91A	91	3-10	29.50
111A	111	4-8	28.40
203A	203	0-2	26.00
210A	210	0-4	24.00
189A	189	16-25	23.20
91B	91	41-42	23.00
201A	201	5-7	22.33
224A	224	9-11	21.67
186A	186	10-11	21.50
118A	118	6-8	20.67
91C	91	14-16	20.67
189B	189	5-6	20.50
201B	201	0-3	19.50
73A	73	24-27	19.25
28A	28	27-28	19.00
248A	248	6-7	18.50
28B	28	36-38	18.33
38A	38	0-7	17.75
99A	99	002-003	17.50
73B	73	30-31	16.00
48A	48	0-1	16.00
106A	106	004-006	15.00
248B	248	1-4	14.75
248C	248	9-11	14.33
248D	248	1-11	14.09
215A	215	0-3	14.00
198A	198	0-2	14.00
190A	190	0-2	13.00
38B	38	14-16	12.67
189C	189	8-9	12.50
32A	32	23-24	11.50

Table 2-5. Isolated wildlife road mortality hotspots on short state routes ≤ ~ 80.5 km (50 mi) in Utah, 1992-2002.

Code	Route	Milepost of Hotspots	Collisions per mile
91D	91	37	33.00
91E	91	25	27.00
203B	203	5	20.00
193A	193	5	20.00
130B	130	0	20.00
71A	71	3	19.00
209A	209	6	16.00
111B	111	2	16.00
48A	48	0	16.00
184A	184	0	15.00
173A	173	0	14.00
109A	109	2	14.00
92B	92	6	14.00
74A	74	4	14.00
9A	9	33	13.00
224B	224	13	12.00
189D	189	11	12.00
111C	111	0	12.00
91F	91	12	12.00
91G	91	35	12.00
73C	73	34	12.00
28C	28	14	12.00
273A	273	1	11.00
91H	91	19	11.00
65A	65	0	11.00
38C	38	9	11.00

Table 2-6. Intensity ranking (deer-vehicle collisions per mile) for state routes in Utah, 1992-2002.[a]

High Intensity Routes:

146 (21.27), **52** (18.32), **111** (17.66), **203** (13.67), **189** (13.55), **99** (12.87), **91** (12.81), **38** (12.04), **248** (11.51), **184** (10.81), **40** (10.61), **201** (10.04)

Moderate Intensity Routes:

92 (9.07), **106** (8.92), **210** (8.80), **227** (8.49), **89** (8.04), **28** (7.47), **224** (7.44), **109** (7.44), **193** (7.21), **145** (6.02), **48** (5.91), **73** (5.75), **165** (5.69), **84** (5.68), **15** (5.49), **132** (5.18)

Low Intensity Routes:

74 (4.92), **273** (4.92), **6** (4.91), **83** (4.90), **75** (4.89), **32** (4.89), **118** (4.88), **80** (4.84), **90** (4.81), **186** (4.75), **167** (4.51), **20** (4.46), **191** (4.21), **190** (4.07), **282** (4.06), **130** (4.02), **158** (3.94), **70** (3.86), **63** (3.79), **226** (3.74), **18** (3.66), **14** (3.60), **260** (3.59), **202** (3.58), **36** (3.57), **68** (3.55), **51** (3.53), **215** (3.49), **17** (3.15), **116** (3.12), **44** (3.11), **24** (3.08), **39** (3.06), **173** (3.05), **102** (2.99), **10** (2.96), **9** (2.70), **121** (2.64), **198** (2.61), **218** (2.56), **41** (2.52), **237** (2.49), **23** (2.37), **149** (2.37), **195** (2.34), **112** (2.33), **137** (2.29), **25** (2.20), **150** (2.13), **13** (2.13), **139** (2.12), **50** (2.11), **113** (2.10), **288** (2.04), **157** (1.99), **46** (1.94), **119** (1.94), **56** (1.92), **61** (1.92), **199** (1.91), **180** (1.91), **239** (1.91), **211** (1.85), **66** (1.80), **209** (1.78), **71** (1.78), **87** (1.73), **29** (1.70), **123** (1.66), **35** (1.62), **125** (1.60), **140** (1.56), **141** (1.54), **120** (1.54), **65** (1.52), **43** (1.52), **208** (1.47),**105** (1.44), **271** (1.43), **62** (1.26), **256** (1.25), **88** (1.24), **31** (1.24), **142** (1.21), **143** (1.21), **30** (1.19), **172** (1.19), **21** (1.10), **94** (1.04), **16** (1.03), **114** (1.02), **12** (1.01), **11** (1.00), **265** (0.92), **60** (0.87), **144** (0.84), **126** (0.84), **148** (0.80), **101** (0.78), **45** (0.78), **72** (0.73), **151** (0.72), **100** (0.71), **55** (0.67), **226** (0.67), **152** (0.66), **78** (0.64), **200** (0.64), **219** (0.60), **153** (0.59), **128** (0.58), **284** (0.58), **155** (0.56), **133** (0.56), **269** (0.55), **154** (0.53), **275** (0.52), **95** (0.45), **138** (0.44), **77** (0.44), **22** (0.44), **238** (0.43), **232** (0.41), **79** (0.41), **257** (0.39), **124** (0.38), **57** (0.38), **204** (0.37), **313** (0.36), **104** (0.33), **161** (0.32), **171** (0.32), **261** (0.31), **302** (0.28), **160** (0.26), **117** (0.25), **108** (0.23), **107** (0.22), **235** (0.21), **264** (0.19), **141** (0.15), **279** (0.13), **115** (0.12), **122** (0.11), **163** (0.11), **37** (0.08), **134** (0.08), **276** (0.03)

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[a] **Route Number** (Collisions per mile).

Table 2-7. Deer-vehicle collision hotspots by category and route length, Utah, (1992-2002).[a]

	Route Length		
	Short	Long	Totals
Hotspot Category			
Isolated	25 (13.9%)	66 (36.7%)	91 (50.5%)
Core	36 (20.0%)	53 (29.4%)	89 (49.5%)
Totals	61 (33.9%)	119 (66.1%)	180 (100%)

---

[a] Number of deer-vehicle collisions (Percent of total)

Table 2-8. Number of "core" deer-vehicle collision hotspot types by intensity ranking (collisions per mile), Utah, 1992-2002. Core hotspots consist of segments of at least 2 consecutive miles or more. Long routes have a total length > ~ 80.5 km (~50 mi) and short routes have a total length ≤ ~ 80.5 km.[a]

	Hotspot Type		
	Long route Core	Short route Core	Totals
Intensity Ranking			
Very High (≥30)	6 (6.7%)	5 (5.6%)	11 (12.4%)
High (20-29.99)	11 (12.4%)	12 (13.5%)	24 (27.0%)
Moderate (15-19.99)	21 (23.6%)	10 (11.2%)	33 (37.0%)
Low (11-14.99)	15 (16.9%)	9 (10.1%)	24 (27.0%)
Totals	53 (59.6%)	36 (40.4%)	89 (100.0%)

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[a] Number of deer-vehicle collisions (Percent of total).

Table 2-9. Number of "isolated" deer-vehicle collision hotspot types by intensity ranking (collisions per mile), Utah, 1992-2002. Isolated hotspots consist of segments of only 1 mile. Long routes have a total length > ~ 80.5 km (50 mi) and short routes have a total length ≤ ~ 80.5 km.[a]

	Hotspot Type		
	Long route isolated	Short route isolated	Totals
Intensity Ranking			
High (> 20)	4 (4.39%)	5 (5.49%)	9 (9.89%)
Moderate (15-19.99)	4 (4.39%)	4 (4.40 %)	8 (8.79%)
Low (11-14.99)	58 (63.74%)	16 (17.58%)	74 (81.31%)
Totals	66 (72.52 %)	25 (27.48 %)	91 (100.0%)

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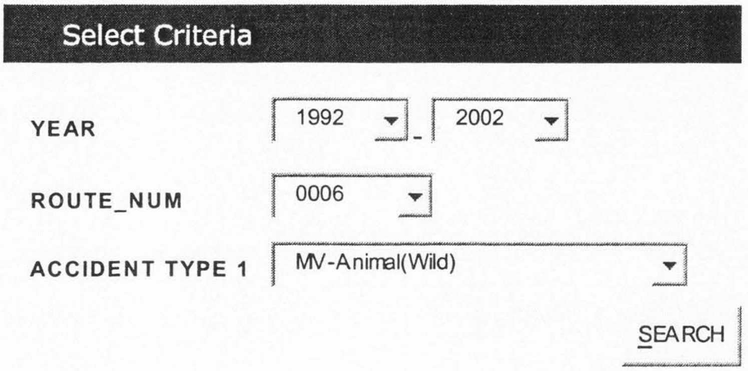
[a] Number of deer-vehicle collisions (Percent of total).

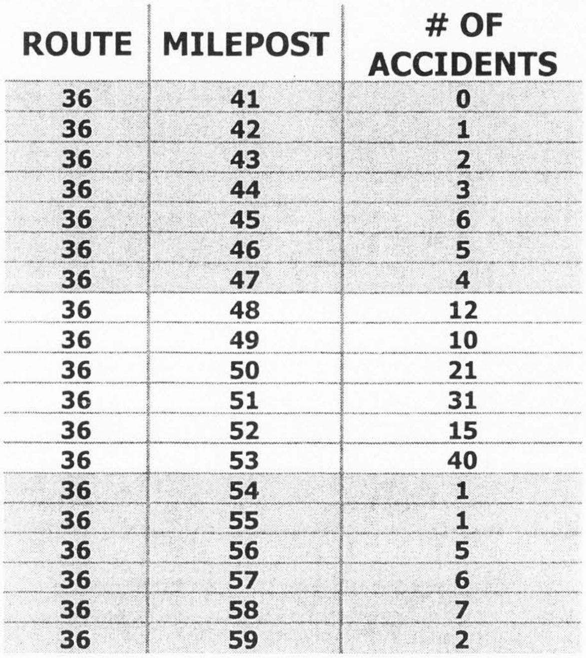


YEAR 1992 - 2002

ROUTE_NUM 0006

ACCIDENT TYPE 1 MV-Animal(Wild)

Figure 2-1. Criteria used to search the Utah Department of Transportation (UDOT) Centralized Accident Record System (CARS) database for wildlife- vehicle collisions, Utah, 1992-2002.



ROUTE	MILEPOST	# OF ACCIDENTS
36	41	0
36	42	1
36	43	2
36	44	3
36	45	6
36	46	5
36	47	4
36	48	12
36	49	10
36	50	21
36	51	31
36	52	15
36	53	40
36	54	1
36	55	1
36	56	5
36	57	6
36	58	7
36	59	2

Figure 2-2. Partial results of a fixed segment analysis showing the number of deer-vehicle collisions by milepost for Route 36, Juab and Tooele Counties, Utah, 1992-2002.

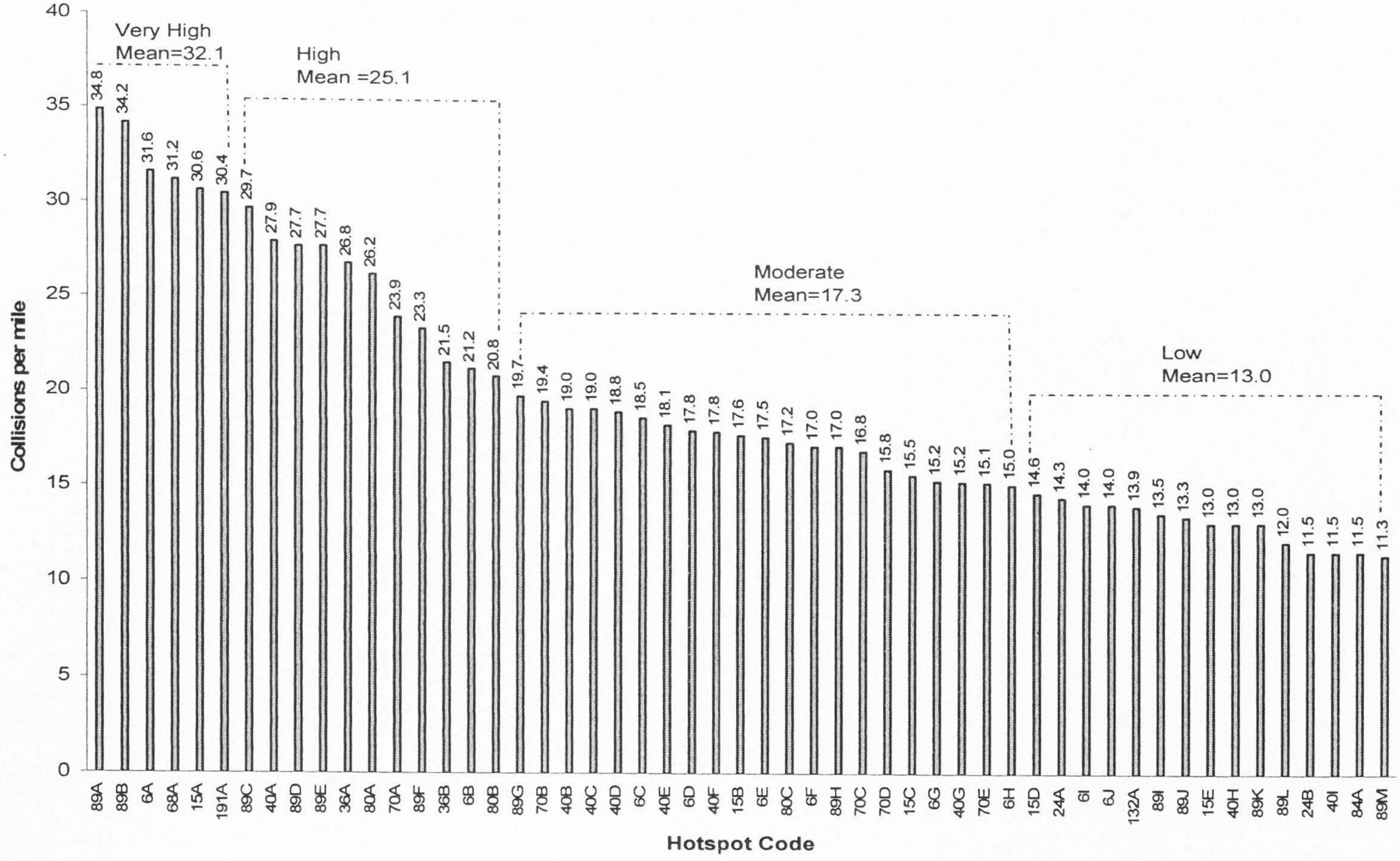


Figure 2-3. Core hotspots of wildlife-vehicle collisions on long state routes > ~ 80.5 km (50 mi) in Utah, 1992-2002. Refer to Table 2-2 for the location of each hotspot by hotspot code.

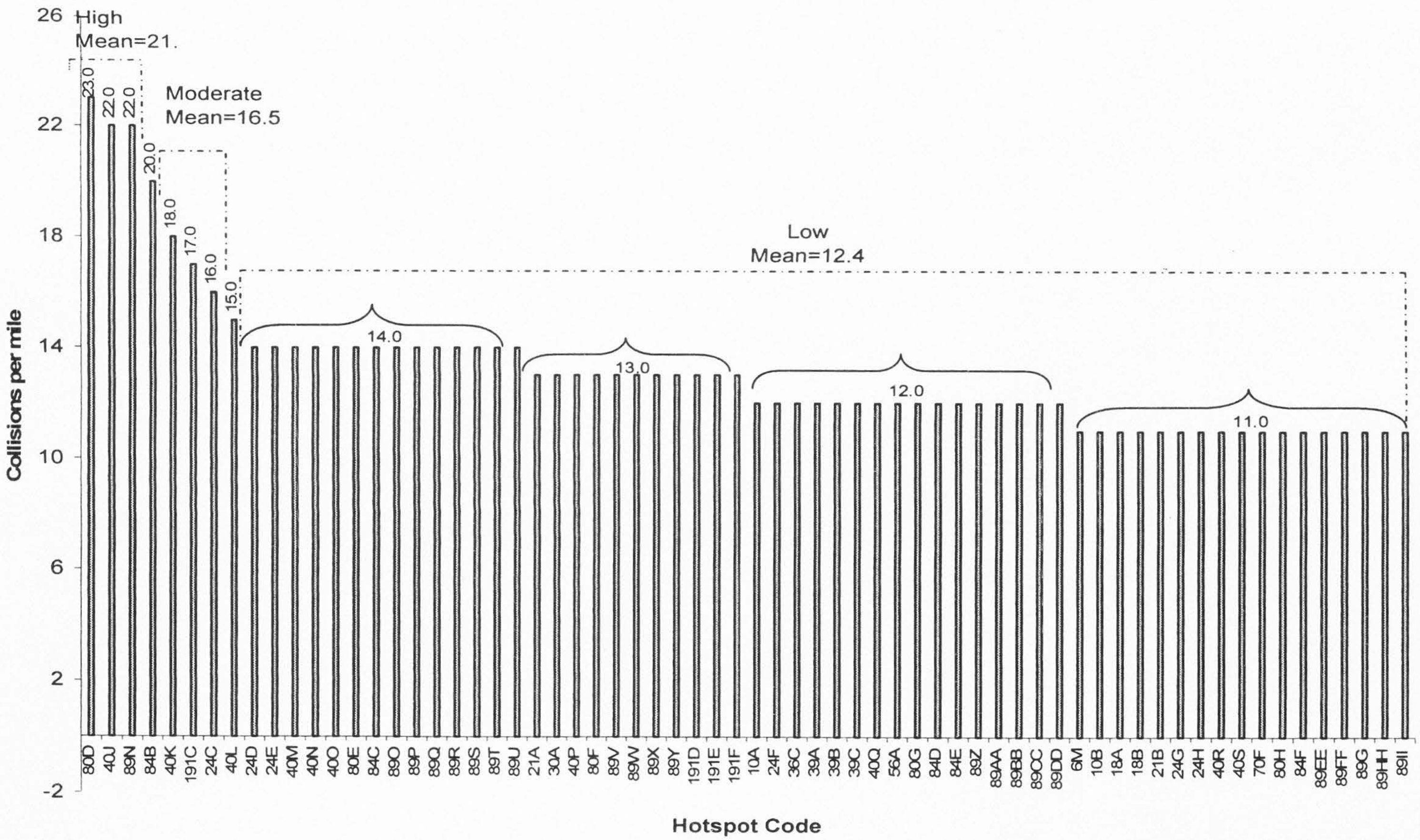


Figure 2-4. Isolated hotspots of wildlife-vehicle collisions on long state routes > ~ 80.5 km (50 mi) in Utah, 1992-2002. Refer to Table 2-3 for the location of each hotspot by hotspot code.

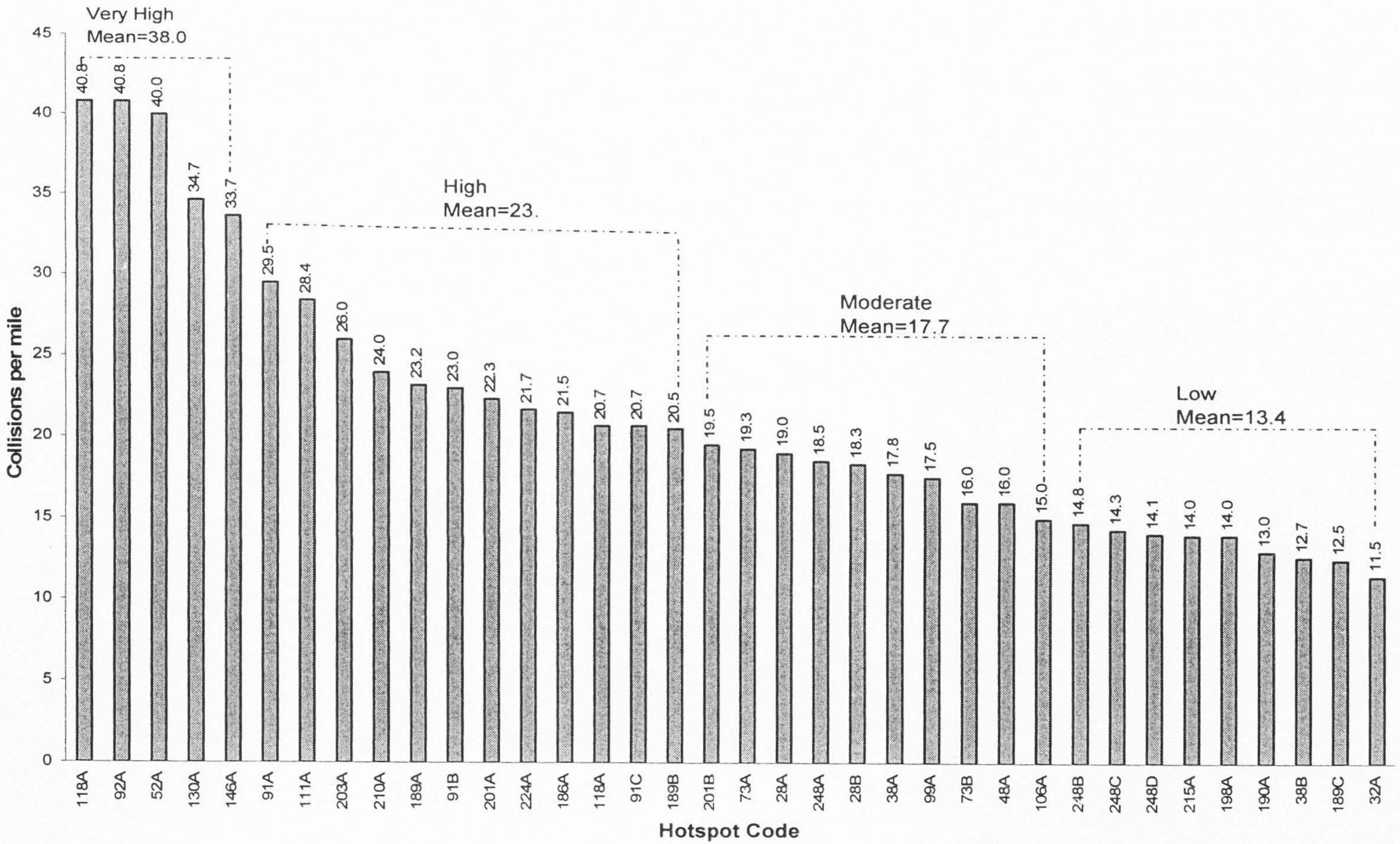


Figure 2-5. Core hotspots of wildlife-vehicle collisions on short state routes ≤ ~ 80.5 km (50 mi) in Utah, 1992-2002. Refer to Table 2-4 for the location of each hotspot by hotspot code.

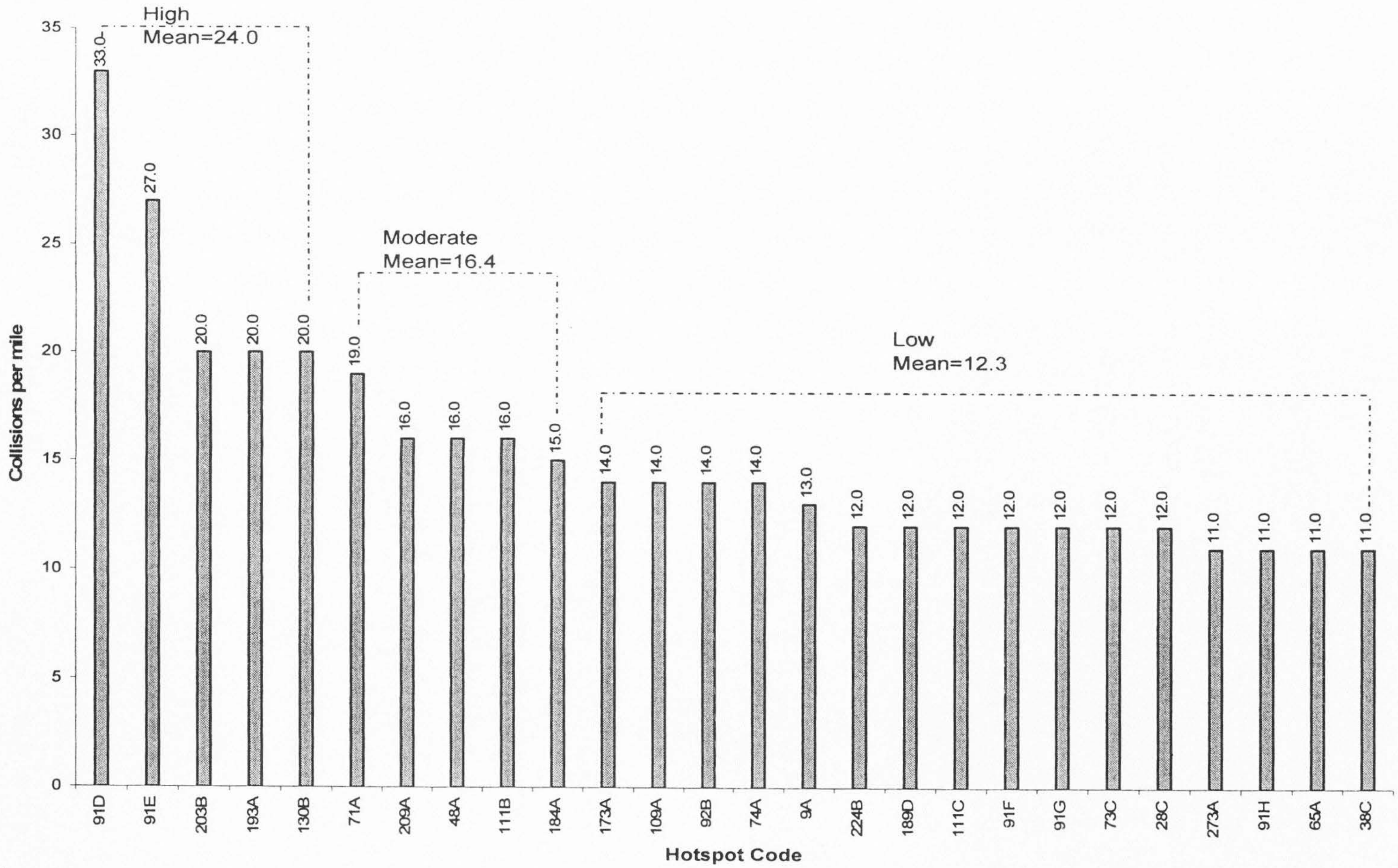


Figure 2-6. Isolated hotspots of wildlife-vehicle collisions on short state routes ≤ ~ 80.5 km (50 mi) in Utah,1992-2002. Refer to Table 2-5 for the location of each hotspot by hotspot code.

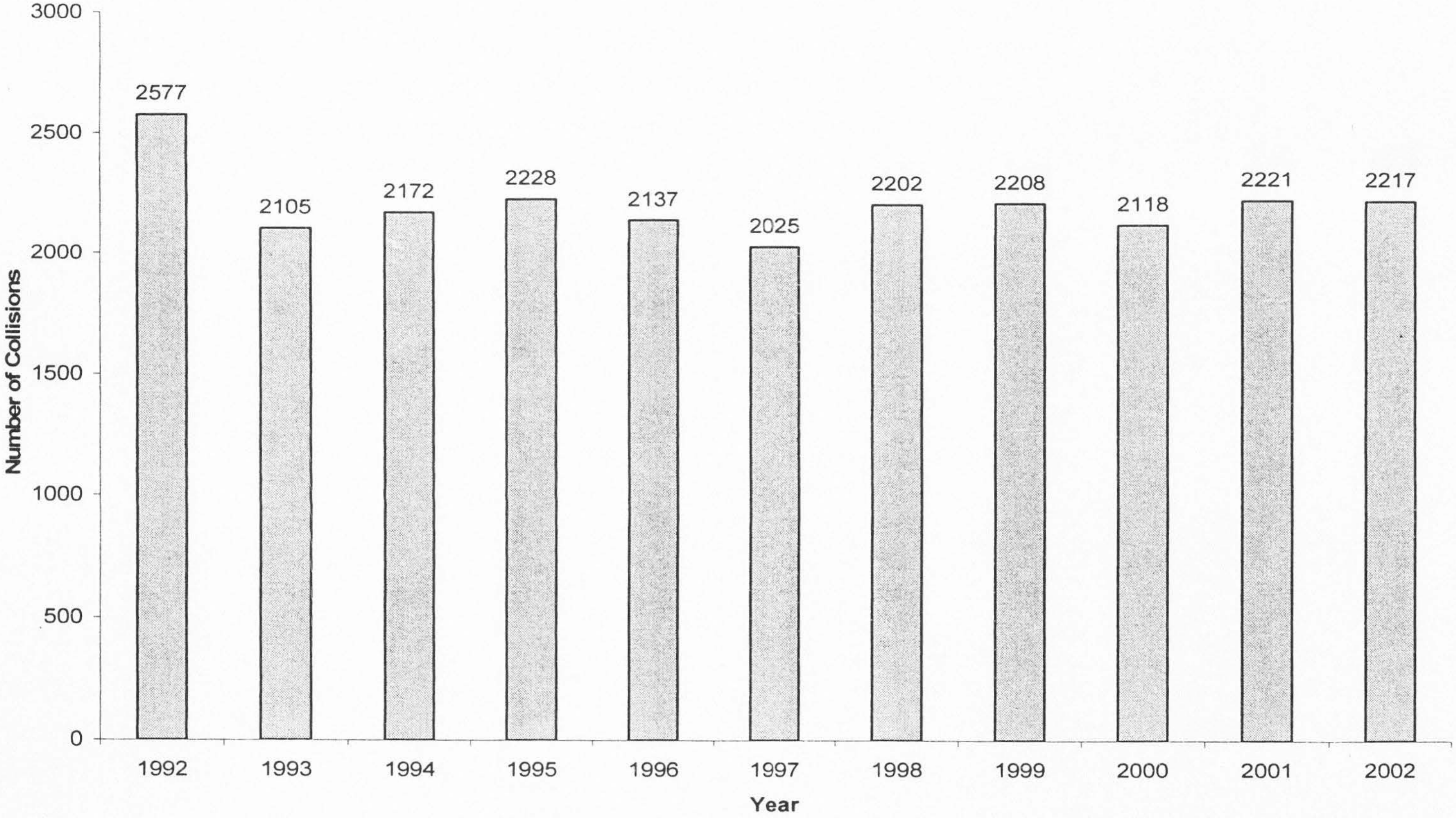


Figure 2-7. Wildlife-vehicle collisions by year for 248 state routes in Utah, 1992-2002.

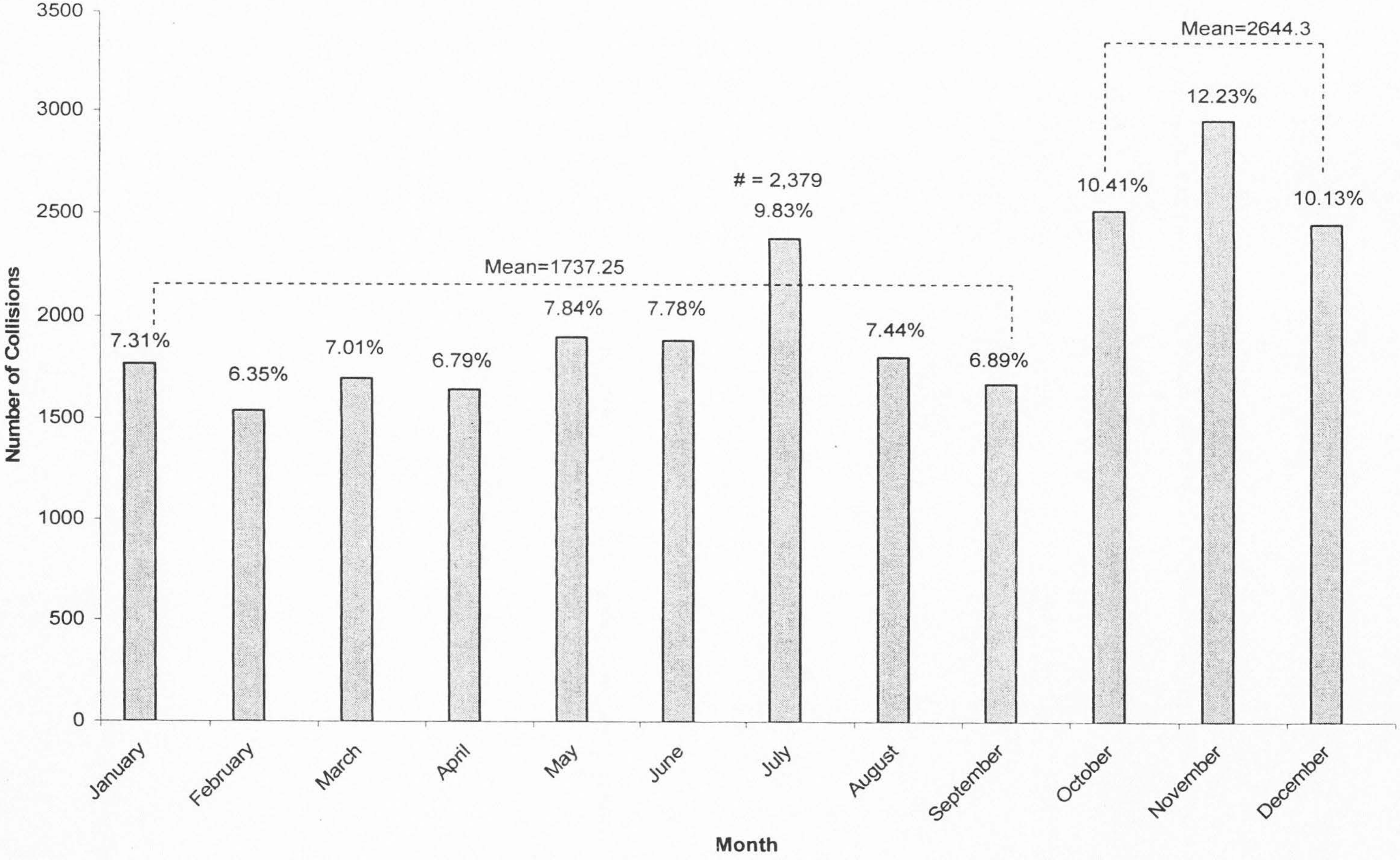


Figure 2-8. Trends in wildlife-vehicle collisions by month for 248 state routes in Utah, 1992-2002.

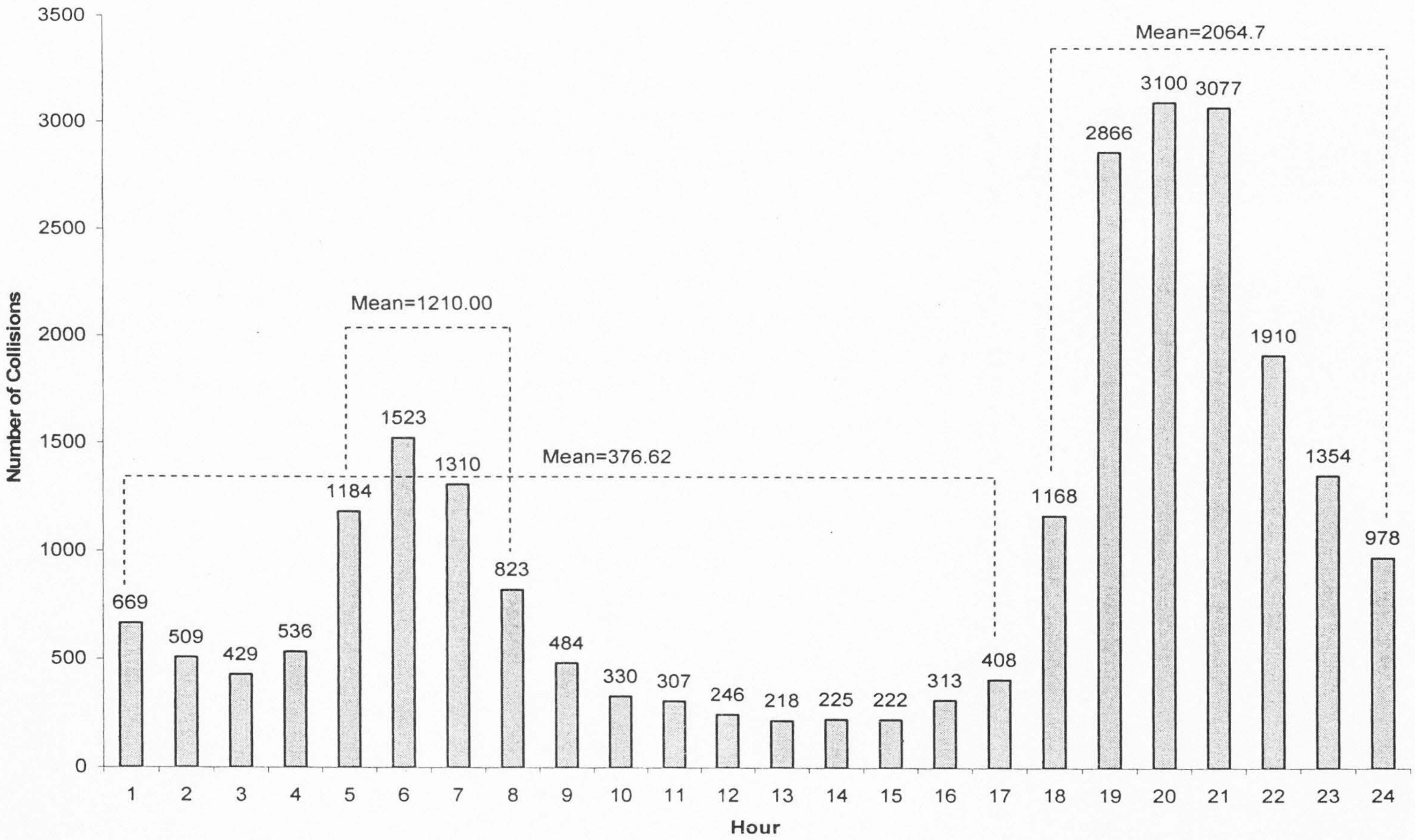


Figure 2-9. Trends in wildlife-vehicle collisions by hour for 248 state routes in Utah, 1992-2002.

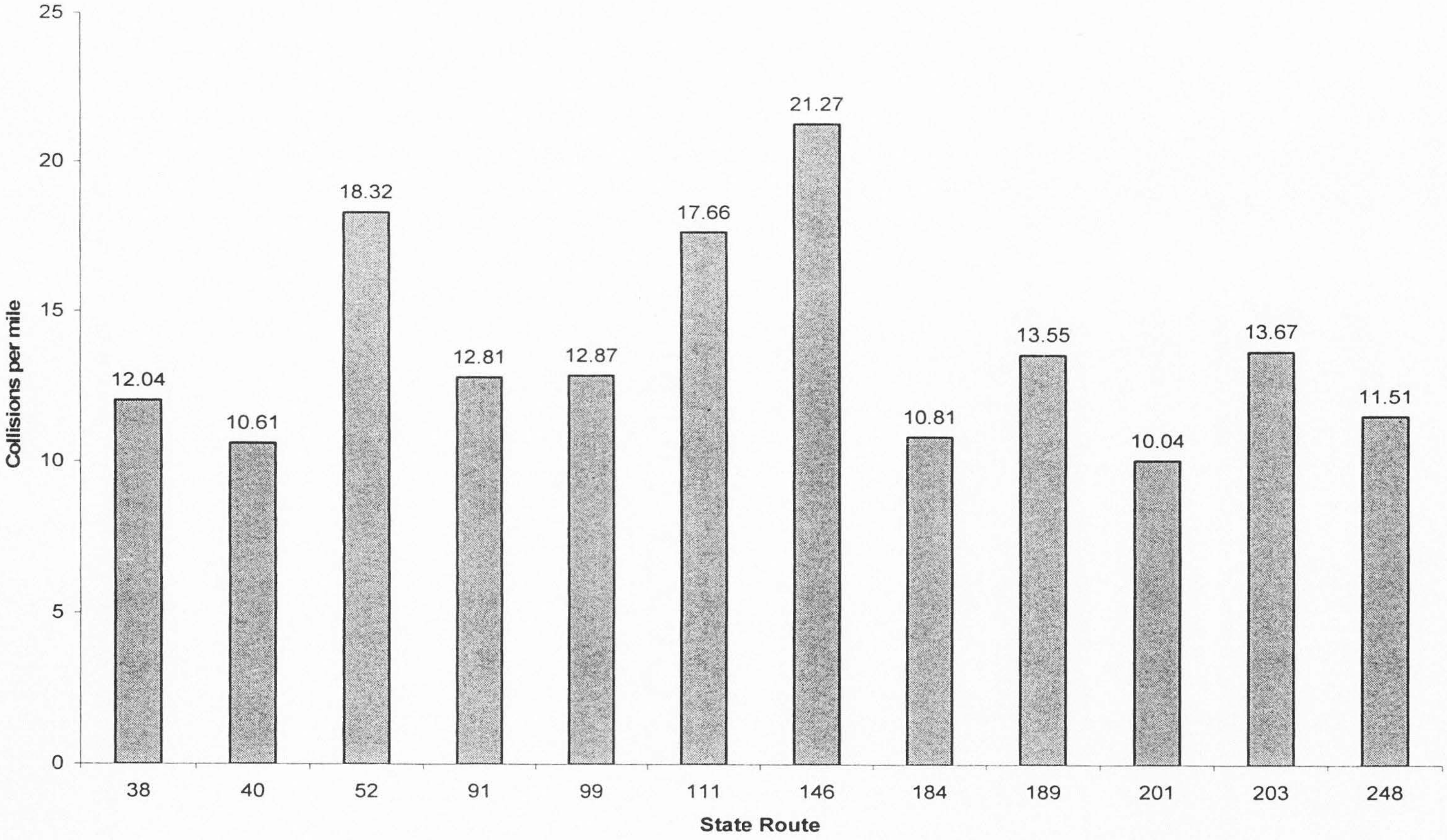


Figure 2-10. State routes with a high rate of wildlife-vehicle collisions per mile, Utah, 1992-2002. Route 40 is a long route > ~ 80.5 km (50 mi) while the rest are short routes ≤ ~ 80.5 km.

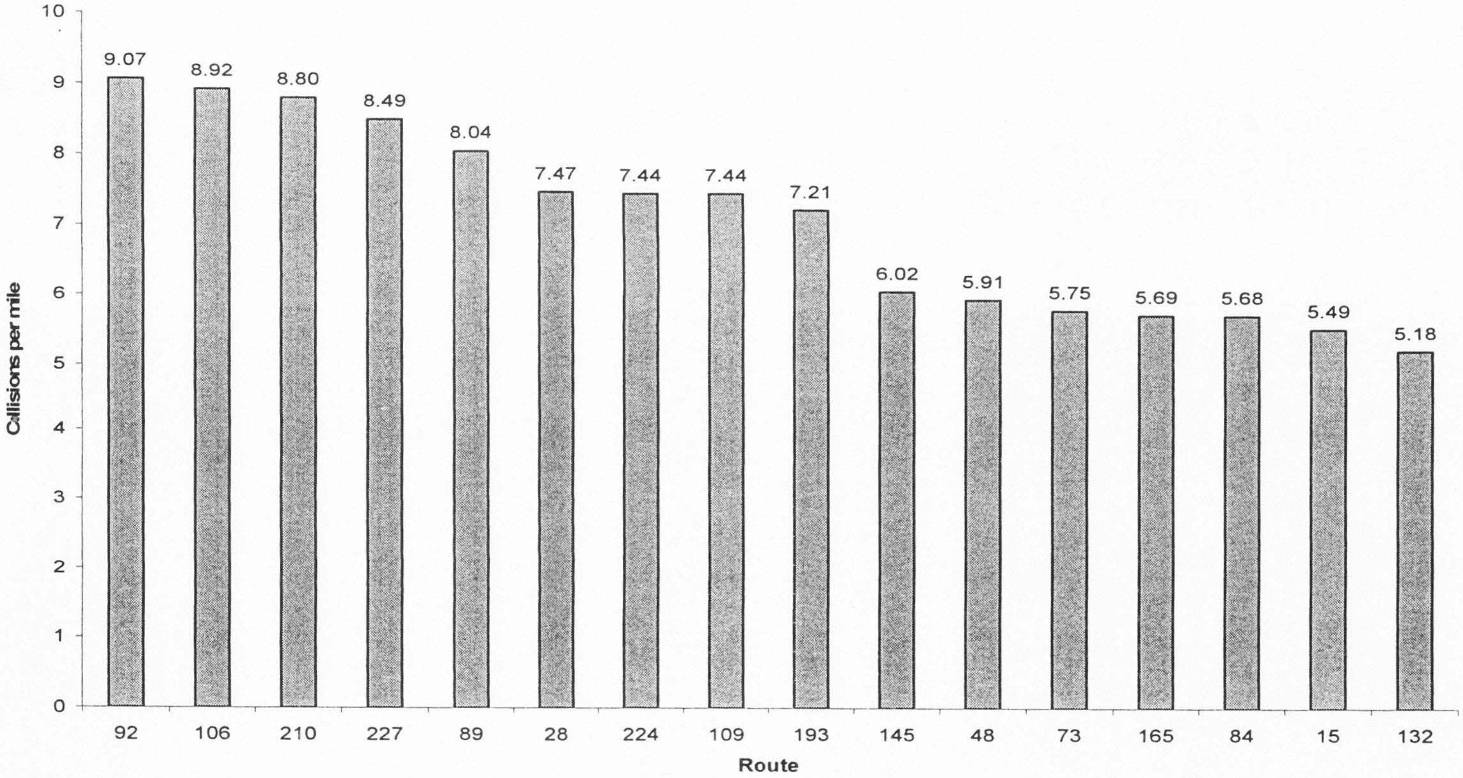


Figure 2-11. State routes with a moderate rate of wildlife-vehicle collisions per mile, Utah, 1992-2002. Routes 89, 84, 15 and 132 are long routes > ~ 80.5 km (50 mi) while the rest are short routes ≤ ~ 80.5 km.

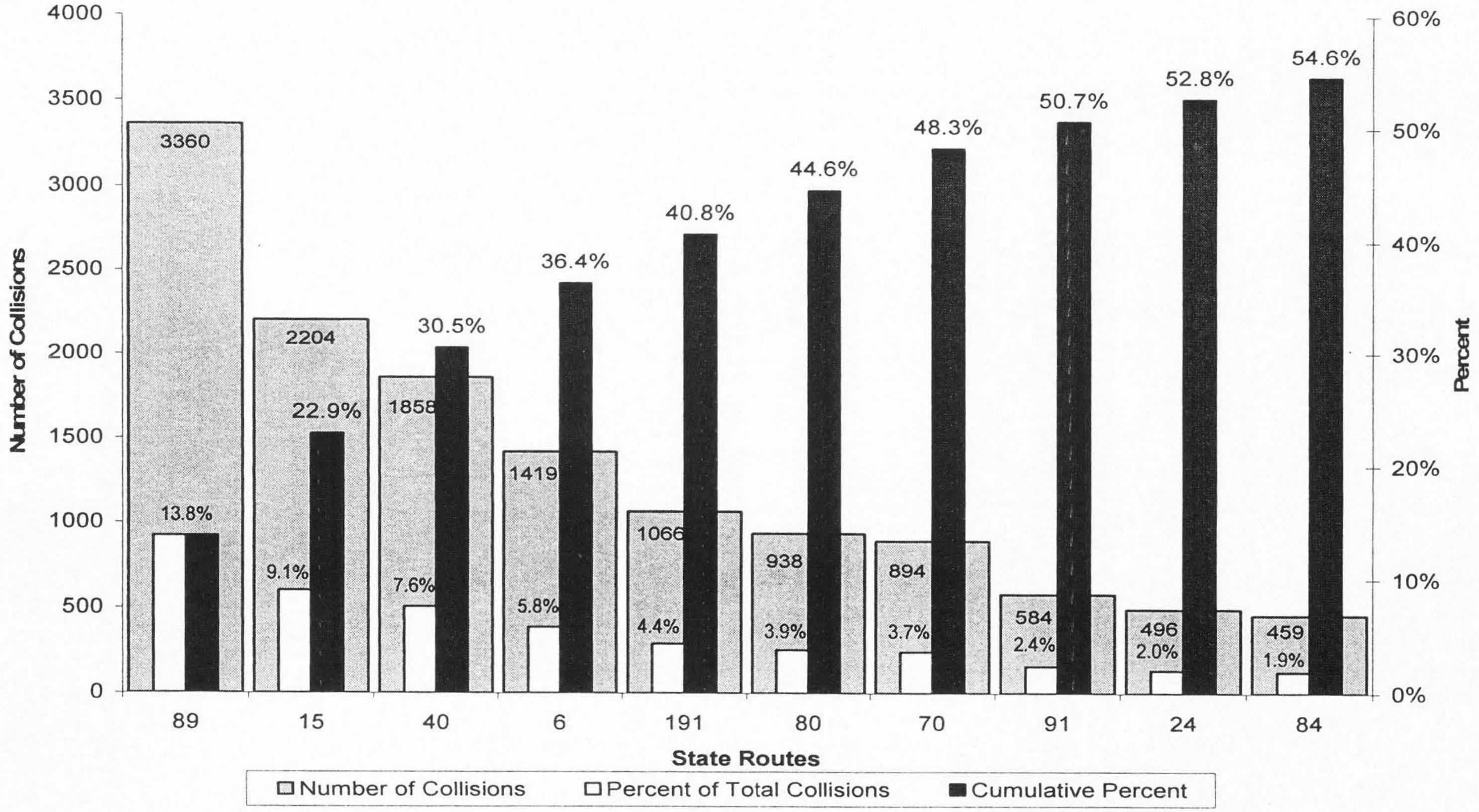


Figure 2-12. Ten state routes with the highest total number of overall wildlife-vehicle collisions in Utah, 1992-2002. Route 91 is a short route and the rest are long routes.

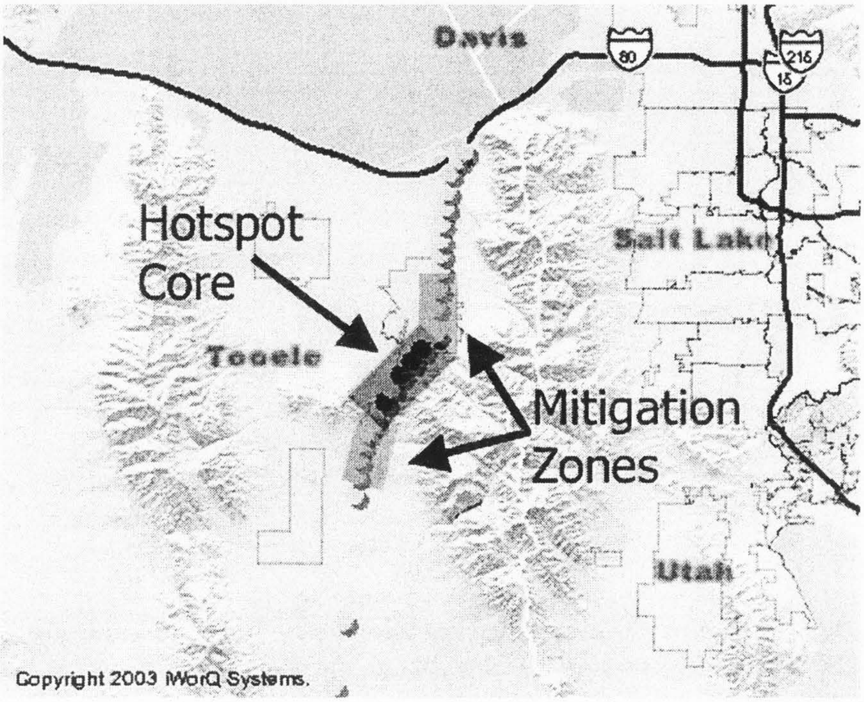


Figure 2-13. Parts of a wildlife-vehicle collision hotspot: (1) the core area where collisions are concentrated and (2) the suggested mitigation zones to account for animal behavior and to address the "end of the fence" problem.

CHAPTER 3

DATA ISSUES IN DESCRIBING ROAD MORTALITY HOTSPOTS AND CREATING PREDICTIVE MODELS: A CASE STUDY OF UTAH

Abstract

In the United States, the roaded landscape has had significant ecological effects. Specific to this research, the number of wildlife-vehicle crashes is increasing, due to compromised landscape permeability and associated conservation values. Significant economic costs are involved as well as human safety. Many authors have investigated factors that may contribute to wildlife-vehicle collisions. We reviewed the literature and found that vehicle speed and volume often are cited as important determinants of the number of animal-vehicle collisions. However, there is variation in the conclusions drawn and in the strength of correlations found within the literature regarding the impacts of posted speed limit and traffic volume on wildlife-vehicle collisions. To understand the effects of posted speed limit and annual average daily traffic flow (AADT) and to make sense of the conflicting reports in the literature on wildlife-vehicle collisions, we conducted a 2-part investigation that included an extensive literature review and a case study involving an analysis of traffic volume and posted speed limit correlations on 4 state routes in Utah. We found that trends in the literature varied; the results from our case study showed no relationship between traffic volume and/or posted speed limit and the number of wildlife-vehicle collisions that occurred. We discuss 5 possible hypotheses to explain these results: (1) lack of a causal relationship, (2) nature of the data, (3) variations within scale and resolution of

the data, (4) speed and volume explain only a small part of the variance of the relationship, and (5) some combination of 2, 3, or 4. We argue that if the objective is to *define hotspots of road kill for mitigation action*, then hotspot analyses that use existing data accurate to the mile marker can produce excellent results and can be done for most states, provinces, and countries that have these data. Use of hotspot analysis to prioritize mitigation measures will have quick beneficial effects on restoring landscape permeability. However, we argue that developing reliable and accurate *predictive models* of animal-vehicle crashes using explanatory environmental and/or roadway variables requires that: (1) road kill data is spatially explicit, (2) data regarding explanatory variables and road kill are recorded at appropriate scale extents and resolutions, (3) data are recorded accurately and completely, (4) the model considers not only road geometrics but also environmental variables, and (5) the model considers both driver behavior and animal behavior. We discuss the problems with describing wildlife-vehicle hotspots and identify ways to address these issues.

Introduction

Roads have a significant impact on the natural environment (Trombulak and Frissell 2000) including the health of ecosystems (Forman and Alexander 1998), the diversity of communities (Forman 1998), and the abundance of species in an area (Groot Bruinderink and Hazebroek 1996). Direct effects of these impacts are most evident on the landscape through animal mortality or road kill (Bissonette 2002). Scientists have attempted to explain wildlife road mortality by identifying certain explanatory environmental and road variables that correlate with areas of a high concentration of collisions.

Road characteristics, usually referred to collectively as road geometrics, including vehicle traffic volume and speed limit, have been reported to affect animal road kill rates (Forman and Alexander 1998). Depending on the species and area, certain studies imply that vehicle volume is highly correlated with road mortality (Inbar and Mayer 1999), while others implicate speed as the major cause of collisions (Case 1978; Staines et al. 2001).

McCaffrey (1973) argued that local average daily traffic flow is too variable to allow for conclusions. Allen and McCullough (1976) found that traffic volume varied throughout different times of the day and it was not closely correlated with deer-vehicle collisions. However, when deer activity increased during dusk and dawn periods, traffic volume explained a large part (85%) of deer-vehicle collisions. They found a low correlation between seasonal traffic volume and deer-vehicle collisions. Romin and Bissonette (1996) evaluated mule deer kills on 3 highways and found that areas with more kills also had greater vehicle volumes and speed. In their discussion, however, they emphasized the impact that traffic volume had on overall deer kills; vehicle speeds were not as strongly or consistently correlated. Rolley and Lehman (1992) did not find a positive correlation between traffic volume and kills; rather they implicated speed as a major cause of mortality, but suggested difficulties in determining the relative importance of speed in relation to other variables on road mortality of raccoons. Gunther et al. (1998) concluded that the actual speed of vehicles, rather than the posted speed limit was better correlated with wildlife-vehicle collisions. Bashore et al. (1985) evaluated posted speed limit at kill sites and found that it was negatively correlated with deer kill probability. They suggest that posted speed may have little relationship to actual vehicle speeds and that deer may cross less frequently at spots where vehicles move more quickly.

We perused the literature and found that vehicle speed and volume are often cited as important determinants of the number of animal-vehicle collisions. However, we found variation in the conclusions drawn and in the strength of correlations found within the literature on the impacts of posted speed limit and traffic volume on wildlife-vehicle collisions. To understand the effects of posted speed limit and annual average daily traffic flow (AADT) and to make sense of the conflicting reports in the literature on wildlife-vehicle collisions, we conducted a two-part study, including an extensive literature review and a case study involving an analysis of traffic volume and posted speed limit correlations on four state routes in Utah.

Methods

Study area description

Utah is diverse, consisting of mountainous, desert, rangeland, agricultural, wetland and urban regions. This varied terrain is transected by ~9500 km (~5,900 miles) of state routes and ~ 56, 327 km (~35,000 miles) of city and county roads that are being used by a growing number of drivers. The case study area consisted of 4 state routes within Utah that had a significant amount of collisions (6,198 or 25.6% of total collisions). The routes chosen from the 248 total routes in Utah were: 40, 89, 189 and 91 (Tables 3-1, 3-2, 3-3, 3-4, Appendix A, Figure A-2).

Literature Review

To determine if there was any consistency among findings, we conducted an extensive review of the literature on wildlife-vehicle collisions and factors that may contribute to them. This literature included a random sample of those articles cited most consistently. To ensure that we had a representative sample, we performed a BIOSIS computer search and categorized the results by authors who stated conclusions based on their own data, on other literature, or based on both data and literature.

Route Analysis: Data Description

The Utah Department of Transportation (UDOT) maintains a database of information on vehicle crashes reported within Utah from 1992 to 2002. The data originates from accident forms filled out by law enforcement officers that are provided to UDOT by the Utah Department of Public Safety. The database contains information for all types of collisions, including those that involved a motor vehicle hitting a wild animal. A wildlife-vehicle collision was included in the database only if an animal was actually hit, and if the damage due to the crash exceeded $1,000, and/or personal injury resulted. Collisions included in the database do not account for crashes that occurred as a result of swerving to miss an animal, those that resulted in less than $1,000 in damage and/or those with no human injuries. Due to these constraints, animal-vehicle collisions are underreported, and the number of collisions reported here should be considered minimum estimates (Jahn 1959; Groot

Bruinderink and Hazebroek 1996). This analysis does not deal with smaller wild animals or large domestic animal collisions (e.g. livestock).

The collision data used for this paper came directly from the UDOT database in a spreadsheet containing information for each wildlife-vehicle collision occurring on all 248 routes in Utah from 1992-2002. For each of the 24, 210 wildlife-vehicle collision records within the data set, there were corresponding variables, including: route number, milepost, date, time, locality, alignment and posted speed limit. The UDOT collision database consists of two main sections: 'Accident' and 'Traffic.' The 'Traffic' section contains the Annual Average Daily Traffic (AADT) flow information for each route by year. We searched the 'Traffic' section for each route individually from 1992-2002 and compiled this into a spreadsheet which was then imported into SAS 9.1.3 (Appendix B, Tables B-1, B-2, B-3, B-4).

We identified segments of road that had 11 or more collisions per mile over the 11 year period 1992-2002, i.e., at least one accident per year. This process was repeated for each of the 248 state routes that exist in Utah. For this analysis, we chose 4 routes: 40, 89, 91 and 189 because they have a significant number of wildlife-vehicle collisions (6,198 or 25.6% total collisions) (Tables 3-1, 3-2, 3-3, 3-4).

Route Analysis: Traffic Volume Data

In Utah, raw traffic volume data is recorded by hose-like sensors placed on sections of each highway for a 48-hour time period. These sensors record the days of the week, the month, and the functional class of the route, i.e, interstate, collector, etc. Full time, inductive loop based counters all over the state provide 365 days of data that are used to generate growth factors for each functional class. These growth factors are used to estimate changes in volume and adjust the 48-hour counts the time of year that the count was taken. Sections are counted on a rotating 3 year cycle; the other 2 years the AADT is based on a growth factor. To yield an AADT for a specific section of road, conversion growth factors for the day of the week and month are applied to the figure recorded within the 48-hour period. As development occurs, the actual point the data is collected may differ from year to year. An entire route may not be counted on the same day and individual sections may not be recorded on the same days each year. Presumably, functional class conversion factors adjust the 48-hour reading to reflect correct AADT volumes. Counters are placed on the landscape according to parameters that affect road design (i.e., number of lanes or intersections). Thus, AADT is collected from road segments with unequal lengths. These segments are not uniform in length among or within routes. In the data set AADT varied the most along a route because it corresponded to individual segments of unequal length. Because this variable had the most variation in length, we used these sections of road as the defining sections for our model. Using SAS, we extracted the data for each route from the larger dataset and created 4 separate traffic volume datasets (Fig. 1, STEP 1). For each route, we assigned a section number to each volume-defined segment of road (Fig. 1, STEP 2, Table 3-5, 3-6, 3-7, 3-8). We took the mean volume of all the years for each segment of road and based on milepost, assigned it to its corresponding section (Fig.1, STEP 3). We used the mean value for volume because it evenly weights data from each of the 11 years. This was necessary because the number of wildlife-vehicle collisions did not vary significantly from year to year

(Bissonette and Kassar, unpublished data). Then, we assigned each collision that occurred on that route into a section based on its milepost (Fig.1, STEP 4). We then tallied the number of records in each section and calculated the event density (number of collisions per mile) for each of these sections (Fig. 1, STEP 5). By standardizing the collision data into event density, we were able to determine if a correlation exists between AADT and the number of collisions across road segments of unequal lengths.

Route Analysis: Posted Speed Limit (mph) Data

In the original dataset the posted speed limit (mph), as well as an actual estimated vehicle speed were assigned for each collision. We calculated the median posted speed for collisions occurring in each section and compared it to the event density (number of collisions per miles of section) to determine the nature of the relationship. The speed limit data were variable; values reported ranged from 0 to 75 mph. Because there are no road segments with a posted speed limit of 0, we removed these collisions from our analysis. Compared to the mean, the median is less affected by high or low measurements and is thus, "a resistant statistic" (Zar 1999). In addition, the median can still be calculated if data is not accurate for all members of the sample (Zar 1999) . Because we questioned the reliability of the data and because the reported speed limit for a route did change frequently, we chose the median value to reflect the most common condition drivers would face and to prevent outliers from skewing the results. By doing this we were purposely trying to maximize the possibility of a significant relationship; in other words, this was a best possible case scenario for these data.

Individual Route Analysis

Using SAS 9.1.3 to perform a multiple regression we evaluated how the independent variables (AADT and posted speed limit) related to the dependent variable (the number of collisions). We standardized the number of collisions by calculating event density because each of the volume-defined sections was of different length. We compared event density (collisions per mile), mean volume, and median posted speed with the AADT volume-defined sections to show how these variables were distributed across the route. We compared mean volume and median posted speed with event density to show the relationship between the accident rate and these two road geometric variables.

For each of the routes, we created the following graphs:

1. Event density (number of collisions/section miles) vs. Section Number (Figs.3-2, 3-7, 3-12, 3-17). This shows the distribution of events as they occur across road segments,
2. Median posted speed (mph) vs. Section Number (Figs. 3-3, 3-8, 3-13, 3-18). This shows the distribution of the posted speed limits of collisions across a route.
3. Volume mean (AADT) vs. Section Number (Figs. 3-4, 3-9, 3-14, 3-19). This shows the distribution of mean traffic volumes across a route.
4. Event density and Median Posted Speed vs. Section Number (Figs. 3-5, 3-10, 3-15, 3-20). This shows how collisions are related to posted speeds

across a route.

5. Event density and Volume mean vs. Section Number (Figs 3-6, 3-11, 3-16, 3-21). This shows how collisions are related to traffic volumes across a route.

It is important to remember that the sections on the x-axis represent different lengths of road that were defined by the volume data. However, event density has been standardized so that the graphs accurately represent the collision pattern on the road.

Results

Literature Review

We reviewed 40 articles from the literature on animal-vehicle collisions for findings regarding correlations between wildlife-vehicle collisions and posted speed limit, vehicle speed and traffic volume (Tables 3-9 through 3-17).

Posted speed limit was addressed in 7 of 40 papers that reported on animal-vehicle collisions (17.5%). For posted speed limit, of the 30 authors who drew conclusions from data, four found a significant correlation, one no significant correlation, and 25 did not consider speed limit in their analysis (Table 3-9). Of the seven authors who used literature to make their assertions, one cited a correlation while six did not consider the impacts of posted speed limit (Table 3-10). Three authors used both data and literature; one reported no significant correlation while two did not consider posted speed in their analysis (Table 3-11). Overall, five cited a correlation (12.5%), two found no correlation (5%) and 33 did not address speed limit in their research (82.5%).

Vehicle speed was considered more often than posted speed by all three classes of authors (n=21, 52.5%). Using data, six authors found a significant correlation, two found no significant correlation, four cited that vehicle speed had an impact, but did not cite statistics to support this claim while 18 authors did not address the impacts of vehicle speed (Table 3-12). Assertions based on literature resulted in five correlations; one author in this category said that correlations vary depending on species and another did not consider vehicle speed in his analysis (Table 3-13). All three authors using both literature and data stated that a correlation exists (Table 3-14). In total, 18 found a correlation between vehicle speed and wildlife-vehicle collisions (45%), two found no correlation (5%), one argued that correlations vary (2.5%) and 19 did not consider vehicle speed (47.5%).

Traffic volume was considered more often than posted speed limit or vehicle speed with 31 authors making a conclusion regarding this variable (n=30, 77.5%). Correlation results for traffic volume reported by authors based on data were as follows: nine found a significant correlation, four found no significant correlation, two found a negative correlation, five stated that traffic volume did have an impact, but did not cite statistics and one cited changing traffic volume as a source of bias in his study. Nine of these authors did not address traffic volume in their research (Table 3-15). Six authors who made assertions from literature stated that traffic volume has an impact, while 1 author cited that no conclusions could be drawn because the effects of traffic volume are ambiguous (Table 3-16). Two authors who used data and literature reported that traffic volume has an impact, while 1 author found a negative correlation between traffic volume and wildlife collisions due to population fluctuations and road type (Table 3-17). In summary, 22 reported a correlation (55%), four found no correlation (10%), three found a negative correlation (7.5%), and nine authors did not include traffic volume in their analysis of explanatory variables (22.5%). Two authors did not fall into these categories because one claimed the relationship is too ambiguous (2.5%) and another cited traffic volume as a source of bias (2.5%).

Individual Route Analysis

Route 40. Route 40 is 175.138 miles in length running from Route 80 at Silver Creek Junction south through Heber City then east through Duchesne, Vernal, and Jensen to the Utah-Colorado state line.

From 1992 to 2002 there were a total of 1858 deer-vehicle collisions, resulting in an overall 10.61 accidents per mile on this route. With 10.61 accidents per mile, Route 40 ranked as the most dangerous long route (50 miles or more) of those analyzed in Utah.

There were 36 volume-defined sections on this route; 35 were used in this analysis. One (section 31) lacked event data and median posted speed limit. The event density on this route ranged from 0.63 collisions per section miles at Section 30 to 46.98 at Section 4 (Table 3-5, Fig. 3-2). Median posted speed limit values ranged from 45 mph at section 28 to 75 mph at section 8; 24 of the 35 records (68.6 %) with data had median posted speed limits of 55 mph (Fig. 3-3). The section with the highest speed had the second lowest event density (1.08) of any section on the route. The mean traffic volume (AADT) ranged from 1,478.27 at section 36 to 24, 938.55 at section 30 and 31 (Fig. 3-4). Section 30 has the lowest event density (0.63) recorded on this route while section 31 has no reported wildlife-vehicle collisions. The patterns on this route do not show that event density has a strong correlation to median posted speed limit (R^2=0.1053, Adj. R^2= 0.0494) or mean traffic volume (R^2=0.1053, Adj. R^2= 0.0494) (Figs. 3-5, 3-6). The correlation values are the same for posted speed and traffic volume because we used the same model and did a multiple regression to determine the nature of the relationship between both of these variables and event density.

Route 89. Route 89 is 417.759 miles in length running from the Utah-Arizona state line northwest of Page, Arizona, westerly to Kanab; then northerly to a junction with Route 70 near Sevier Junction; then beginning again at the junction with Route 70 south of Salina, northerly through Salina, Gunnison and Mt. Pleasant to a junction with Route 6 at Thistle Junction; beginning again at junction with Route 6 at Moark Junction northerly through Springville, Provo, Orem, and American Fork to Route 15 north of Lehi; then beginning again at a junction with Route 15 near Draper Crossroads northerly via Murray and Salt Lake City to a junction with Route 15 at Beck Interchange; then beginning again at a junction with Route 15 near Orchard Drive northerly through Bountiful to a junction with Route 15 at North Bountiful Interchange; then beginning again at a junction with Route 15 at Lagoon Junction northerly through Uintah Junction and Ogden to Route 91 near south city limits of Brigham City; then beginning again at a junction with Route 81 in Logan northeasterly to Garden City; then north to the Utah-Idaho state line.

From 1992 to 2002, there were a total of 3360 deer-vehicle collisions, resulting in an overall 8.04 accidents per mile on this route. With 8.04 accidents per mile, Route 89 ranked as the most dangerous long route (50 miles or more) of those analyzed in Utah.

There were 182 volume-defined sections on this route; 131 were used in this analysis because 51 sections lacked data for events and median posted speed limit. The event density on this route ranged from 0.20 collisions per section miles at Section 1 to 94.87 at Section 61 (Table 3-6, Fig. 3-7). Median posted speed limit values ranged from 40 mph at section 85 and 118 to 67.5 mph at section 148; 98 of the 131 records (74.80%) with data had median posted speed limits of 55 mph (Fig.3-8). The section with the highest speed had a low event density (3.09). The mean traffic volume (AADT) ranged from 1,184.09 at section 21 and 22 to 52,154.55 at section 72 and 73 (Fig. 3-9). Section 72 has one of the lowest event densities on the route (1.09) while section 73 has no reported wildlife-vehicle collisions. The patterns on this route show a weak or nonexistent relationship between event density and median posted speed limit (R^2=0.0381, Adj. R^2= 0.0231) or mean traffic volume (R^2=0.0381, Adj. R^2= 0.0231) (Figs. 3-10, 3-11). The correlation values are the same for posted speed and traffic volume because we used the same model and did a multiple regression to determine the nature of the relationship between both of these variables and event density.

Route 91. Route 91 is 45.591 miles in length beginning at Route 15 south of Brigham City and running east through Brigham Canyon and Logan to the Utah-Idaho state line near Franklin, Idaho.

Over these 11 years there were a total of 584 deer-vehicle collisions, resulting in an overall 12.81 accidents per mile on this route. With 12.81 accidents per mile, Route 91 ranked as the most dangerous short route (less than 50 miles) of those analyzed in Utah.

There were 34 volume-defined sections on this route; 29 were used in this analysis because 5 sections lacked data for events and median posted speed limit. The event density on this route ranged from 0.70 collisions per section miles at Section 19 to 33.33 at Section 10 (Table 3-7, Fig.3-12). Median posted speed limit values ranged from 52.5 mph at section 3 to 65 mph at section 19 and 34; 26 of the 29 records with data had median posted speed limits of 55 mph. Section 19, with the highest median posted speed limit had the lowest event density (0.70) while section 34 had a low event density of 3.76 (Fig. 3-13). The mean traffic volume (AADT) ranged from 5,670.18 at section 21, 33, 34 to 33,209.55 at section 18 (Fig. 3-14). The largest mean traffic volume recorded for this route corresponds with a section that has no reported wildlife-vehicle collisions. The patterns on this route do not show that event density has a strong correlation to median posted speed limit (R^2=0.0851, Adj. R^2= 0.0148) or mean traffic volume (R^2=0.0851, Adj. R^2= 0.0148) (Figs. 3-15, 3-16). The correlation values are the same for posted speed and traffic volume because we used the same model and did a multiple regression to determine the nature of the relationship between both of these variables and event density.

*Route 189. R*oute 189 is 29.216 miles in length beginning from Route 15 south of Provo and running north on University Avenue and Provo Canyon to Route 40 south of Heber City.

From 1992 to 2002, there were a total of 396 deer-vehicle collisions, resulting in an overall 13.55 accidents per mile on this route. With 13.55 accidents per mile, Route 189 ranked fifth in accidents per mile among the short routes (less than 50 miles) analyzed in Utah.

There were 25 volume-defined sections on this route; 19 were used in this analysis because six sections lacked data for events and median posted speed limit. The event density on this route ranged from 1.27 collisions per section miles at section 10 to 37.78 at section 12 (Table 3-8, Fig. 3-17). Median posted speed limit values ranged from 47.5 mph at section 4 and 14 to 65 mph at section 16; 16 of the 19 records (84.21%) with data had median posted speed limits of 55 mph (Fig. 3-18). The mean traffic volume (AADT) ranged from 6,245.72 at section 24 to 45,137.36 at section 4 (Fig.3-19). The patterns on this route do not show that event density is strongly correlated with median posted speed limit (R^2=0.0777, Adj. R^2= -0.0376) or mean traffic volume (R^2=0.0777, Adj. R^2= -0.0376) (Figs. 3-20, 3-21). The correlation values are the same for posted speed and traffic volume because we used the same model and did a multiple regression to determine the nature of the relationship between both of these variables and event density.

Discussion

Although the trends in the literature vary, within a database of over 24,000 records, ceteris paribus, one might expect to see definite patterns in terms of the factors impacting road mortality hotspots, i.e., between traffic volume and/or posted speed limit and wildlife-vehicle collisions. As the values of these road variables increase, the expectation is that the number of wildlife-vehicle events should also increase. However, the results from our analysis did not support these expectations. Instead, our results showed no relationship between traffic volume and/or posted speed limit and the number of wildlife-vehicle collisions that occurred.

At least five possibilities for these results present themselves. First, it is possible that there is no causal relationship between posted speed limit and/or traffic volume and wildlife-vehicle collisions. Second, it is possible that the nature of the data, i.e., how the data is collected and the quality of it, may preclude any meaningful analysis, thereby obscuring the relationship. Third, variations within scale extent and resolution of the data may confound the relationship. Fourth, it is also possible that a relationship may exist, but speed and volume by themselves explain such a small part of the variance of the relationship involved in wildlife-vehicle collisions that the relationship is not apparent in our analysis. Fifth, some combination of reasons 2, 3 and 4 may exist. The following discussion explores these alternative hypotheses.

Lack of a Causal Relationship?

It is unlikely that the potential causal explanations we discuss are independent of one another. Indeed this is our point 5. If there is no causal relationship between posted speed and traffic volume, as our results seem to show, then little more need be said. However, in order to determine this conclusively, it is necessary to explore issues related to problems with the data. If the data are accurate, and collected in a manner that allows comparison, and the result is no relationship, then the conclusion of no effect may be warranted. Additionally, selection of these two variables (speed and traffic volume) as explanatory may be problematic and give poor results if other variables account for some of the variance. As we discuss below, if a relationship is present, it is confounded by data problems and the selection of variables.

Data Problems

We perceive two different problems with these types of data. The first involves the very nature of the data, including how it is assigned and collected, while the second involves data quality. We discuss how these two problems are manifested in our data.

Problems with the nature of data may arise from the way data is assigned or collected. Such problems do not suggest that the data is poor. Rather, such difficulties may arise because data that was collected for one purpose (viz., record-keeping) is being used for another (viz., analysis of wildlife-vehicle collisions.

The nature of how posted speed is assigned to road segments may be inimical to its use in analyzing its relationship to animal-vehicle collisions. For example, posted speed limits may change within a mile segment and on the same segments of road from year to year. This data issue is inherent in how roads are designed (curves, blind spots, straight stretches of road) and how they change over time (i.e., construction, other development), making it difficult to use posted speed limit data to describe causal relationships within a hotspot or to make predictions regarding wildlife-vehicle collisions. Because drivers may not observe the posted speed limit, it may not be a reliable surrogate for actual vehicle speed; actual vehicle speed may impact wildlife-vehicle collisions more than posted speed limit. Perhaps actual vehicle speed would be a better explanatory variable. For each collision that we analyzed, there was an estimated vehicle speed. However, we did not use these data because it varied greatly, calling into question collection methods and reliability. Using radar detectors to record vehicle speed would provide more accurate data (Gunther et al. 1998).

Vehicle volume data likewise is collected in a manner so as to preclude its use to evaluate its effect on animal vehicle collisions. For example UDOT uses sensors to collect traffic volume data on specific sections of road for 48 hours each year; from this value estimates are made based on certain road characteristics to determine an annual average daily traffic flow (AADT). However, traffic volume is continually changing, thus to draw conclusions regarding its impact we need data that can reflect these temporal changes and their effect on wildlife-vehicle collisions. Allen and McCullough (1976) explored how changes in traffic volume due to time of day, day of the week and season affected the number of collisions. They found that traffic volume was an important explanatory variable because deer-vehicle collision patterns shifted based on hour, day and season.

Spatially, different locations along a road will have varying traffic volumes. The sensors that UDOT uses to collect data are placed at locations along a route based on road design. Sections are defined by parameters that affect the road design, i.e., number of lanes or intersection with other state or federal routes. Thus, volume data does not reflect changes in the adjacent landscape, does not correspond to mile markers, and does not correspond to a specific wildlife-vehicle collision. This variation in volume segment length measurement makes it difficult to use this data in a comparison with our hotspot data. We argue that to explain wildlife-vehicle collisions and draw conclusions about causality, traffic volume data at a finer temporal and spatial resolution would be most appropriate.

Data quality issues call into question the accuracy and reliability of recorded values. The posted speed limit value set includes missing values, inaccurate zero values (i.e., posted speed limit=0 mph) and records with more than one value for one field (i.e. 2 different mile markers for one accident). Possible explanations for such inconsistencies include: errors made in recording data at the collision site, errors in entering the data into the database, variation in the road (i.e., curves and construction) leading to changes in posted speed limit within a mile or from year to year, and a lack of data quality checks. We fixed as many of these issues as possible by returning to the original database and cross checking collision records. The vehicle volume data set did not appear to have data quality issues, except for those stemming from data collection procedures (see Nature of Data).

Scaling Issues

Problems with the nature of the data also become evident when we consider the scale at which data is collected and recorded. The database provides road variables in relation to a single collision, but we are attempting to describe a 'hotspot,' or a group of collisions spanning 1 mile or multiple consecutive miles. If the variable of interest (i.e., posted speed limit, traffic volume, road alignment, adjacent vegetative cover, etc.) changes within the distance of the hotspot, then determining which variable value to use becomes problematic. In our analysis, we used three variables, each recorded at different spatial and temporal scales: (1) collisions are recorded to the nearest milepost, hour and minute; (2) posted speed limit is recorded at the level of each collision and may vary within a hotspot, and (3) traffic volume (AADT) is recorded for segments of road of varying lengths and may also vary within a hotspot. Thus, we argue that variation in scale resolution and extent of these variables is great enough that they may not be informative in describing hotspots. Inbar and Mayer (1999) have argued that ambiguous results regarding correlations between traffic volume and wildlife-vehicle collisions may exist because of the scale of traffic-volume data. They state that the traffic volume that animals actually encounter on the landscape may differ from that represented by traffic volume data recorded annually or monthly. Attempts to predict a pattern based on posted speed and volume is difficult because data used to do so is often recorded at differing spatial scales.

Given the recent emphasis on the importance of spatial explicitness, the problem of varying scales might be solved if wildlife-vehicle crash data was recorded at a finer scale than to the specific mile marker, the level of accuracy normally available in crash databases. Mansfield and Miller (1975) suggested that they found poor correlations because the speed and traffic volume data available to them was "not precise enough to be applicable on an explicit (.01 mile) locational scale."

We argue that acceptably accurate predictions could be made if data was recorded in a more spatially explicit manner. Ideally, each collision would be a point that had data regarding the posted speed limit, the traffic volume and other explanatory variables recorded at that same point. This could be achieved if exact collision locations and explanatory variable data were recorded by GPS location and if data was recorded accurately and to appropriate resolutions. Additionally, consideration of collisions at both the landscape level and the local scale may help to make models with more predictive power (Malo et al. 2004). Malo et al. (2004) created a model to analyze collisions by road section and by crash point, allowing for the implementation of both broad-scale and specific mitigation measures. To attain this level of data accuracy will be expensive and time consuming but may be justified for specific purposes (see below).

Are Road Geometrics Sufficient? The Role of Animal Exposure

Posted speed limit and traffic volume may explain only a small part of the variance of the relationship involved in wildlife-vehicle collisions. A model that completely represents relationships between explanatory variables and wildlife-vehicle collisions will consider a range of road and environmental variables. In addition to posted speed limit and traffic volume, other road variables have been evaluated for causality in wildlife road mortality. Romin (1994) found that areas with different road alignments (i.e., straight, hilly, and curved) had no significant impact on collision numbers. However, Romin (1994) suggested that other aspects of highways, including number of lanes and passing opportunities may have contributed to higher road kill levels. Arnold (1978) analyzed the types of roads where accidents occurred in Michigan and found that the most hazardous roads were local roads, accounting for 51.8% of the accidents; 7% occurred on interstates, and 28% on two-lane state highways.

In addition to the road itself, the composition and configuration of the landscape adjacent to a road certainly is expected to have an impact on the number of wildlife-vehicle collisions that occur. Studies show that the proximity of habitat cover and wildlife movement corridors to the road side greatly influence road-kill rates (Forman et al. 2003). This is because the surrounding landscape has an impact on movement patterns of species in relation to roads. When considered in the framework of animal behavior, topographic and vegetative features in proximity to a road may influence habitat use and movement patterns, hence animal exposure, contributing to wildlife mortality.

Landscape spatial pattern plays a role in shaping the behavior of animals because landscape configuration affects how animals use land adjacent to roads. For example, researchers claim that deer found between wooded areas in open landscapes, between fields in forested landscapes and in conservation areas in the suburbs are more prone to being hit by a vehicle (Romin and Bissonette 1996; Forman and Alexander 1998; Forman and Deblinger 1998). A large number of studies on white-tailed deer populations in Pennsylvania suggested that foraging behaviors influence movements caused higher accidents rates in non-wooded areas (Romin and Bissonette 1996). From a study on mule deer in Northeastern Utah, Romin & Bissonette (1996) reported that areas with higher percentages of vegetative cover had higher kills. In contrast, roads bordered by agricultural fields had less kills because fields provided foraging opportunities that drew deer away from roads.

Finder et al. (1999) included 15 variables in an examination of characteristics associated with high collision areas. They found that the distance to forest cover was the most important predictor of high deer-vehicle collision sites; the greater this distance, the less probability that a road segment would be a high deer collision site. They also found that adjacent gullies, riparian corridors, public recreational areas and road bends may increase the probability of deer-vehicle collisions.

Topography may also affect deer movement patterns and foraging behavior because of the limits it places on species and their ability to access areas, as well as the impacts that it has on available food sources (Bellis and Graves 1971). Topography can create drainages or slopes that funnel animals closer to the road, putting them at more risk for vehicle collisions. A complete predictive model will consider a full complement of environmental and road variables, including landscape spatial pattern.

By considering how these variables impact animal exposure, or the proximity of animals to the road, it is clear that the causes of wildlife-vehicle collisions may be more fully understood. A more complete picture of causal relationships in wildlife-vehicle collisions includes a consideration of how these factors affect animal and driver behavior.

Trombulak and Frissell (2000) stated that roads modify animal behavior as reflected in home range shifts, altered movement patterns, altered reproductive success, altered escape response, and altered physiological state. The data that we analyzed was not species specific and included all reported collisions between a motor-vehicle and a wild animal. Due to the constraints of the data (see Data

Description) most collisions in our data set involved large ungulates (deer, elk, moose). However, certain species are more vulnerable to road mortality depending on their life history characteristics and behavior. For example, those animals with high intrinsic mobility, those that are habitat generalists and/or those who must cross roads to migrate are most susceptible to road mortality (Forman et al. 2003). Behavior and habitat use patterns are different within and among wildlife species, implying the need for predictive models, and mitigation and management strategies that are specific to species, to the site, and take into account what is known about animal behavior. For example, Inbar and Mayer (1999) cited a high correlation between traffic volume and armadillo (*Daspyus novemcinctus*) kills on roads in Florida, while Rolley and Lehman (1992) argued that vehicle speed is a major cause of mortality for raccoons (*Procyon lotor*) in Indiana. Groot Bruinderink and Hazebroek (1996) pointed out the differences in behavior between ungulate species: red and roe deer tended to flee while fallow deer stood and waited in response to traffic. Because behavioral and habitat patterns differ, Romin and Bissonette (1996) suggested that the success of mitigation strategies may, in large part, be specific to the site and species. A model attempting to describe and predict factors contributing to areas of high road mortality would be most complete if it included a consideration of species-specific behavior in relation to various site-specific road and environmental variables.

Consideration of animal exposure and availability information is critical to the creation of a reliable and accurate predictive model. Wildlife population density and fluctuations impact collision patterns; a consideration of these factors may aid in describing and predicting areas of high wildlife-vehicle collisions (Rolley and

Lehman 1992; Groot Bruinderink and Hazebroek 1996; Gunson and Clevenger 2003). Hughes et al. (1996) reported that the results of their animal crash rate analysis were constrained because relative locations and densities of animal populations were not included. If we do not consider local population information, we are making an inherently incorrect assumption: that species availability is constant across the landscape.

Driver behavior may also be used to describe wildlife-vehicle mortality. The way that drivers react to environmental and road variables and to animal behavior can affect the number of wildlife-vehicle collisions that occur; the interaction between drivers and these variables is needed to create a complete predictive model. Hartwig (1993) found that 60 % of collisions are caused by improper driver reaction. The presence of woods or gullies adjacent to the road was highly correlated with a high probability of deer-vehicle collisions, implying that this reduced visibility may have obstructed visibility for drivers and contributed to their inability to prevent a collision (Finder et al. 1999). Joyce and Mahoney (2001) stated that "human perception experience" may contribute to wildlife-vehicle collisions. Factors including fatigue, glare, and driver ability to distinguish similarly colored objects and estimate distance may all influence the frequency of collisions. Joyce and Mahoney (2001) stipulated that the type of driver may also have an impact. They attributed a summer peak in moose-vehicle collisions to a combination of moose reproductive and behavioral patterns and an increased number of naïve drivers who are traveling on unfamiliar roads. They suggested that these types of drivers may be more easily distracted.

Mitigation measures can effectively address issues of motorist behavior. Forman et al. (2003) suggested improving the field-of-view so that drivers can see animals on the road side, managing traffic on roads during times when the risk for collisions may be highest (i.e., migration or dispersal), and implementing techniques to directly change motorist behavior (i.e., signs, education, sensory roadside lights).

Conservation Implications

Data on wildlife-vehicle collisions can be used for at least two different purposes: (1) hotspot analysis; and (2) predictive modeling. We illustrate the issues associated with creating models to explain wildlife-vehicle collisions using only road geometrics. We suggest that if the objective is to *define hotspots of road kill for mitigation action,* hotspot analyses that use existing data accurate to the mile marker produce excellent results and can be done for most state, province, or other municipalities who have such data immediately. Use of this analysis to prioritize mitigation measures will have quick beneficial effects on restoring landscape permeability. However, we argue that developing a reliable and accurate *predictive model* of animal-vehicle crashes using explanatory environmental and/or roadway variables requires that: (1) road kill data is spatially explicit, (2) data regarding explanatory variables and road kill are recorded at appropriate scale resolutions and extents, (3) data is recorded accurately and completely, (4) the model consider road geometrics and environmental variables, and (5) the model considers both driver behavior and animal behavior.

We argue that consideration of these factors in correlation with spatially explicit wildlife-vehicle collision data will allow for the development of a model with predictive possibilities. Research informs the decisions made by state wildlife and highway agencies, thus this research may be more useful if data collection and analysis fulfills these requirements. Understanding the patterns and processes that lead to wildlife-vehicle collisions will allow us to develop practical preventative mitigation strategies.

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Table 3-1. Route 40 Hotspots (1992-2002)

Location of Hotspot[a]	Total Hotspot Mileage	Collisions within Hotspot	Hotspot Collisions/Mile	Hotspot Collisions/Mile/ Year
001-13	13	363	27.92	2.54
85	1	22	22.00	2.00
88-89	2	38	19.00	1.73
122-123	2	38	19.00	1.73
96-106	11	207	18.82	1.71
74-81	8	145	18.13	1.65
28	1	18	18.00	1.64
33-36	4	71	17.75	1.61
50-68	19	288	15.16	1.38
43	1	15	15.00	1.36
22	1	14	14.00	1.27
45	1	14	14.00	1.27
92	1	14	14.00	1.27
146-148	3	39	13.00	1.18
112	1	13	13.00	1.18
48	1	12	12.00	1.09
109-110	2	23	11.50	1.05
38	1	11	11.00	1.00
153	1	11	11.00	1.00

[a] Beginning milepost to ending milepost.

Table 3-2. Route 89 Hotspots (1992-2002)

Location of Hotspot[a]	Total Hotspot Mileage	Collisions within Hotspot	Hotspot Collisions/Mile	Hotspot Collisions/Mile/Year
336-348	13	453	34.85	3.17
231-236	6	205	34.17	3.11
362-373	12	356	29.67	2.70
283-288	6	166	27.67	2.52
216-218	3	83	27.67	2.52
38-42	4	93	23.25	2.11
102-107	6	118	19.67	1.79
394-396	3	51	17.00	1.55
109-114	6	81	13.50	1.23
79-84	6	80	13.33	1.21
127-128	2	26	13.00	1.18
69-70	2	24	12.00	1.09
245-247	3	34	11.33	1.03
118	1	22	22.00	2.00
155	1	14	14.00	1.27
180	1	14	14.00	1.27
222	1	14	14.00	1.27
263	1	14	14.00	1.27
375	1	14	14.00	1.27
334	1	14	14.00	1.27
122	1	14	14.00	1.27
94	1	13	13.00	1.18
176	1	13	13.00	1.18
212	1	13	13.00	1.18
253	1	13	13.00	1.18
102	1	12	12.00	1.09
190	1	12	12.00	1.09
226	1	12	12.00	1.09
238	1	12	12.00	1.09
266	1	12	12.00	1.09
57	1	11	11.00	1.00
88	1	11	11.00	1.00
90	1	11	11.00	1.00
255	1	11	11.00	1.00
259	1	11	11.00	1.00

[a] Beginning milepost to ending milepost

Table 3-3. Route 91 Hotspots (1992-2002)

Location of Hotspot[a]	Total Hotspot Mileage	Collisions within Hotspot	Hotspot Collisions/Mile	Hotspot Collisions/Mile/Yr
37	1	33	33.00	3.00
3-10	8	236	29.50	2.68
25	1	27	27.00	2.45
41-42	2	46	23.00	2.09
14-16	3	62	20.67	1.88
12	1	12	12.00	1.09
35	1	12	12.00	1.09
19	1	11	11.00	1.00

[a] Beginning milepost to ending milepost

Table 3-4. Route 189 Hotspots (1992-2002)

Location of Hotspot[a]	Total Hotspot Mileage	Collisions within Hotspot	Hotspot Collisions/Mile	Hotspot Collisions/Mile/ Year
16-25	10	232	23.20	2.11
5-6	2	41	20.50	1.86
8-9	2	25	12.50	1.14
11	1	12	12.00	1.09

[a] Beginning milepost to ending milepost

Table 3-5. Route 40 (Summit, Wasatch, Duchesne and Uintah Counties) wildlife-vehicle mortality data, 1992-2002. Section numbers were assigned based on how traffic volume data is recorded by the Utah Department of Transportation.

Section Number	Mileposts (begin-end)	Section Length (miles)	Event Count (total #)	Median Posted Speed Limit (mph)	Mean Volume (AADT)	Event Density (collisions/mi)
1	0 - 1.24	1.24	12	57.5	17183.45	9.68
2	1.24 - 3.96	2.72	42	55	16755.18	15.44
3	3.96 - 6.04	2.08	37	55	12392.27	17.79
4	6.04 - 8.19	2.15	101	55	12392.27	46.98
5	8.19 - 13.21	5.02	170	55	12273.82	33.86
6	13.21 - 16.38	3.17	29	65	10171.45	9.15
7	16.38 - 17.01	0.63	1	65	18409.00	1.59
8	17.01 - 17.94	0.93	1	75	18409.00	1.08
9	17.94 - 20.51	2.57	12	55	7206.82	4.67
10	20.51 - 33.2	12.69	111	55	4160.00	8.75
11	33.2 - 40.28	7.08	101	55	4160.00	14.27
12	40.28 - 58.67	18.39	240	55	3028.45	13.05
13	58.67 - 68.25	9.58	127	55	3323.45	13.26
14	68.25 - 85.92	17.67	221	55	3383.82	12.51
15	85.92 - 86.57	0.65	5	57.5	3008.18	7.69
16	86.57 - 87.23	0.66	6	60	3710.27	9.09
17	87.23 - 96.63	9.4	103	55	3262.82	10.96
18	96.63 - 105.00	8.37	165	55	3621.55	19.71
19	105.00 - 105.46	0.46	8	55	3944.00	17.39
20	105.46 - 109.59	4.13	42	55	4586.09	10.17
21	109.59 - 111.39	1.8	19	55	6985.00	10.56
22	111.39 - 114.62	3.23	23	65	7124.55	7.12
23	114.62 - 115.24	0.62	1	65	8489.55	1.61
24	115.24 - 118.43	3.19	16	55	5682.45	5.02
25	118.43 - 121.44	3.01	16	55	5682.45	5.32
26	121.44 - 130.48	9.04	73	55	2930.91	8.08
27	130.48 - 141.39	10.91	28	62.5	4017.27	2.57
28	141.39 - 141.47	0.08	1	45	4017.27	12.50

29	141.47 - 144.31	2.84	7	55	24017.55	2.46
30	144.31 - 145.89	1.58	1	55	24938.55	0.63
31	145.89 - 145.98	0.09			24938.55	
32	145.98 - 148.28	2.3	30	65	9723.45	13.04
33	148.28 - 148.52	0.24	1	65	5092.55	4.17
34	148.52 - 157.18	8.66	66	55	5037.18	7.62
35	157.18 - 168.79	11.61	24	55	1609.73	2.07
36	168.79 - 174.78	5.99	19	55	1478.27	3.17

Table 3-6. Route 89 (spanning 12 counties from Kane to Rich) wildlife-vehicle mortality data, 1992-2002. Section numbers were assigned based on how traffic volume data is recorded by the Utah Department of Transportation.

Section Number	Mileposts (begin-end)	Section Length (miles)	Event Count (total number)	Median Posted Speed Limit (mph)	Mean Volume (AADT)	Event Density (collisions/section mi)
1	0 - 5.03	5.03	1		1909.27	0.20
2	5.03 - 8.87	3.84			1894.55	
3	8.87 - 54.93	46.06	214	55	1894.55	4.65
4	54.93 - 61.59	6.66	32	55	2175.91	4.80
5	61.59 - 64.18	2.59	11	55	4648.36	4.25
6	64.18 - 65.40	1.22	5	60	6383.18	4.10
7	65.40 - 81.62	16.22	130	55	2823.64	8.01
8	81.62 - 85.25	3.63	38	55	1936.36	10.47
9	85.25 - 86.99	1.74	10	55	2390.45	5.75
10	86.99 - 89.71	2.72	22	55	2117.27	8.09
11	89.71 - 90.51	0.8	6	55	2103.45	7.50
12	90.51 - 104.20	13.69	134	55	1329.55	9.79
13	104.20 - 108.32	4.12	73	55	1395.45	17.72
14	108.32 - 116.36	8.04	94	55	1387.27	11.69
15	116.36 - 117.01	0.65	2	50	2111.36	3.08
16	117.01 - 124.85	7.84	75	55	2087.36	9.57
17	124.85 - 131.17	6.32	50	55	2752.45	7.91
18	131.17 - 131.74	0.57	2	65	5476.82	3.51
19	131.74 - 132.63	0.89	11	55	6835.45	12.36
20	132.63 - 141.81	9.18	33	55	2227.36	3.59
21	141.81 - 156.98	15.17	88	55	1184.09	5.80
22	156.98 - 160.81	3.83	19	60	1184.09	4.96
23	160.81 - 163.17	2.36	5	55	1829.55	2.12
24	163.17 - 165.81	2.64	1	55	1829.55	0.38
25	165.81 - 167.85	2.04	4	55	1829.55	1.96
26	167.85 - 179.07	11.22	72	55	1254.09	6.42
27	179.07 - 181.38	2.31	25	55	1542.82	10.82
28	181.38 - 185.58	4.2	26	55	1393.18	6.19

29	185.58 - 193.31	7.73	51	55	1393.18	6.60
30	193.32 - 194.78	1.46	4	55	4930.91	2.74
31	194.78 - 195.08	0.3	2	50	6423.73	6.67
32	195.08 - 195.74	0.66	3	55	8142.73	4.55
33	195.74 - 200.67	4.93	23	55	7367.64	4.67
34	200.67 - 206.49	5.82	5	55	6741.36	0.86
35	206.49 - 207.86	1.37	2	65	6994.09	1.46
36	207.86 - 209.50	1.64			8307.82	
37	209.50 - 211.09	1.59	7	55	2977.18	4.40
38	211.09 - 215.90	4.81	44	55	2945.91	9.15
39	215.90 - 217.31	1.41	15	55	2945.91	10.64
40	217.31 - 217.90	0.59	32	55	3163.64	54.24
41	217.90 - 222.92	5.02	63	55	3538.73	12.55
42	222.92 - 224.67	1.75	16	55	7643.18	9.14
43	224.67 - 230.24	5.57	40	55	5030.45	7.18
44	230.24 - 231.74	1.5	26	65	6538.64	17.33
45	231.74 - 235.53	3.79	158	55	5424.09	41.69
46	235.53 - 244.92	9.39	84	55	2410.00	8.95
47	244.92 - 246.11	1.19	15	55	3893.91	12.61
48	246.11 - 246.63	0.52	6	55	4837.73	11.54
49	246.63 - 251.47	4.84	31	62.5	3554.09	6.40
50	251.47 - 252.26	0.79	8	55	4646.36	10.13
51	252.26 - 252.69	0.43	5	55	2952.27	11.63
52	252.69 - 265.38	12.69	111	55	2146.82	8.75
53	265.38 - 281.20	15.82	121	55	2146.82	7.65
54	281.20 - 282.74	1.54	1		4009.82	0.65
55	282.74 - 283.62	0.88	9	55	5288.73	10.23
56	283.62 - 284.62	1	34	55	5938.73	34.00
57	284.62 - 285.68	1.06	26	55	8600.45	24.53
58	285.68 - 286.62	0.94	11	55	8852.45	11.70
59	286.62 - 286.93	0.31	6	55	16198.64	19.35
60	286.93 - 287.31	0.38	20	55	17404.55	52.63

61	287.31 - 287.70	0.39	37	55	21361.82	94.87
62	287.70 - 288.62	0.92	22	60	22372.64	23.91
63	288.62 - 289.05	0.43	4	55	18358.09	9.30
64	289.05 - 290.75	1.7	7	55	17444.91	4.12
65	290.75 - 291.87	1.12	2	60	17444.91	1.79
66	291.87 - 292.23	0.36	1	65	17444.91	2.78
67	292.23 - 292.88	0.65			19437.27	
68	292.88 - 293.34	0.46	1	55	24073.91	2.17
69	293.34 - 293.61	0.27			24073.91	
70	293.61 - 294.33	0.72			32986.55	
71	294.33 - 294.77	0.44			39718.64	
72	294.77 - 295.69	0.92	1	65	52154.55	1.09
73	295.69 - 296.61	0.92			52154.55	
74	296.61 - 297.26	0.65			47909.27	
75	297.26 - 298.33	1.07	2	50	51297.82	1.87
76	298.33 - 299.39	1.06			48822.55	
77	299.39 - 300.45	1.06	4	55	41272.27	3.77
78	300.45 - 301.02	0.57	2	55	28227.82	3.51
79	301.02 - 302.33	1.31	3	55	27148.18	2.29
80	302.33 - 303.28	0.95	1	65	26082.45	1.05
81	303.28 - 305.04	1.76	1	45	18436.27	0.57
82	305.04 - 305.93	0.89			25087.27	
83	305.93 - 306.16	0.23			32993.09	
84	306.16 - 306.54	0.38			32993.09	
85	306.54 - 307.32	0.78	1	40	23483.64	1.28
86	307.32 - 308.4	1.08	1	55	12444.45	0.93
87	308.4 - 308.59	0.19	3	45	15108.18	15.79
88	308.59 - 309.14	0.55	1	55	15401.00	1.82
89	309.14 - 310.49	1.35	5	55	9699.91	3.70
90	310.49 - 311.27	0.78	1		9699.91	1.28
91	311.27 - 311.49	0.22			7820.00	
92	311.49 - 312.05	0.56			19769.00	

93	312.05 - 313.05	1	6	55	24234.27	6.00
94	313.05 - 314.54	1.49			28598.09	
95	314.54 - 315.06	0.52			24378.82	
96	315.06 - 315.53	0.47			26625.09	
97	315.53 - 315.93	0.4			28860.55	
98	315.93 - 316.54	0.61			25288.82	
99	316.54 - 316.92	0.38			36670.64	
100	316.92 - 317.31	0.39			36670.64	
101	317.31 - 317.81	0.5			33705.00	
102	317.81 - 318.07	0.26			35611.64	
103	318.07 - 318.84	0.77			36062.55	
104	318.84 - 319.74	0.9			34230.36	
105	319.74 - 320.31	0.57			34826.91	
106	320.31 - 320.49	0.18			34826.91	
107	320.49 - 321.00	0.51			35897.00	
108	321.00 - 321.14	0.14			33980.91	
109	321.14 - 321.87	0.73			33536.73	
110	321.87 - 322.75	0.88			32606.09	
111	322.75 - 323.63	0.88			35885.27	
112	323.63 - 324.02	0.39			40039.27	
113	324.02 - 324.51	0.49			43754.36	
114	324.51 - 325.07	0.56			32673.36	
115	325.07 - 325.62	0.55	2	60	32155.00	3.64
116	325.62 - 326.18	0.56	2	50	34183.45	3.57
117	326.18 - 326.93	0.75	1	55	33001.18	1.33
118	326.93 - 327.53	0.6	2	40	31038.73	3.33
119	327.53 - 327.68	0.15			29561.64	
120	327.68 - 328.27	0.59	3	55	26974.64	5.08
121	328.27 - 329.01	0.74	7	55	22104.55	9.46
122	329.01 - 329.88	0.87	2	60	25704.09	2.30
123	329.88 - 331.96	2.08	10	55	37137.27	4.81
124	331.97 - 332.12	0.15	2	57.5	31385.00	13.33

125	332.12 - 332.49	0.37	2	55	21323.09	5.41
126	332.49 - 333.52	1.03	8	55	15777.45	7.77
127	333.52 - 334.04	0.52	3	55	21231.64	5.77
128	334.04 - 334.45	0.41	10	55	34756.82	24.39
129	334.45 - 335.65	1.2	4	55	21500.00	3.33
130	335.65 - 336.33	0.68	11	60	27894.55	16.18
131	336.33 - 336.73	0.4	20	55	16932.55	50.00
132	336.74 - 337.07	0.33	6	52.5	35841.82	18.18
133	337.07 - 337.84	0.77	28	55	29877.55	36.36
134	337.84 - 338.66	0.82	36	55	29639.91	43.90
135	338.66 - 339.00	0.34	14	55	28972.27	41.18
136	339.00 - 340.03	1.03	45	55	28972.27	43.69
137	340.03 - 341.18	1.15	70	55	26605.27	60.87
138	341.18 - 342.04	0.86	43	55	28672.64	50.00
139	342.04 - 342.46	0.42	13	60	28672.64	30.95
140	342.46 - 344.26	1.8	63	55	27819.09	35.00
141	344.26 - 345.59	1.33	49	55	27819.09	36.84
142	345.59 - 345.91	0.32	13	65	39128.18	40.62
143	345.91 - 346.16	0.25	8	60	39128.18	32.00
144	346.16 - 347.67	1.51	31	55	37259.55	20.53
145	347.67 - 347.88	0.21	4	60	40785.00	19.05
146	347.88 - 347.93	0.05			41249.36	
147	347.93 - 348.68	0.75	11	55	41249.36	14.67
148	348.68 - 349.8	1.12	4	67.5	41249.36	3.57
149	349.8 - 349.95	0.15	1	65	19623.64	6.67
150	349.95 - 350.67	0.72	3	55	19623.64	4.17
151	350.67 - 353.58	2.91	4	55	24764.09	1.37
152	353.58 - 353.77	0.19			25734.09	
153	353.77 - 354.29	0.52			27794.55	
154	354.29 - 354.43	0.14			29902.45	
155	354.43 - 355.3	0.87			31518.91	
156	355.3 - 355.88	0.58			27509.00	

157	355.88 - 356.78	0.9			26876.36	
158	356.78 - 357.81	1.03			30085.00	
159	357.81 - 358.38	0.57			23169.09	
160	358.38 - 358.74	0.36			23169.09	
161	358.74 - 360.83	2.09			20822.27	
162	360.83 - 361.61	0.78	5	55	20822.27	6.41
163	361.61 - 363.79	2.18	28	55	11208.64	12.84
164	363.79 - 364.07	0.28	3	60	8449.18	10.71
165	364.07 - 364.55	0.48	6	55	8522.27	12.50
166	364.55 - 367.63	3.08	82	55	11064.09	26.62
167	367.63 - 370.01	2.38	43	55	10118.73	18.07
168	370.01 - 371.12	1.11	45	55	10118.73	40.54
169	371.12 - 372.05	0.93	69	55	11239.64	74.19
170	372.05 - 374.62	2.57	81	55	11140.00	31.52
171	374.62 - 374.75	0.13	1	65	11280.45	7.69
172	374.75 - 375.54	0.79	11	55	25366.36	13.92
173	375.54 - 377.62	2.08	22	55	18856.82	10.58
174	377.62 - 377.65	0.03			18856.82	
175	377.65 - 387.27	9.62	36	55	4692.73	3.74
176	387.27 - 396.5	9.23	61	55	2598.09	6.61
177	396.5 - 402.57	6.07	34	55	2310.00	5.60
178	402.57 - 407.61	5.04	14	55	1884.09	2.78
179	407.61 - 410.2	2.59	6	55	1884.09	2.32
180	410.2 - 414.64	4.44	17	55	1802.91	3.83
181	414.64 - 415.84	1.2	1	65	1939.09	0.83
182	415.84 - 418.71	2.87	5	55	1938.64	1.74

Table 3-7. Route 91 (Box Elder and Cache Counties) wildlife-vehicle mortality data, 1992-2002. Section numbers were assigned based on how traffic volume data is recorded by the Utah Department of Transportation.

Section Number	Mileposts (begin-end)	Section Length (miles)	Event Count (total #)	Median Posted Speed (mph)	Mean Volume (AADT)	Event Density (collisions/section mi)
1	0 - 0.48	0.48			15312.64	
2	0.48 - 1.35	0.87	2	55	15312.64	2.30
3	1.35 - 1.96	0.61	5	52.5	17290.00	8.20
4	1.96 - 3.82	1.86	17	55	12313.18	9.14
5	3.82 - 4.96	1.14	27	55	16200.91	23.68
6	4.96 - 5.63	0.67	12	55	16200.91	17.91
7	5.63 - 7.72	2.09	49	55	14611.00	23.44
8	7.75 - 10	2.25			13394.55	
9	10 - 16.59	6.59	219	55	13394.55	13.28
10	16.59 - 16.86	0.27	9	55	13394.55	33.33
11	16.86 - 19.13	2.27	13	55	13987.27	5.73
12	19.13 - 19.55	0.42	4	55	14350.36	9.52
13	19.55 - 21.34	1.79	12	55	14972.73	6.70
14	21.34 - 24.27	2.93	20	55	13932.18	6.83
15	24.27 - 25.6	1.33	23	55	14621.27	17.29
16	25.6 - 26.19	0.59	14	55	32137.82	23.73
17	26.19 - 26.83	0.64	4	55	29332.27	6.25
18	26.83 - 27.09	0.26			33209.55	
19	27.09 - 28.51	1.42	1	65	29087.36	0.70
20	28.51 - 29.78	1.27	1	55	26631.82	0.79
21	29.78 - 30.59	0.81			25834.36	
22	30.59 - 31.26	0.67	4	55	26026.82	5.97
23	31.26 - 31.81	0.55	1		26026.82	1.82
24	31.81 - 32.41	0.6	1	55	26181.36	1.67
25	32.41 - 33.98	1.57	7	55	22144.09	4.46
26	33.98 - 34.98	1	7	55	15023.36	7.00
27	34.98 - 35.5	0.52	7	55	10809.00	13.46
28	35.5 - 38.64	3.14	52	55	10727.27	16.56

29	38.64 - 39.96	1.32	8	55	10445.91	6.06
30	39.96 - 41.15	1.19	8	55	9835.91	6.72
31	41.15 - 43.24	2.09	46	55	8179.55	22.01
32	43.24 - 43.64	0.4	3	55	8179.55	7.50
33	43.64 - 43.89	0.25	1	55	5670.18	4.00
34	43.89 - 45.22	1.33	5	65	5670.18	3.76

Table 3-9. Correlation results for posted speed limit reported by authors based on data.

Author	Results [i]	Variables examined[ii]
Joyce and Mahoney (2001)	SC (w/ injury)	
Maine Interagency Work Group (2001)	SC (50-55mph)	
Gunther et al. (1998)	SC	RA impacts speed most
Cristoffer (1991)	SC	
Bashore et al. (1985)	NSC	
Rolley and Lehman (1992)	N/A	
Allen & McCullough (1976)	N/A	
Case (1978)	N/A	
Romin and Bissonette (1996)	N/A	VEG,TOPO,RA,DEER USE
Jahn (1959)	N/A	
Mansfield and Miller (1975)	N/A	
Puglisi et al. (1974)	N/A	VEG,TOPO,FENCES
Pojar et al. (1975)	N/A	
van Langevelde and Jaarsma (2004)	N/A	RW, Animal crossing speed
Arnold (1978)	N/A	
Bellis and Graves (1971)	N/A	VEG,TOPO,FENCES
Brody and Pelton (1989)	N/A	
Carbaugh et al. (1975)	N/A	
Clevenger et al. (2003)	N/A	TOPO,ALP
Elzohairy et al. (2004)	N/A	RT,LT,W,TEMP
Fahrig et al. (1995)	N/A	
Fahrig (2001)	N/A	
Feldhammer (1986)	N/A	TOPO,HAB,ROW,FENCES
Finder et al. (1999)	N/A	TOPO,RV
Hughes et al. (1996)	N/A	RT,TEMP
Inbar and Mayer (1999)	N/A	VEG,TOPO,TEMP
Nielsen et al. (2003)	N/A	FC,SDI, # of buildings
Rost and Bailey (1979)	N/A	
Schwabe et al. (2002)	N/A	
Seiler et al. (2004)	N/A	

Table 3-10. Correlation results for posted speed limit reported by authors based on literature.

Author	Results	Variables examined
Forman and Alexander (1998)	Y	RW
Cook and Daggett (1995)	N/A	
Danielson and Hubbard (1998)	N/A	
Forman et al. (2003)	N/A	
Groot Bruinderink and Hazebroek (1996)	N/A	
Putnam (1997)	N/A	
Trombulak and Frissell (2000)	N/A	

Table 3-11. Correlation results for posted speed limit reported by authors based on data and literature.

Author	Results
Gunson and Clevenger (2003)	NSC
Knapp and Yi (2003)	N/A
Staines et al (2001)	N/A

Table 3-12. Correlation results for vehicle speed reported by authors based on data.

Author	Findings
Joyce and Mahoney (2001)	SC (w/injury)
Rolley and Lehman (1992)	SC (PD can't be separated)
Gunther et al. (1998)	SC (more significant)
Allen & McCullough (1976)	SC (≤ 80-95 km/h (50-59 mph))
Case (1978)	SC
Romin and Bissonette (1996)	SC
Jahn (1959)	NSC
Mansfield and Miller (1975)	NSC
Puglisi et al. (1974)	Y (cited)
Maine Interagency Work Group (2001)	Y
Pojar et al. (1975)	Y
van Langevelde and Jaarsma (2004)	Y
Arnold (1978)	N/A
Bashore et al. (1985)	N/A
Bellis and Graves (1971)	N/A
Brody and Pelton (1989)	N/A
Carbaugh et al. (1975)	N/A
Clevenger et al. (2003)	N/A
Cristoffer (1991)	N/A
Elzohairy et al. (2004)	N/A
Fahrig et al. (1995)	N/A
Fahrig (2001)	N/A
Feldhammer (1986)	N/A
Finder et al. (1999)	N/A
Hughes et al. (1996)	N/A
Inbar and Mayer (1999)	N/A
Nielsen et al. (2003)	N/A
Rost and Bailey (1979)	N/A
Schwabe et al. (2002)	N/A
Seiler et al. (2004)	N/A

Table 3-13. Correlation results for vehicle speed reported by authors based on literature.

Author	Findings
Cook and Daggett (1995)	Y
Danielson and Hubbard (1998)	Y
Forman et al. (2003)	Y
Forman and Alexander (1998)	Y
Groot Bruinderink and Hazebroek (1996)	Y
Putnam (1997)	N/A
Trombulak and Frissell (2000)	Varies (w/species)

Table 3-14. Correlation results for vehicle reported by authors based on data and literature.

Author	Findings
Gunson and Clevenger (2003)	Y (cited)
Knapp and Yi (2003)	Y
Staines et al (2001)	Y

Table 3-15. Correlation results for traffic volume reported by authors based on data.

Author	Results
Allen & McCullough (1976)	SC (w/TOD, DOW). NSC w/season.
Fahrig (2001)	SC (w/ trends in wildlife populations)
Inbar and Mayer (1999)	SC (summer), NSC (winter)
Romin and Bissonette (1996)	SC (more signifcant than speed)
Brody and Pelton (1989)	SC
Arnold (1978)	SC
Fahrig et al. (1995)	SC
Joyce and Mahoney (2001)	SC
van Langevelde and Jaarsma (2004)	SC
Carbaugh et al. (1975)	NSC
Case (1978)	NSC
Clevenger et al. (2003)	NSC
Mansfield and Miller (1975)	NSC
Cristoffer (1991)	NEGC (volume effects masked by speed)
Rolley and Lehman (1992)	NEGC (due to RT and PF)
Puglisi et al. (1974)	Y (cited)
Rost and Bailey (1979)	Y (affects distribution of deer and elk)
Maine Interagency Work Group (2001)	Y
Schwabe et al. (2002)	Y
Seiler et al. (2004)	Y
Jahn (1959)	Source of bias in study (as cited by author)
Bashore et al. (1985)	N/A
Bellis and Graves (1971)	N/A
Elzohairy et al. (2004)	N/A
Feldhammer (1986)	N/A
Finder et al. (1999)	N/A
Gunther et al. (1998)	N/A
Hughes et al. (1996)	N/A
Nielsen et al. (2003)	N/A
Pojar et al. (1975)	N/A

Table 3-16. Correlation results for traffic volume reported by authors based on literature.

Author	Results
Cook and Daggett (1995)	Y
Danielson and Hubbard (1998)	Y
Forman et al. (2003)	Y
Forman and Alexander (1998)	Y
Putnam (1997)	Y (affects deer movement patterns)
Trombulak and Frissell (2000)	Y
Groot Bruinderink and Hazebroek (1996)	Ambiguous (due to PF)

Table 3-17. Correlation results for traffic volume reported by authors based on data and literature.

Author	Results
Gunson and Clevenger (2003)	NEGC (due to RT and PF)
Knapp and Yi (2003)	Y
Staines et al (2001)	Y

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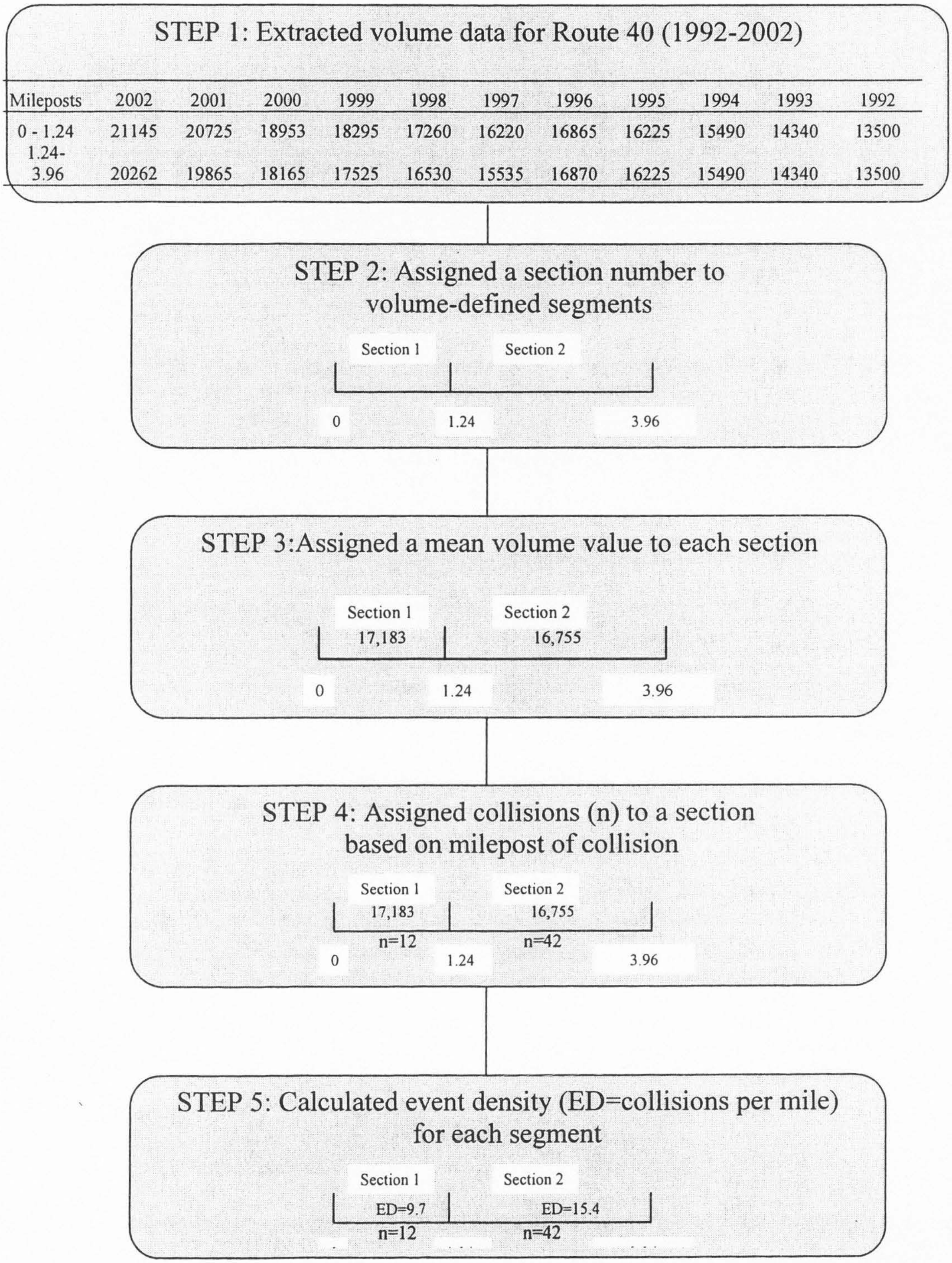
[i] Result abbreviations: N/A=not available/not considered, NC=negative correlation, NSC=no significant correlation, NEGC=negative correlation, SC=significant correlation, Y=Authors state factor has impact (no statistics cited).

[ii] These are other factors considered to explain wildlife-vehicle collisions by authors who did not conclude that traffic volume, speed or speed limit were the only explanatory variables. They are only reported in Table 3-6 to avoid repetition. Abbreviations: ALP=Adjacent land patterns, DOW=day of week, FC=forest cover, FENCES=presence/absence of deer-proof fences, LT=light conditions PD=population density, PF=population fluctuations, RA=road alignment, RT=road type, ROW=right-of-way, RV=road variables, RW=road width, , SD=Shannon's diversity index, TEMP=temporal factors (seasonality, time of day), TOD=time of day, TOPO=topography, VEG=adjacent vegetation, W=weather conditions.



Mileposts	2002	2001	2000	1999	1998	1997	1996	1995	1994	1993	1992
0 - 1.24	21145	20725	18953	18295	17260	16220	16865	16225	15490	14340	13500
1.24-3.96	20262	19865	18165	17525	16530	15535	16870	16225	15490	14340	13500

Figure 3-1. Flow chart showing an example of the process of creating the traffic volume data set for a portion of Route 40.

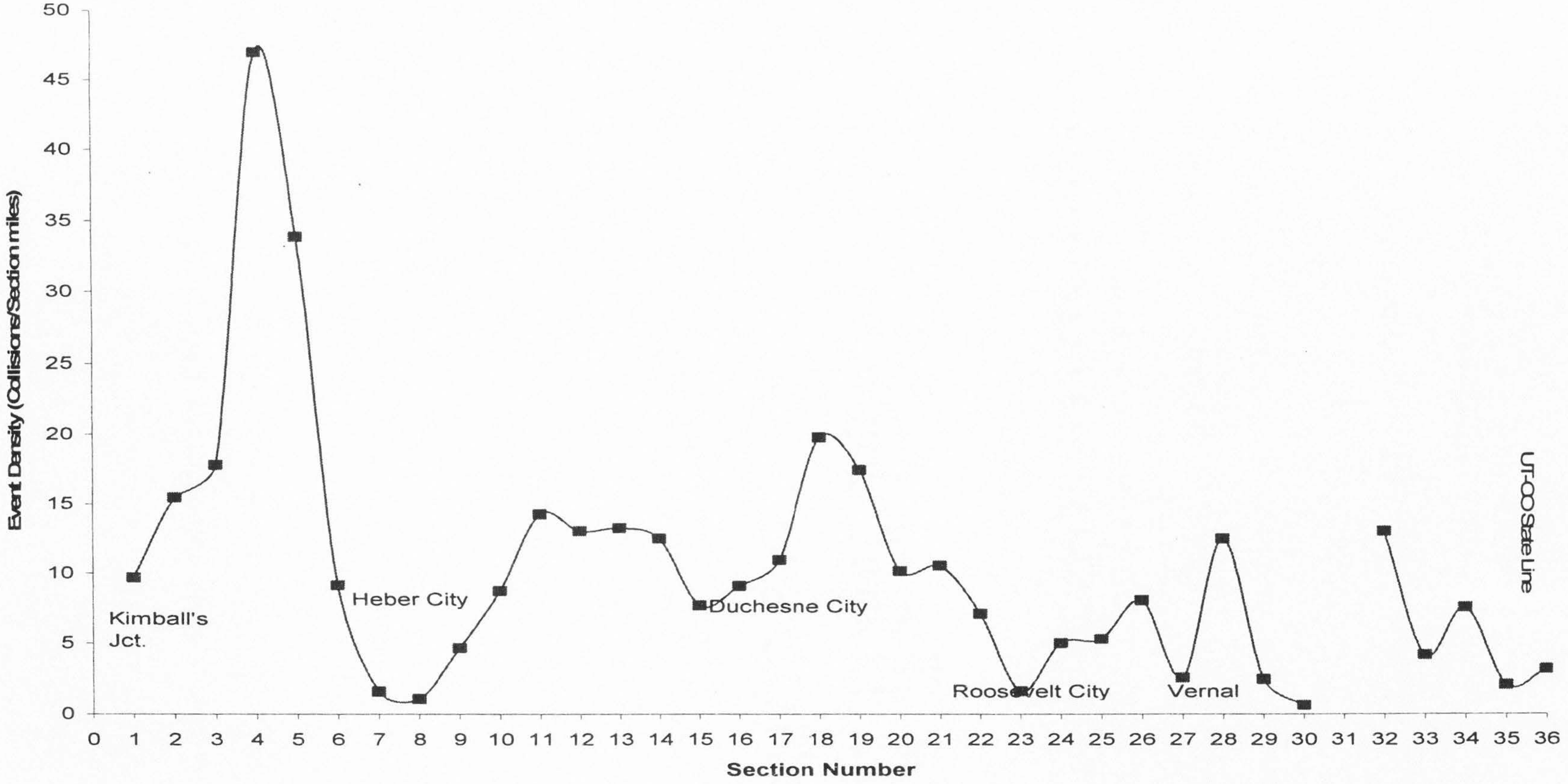


Figure 3-2. Event density vs. section number for Route 40 (Summit, Wasatch, Duchesne and Uintah counties), Utah, 1992-2002.These sections are not of equal length and were assigned based on how traffic volume is recorded by the Utah Department of Transportation. Event density is a rate: collisions per section length.

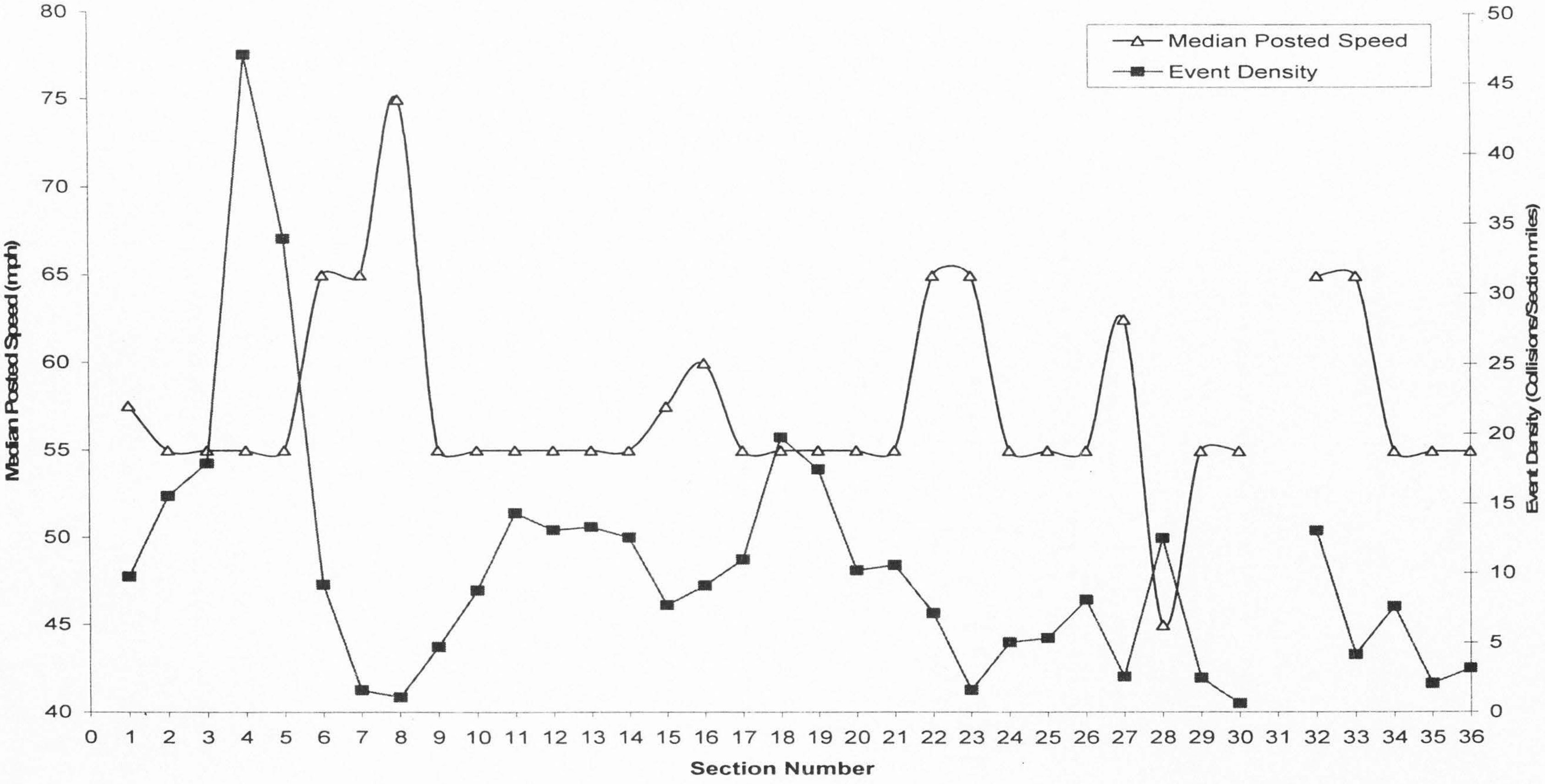


Figure 3-3. Median posted speed limit (mph) and event density vs. section number for Route 40, (Summit, Wasatch, Duchesne and Uintah counties), Utah, 1992-2002. These sections are not of equal length and were assigned based on how traffic volume is recorded by the Utah Department of Transportation. Event density is a rate: collisions per section length.

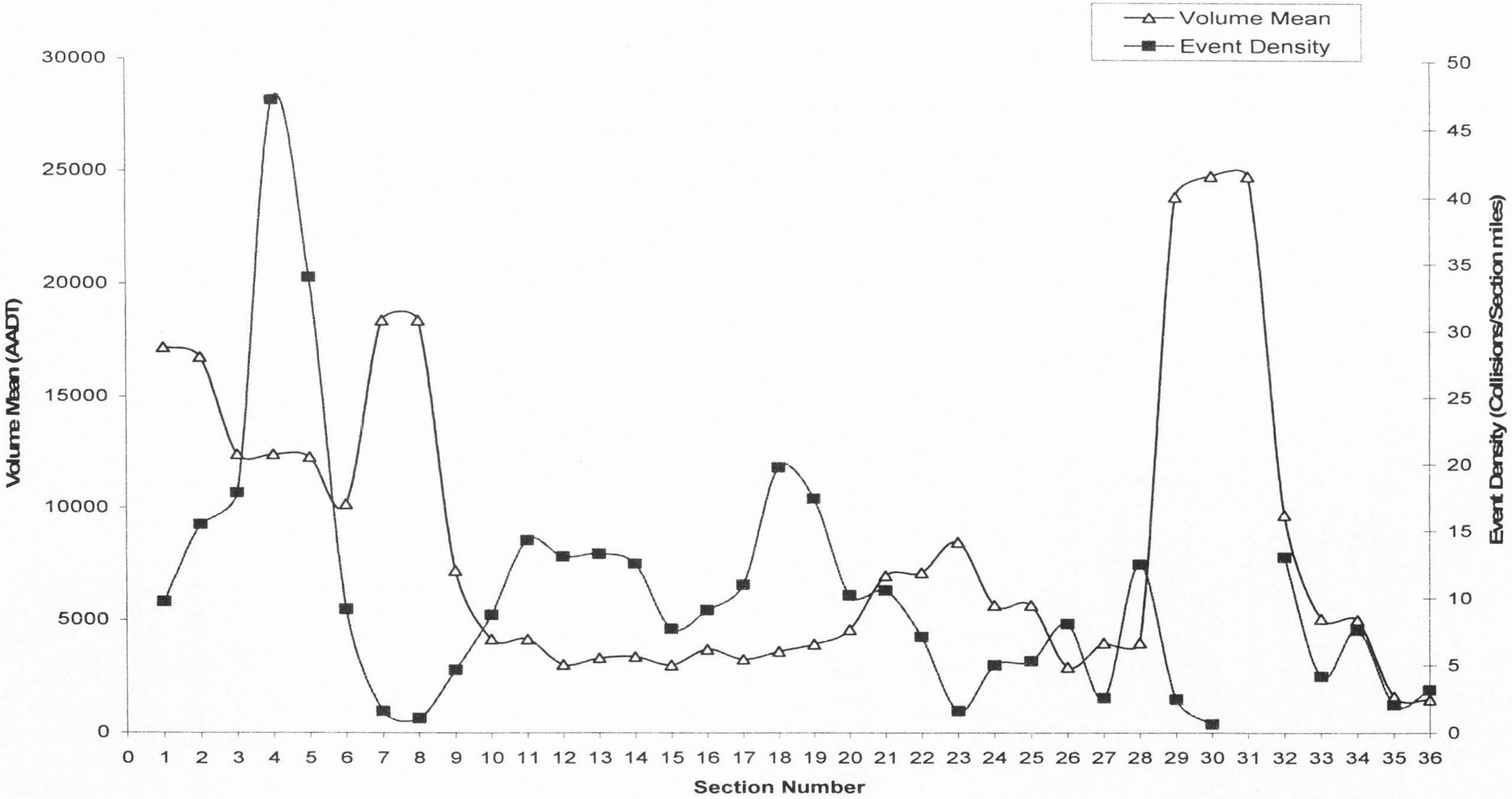


Figure 3-4. Traffic volume mean and event density vs. section number for Route 40, (Summit, Wasatch, Duchesne and Uintah counties), Utah, 1992-2002. These sections are not of equal length and were assigned based on how traffic volume is recorded by the Utah Department of Transportation. Event density is a rate: collisions per section length.

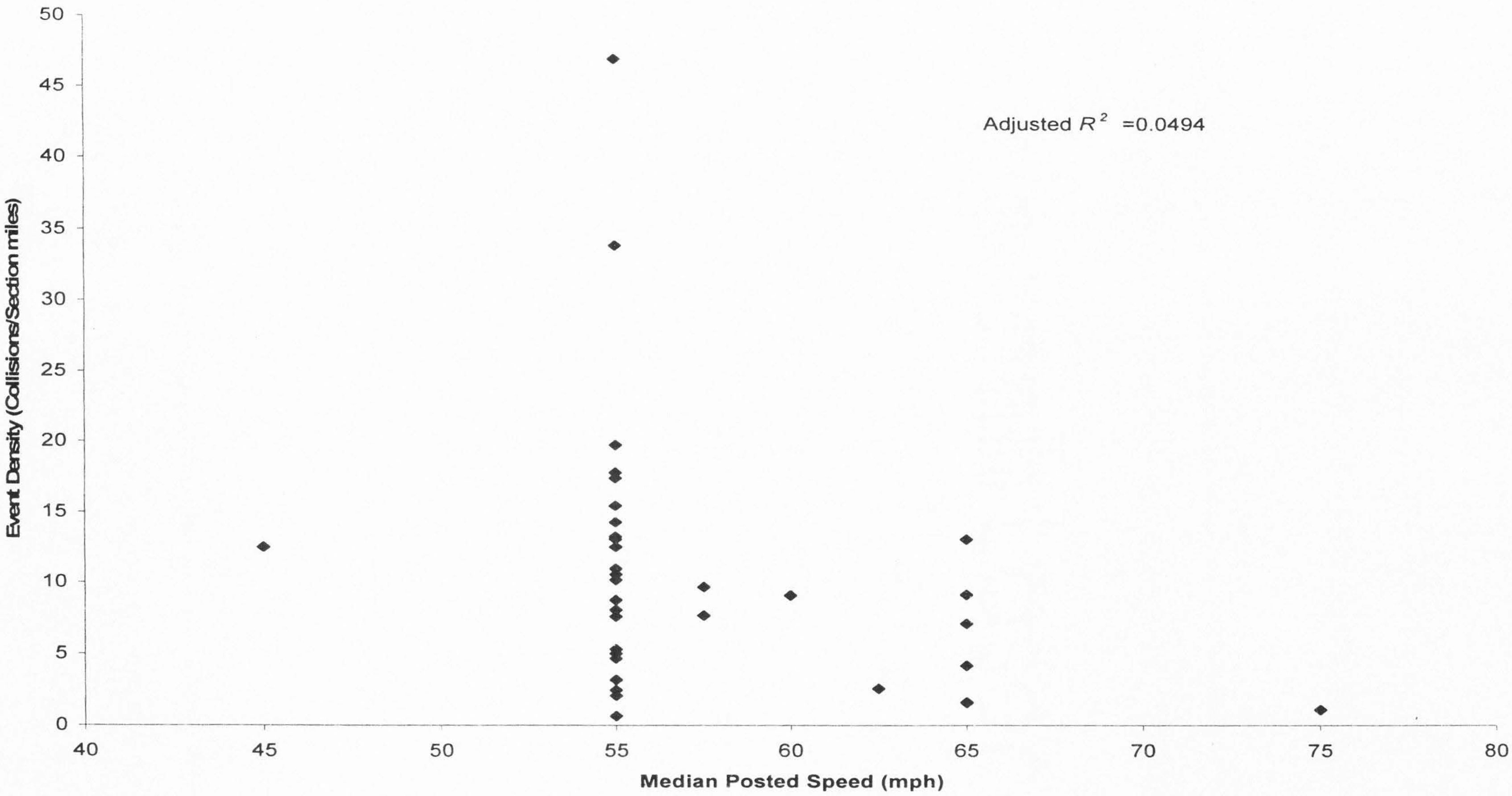


Figure 3-5. Event density vs. median posted speed for Route 40, (Summit, Wasatch, Duchesne and Uintah counties), Utah, 1992-2002. Event density is a rate (collisions per section length) shown as distributed across median posted speed (mph). The adjusted $R^2 = 0.0494$.

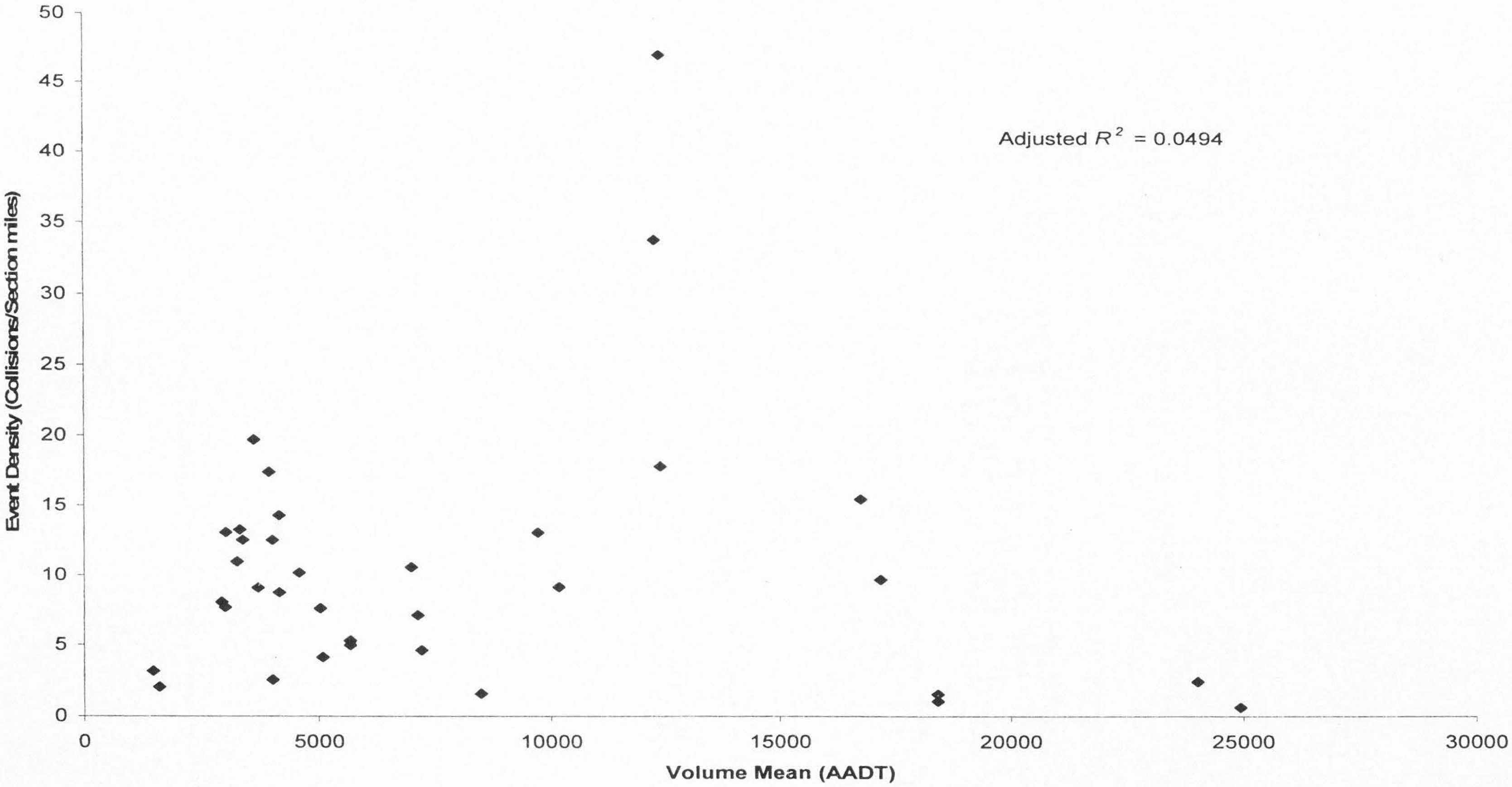


Figure 3-6. Event density vs. volume mean for Route 40, (Summit, Wasatch, Duchesne and Uintah counties),Utah, 1992-2002. Event density is a rate (collisions per section length) shown as distributed across mean volume (annual average daily traffic flow). The adjusted R^2=0.0494.

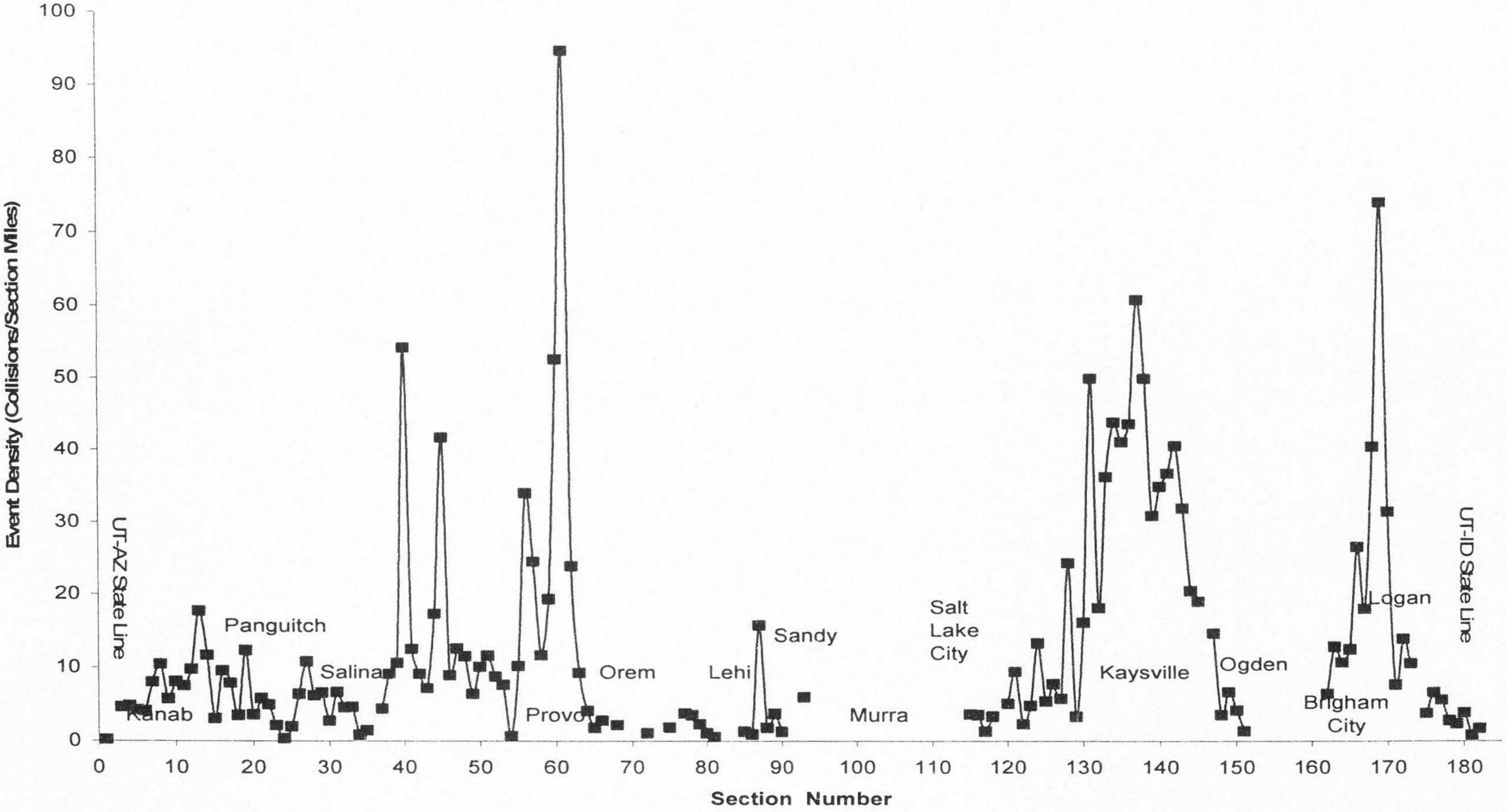


Figure 3-7. Event density vs. section number for Route 89 (spanning 12 counties from Kane to Rich), Utah, 1992-2002.These sections are not of equal length and were assigned based on how traffic volume is recorded by the Utah Department of Transportation. Event density is a rate: collisions per section length.

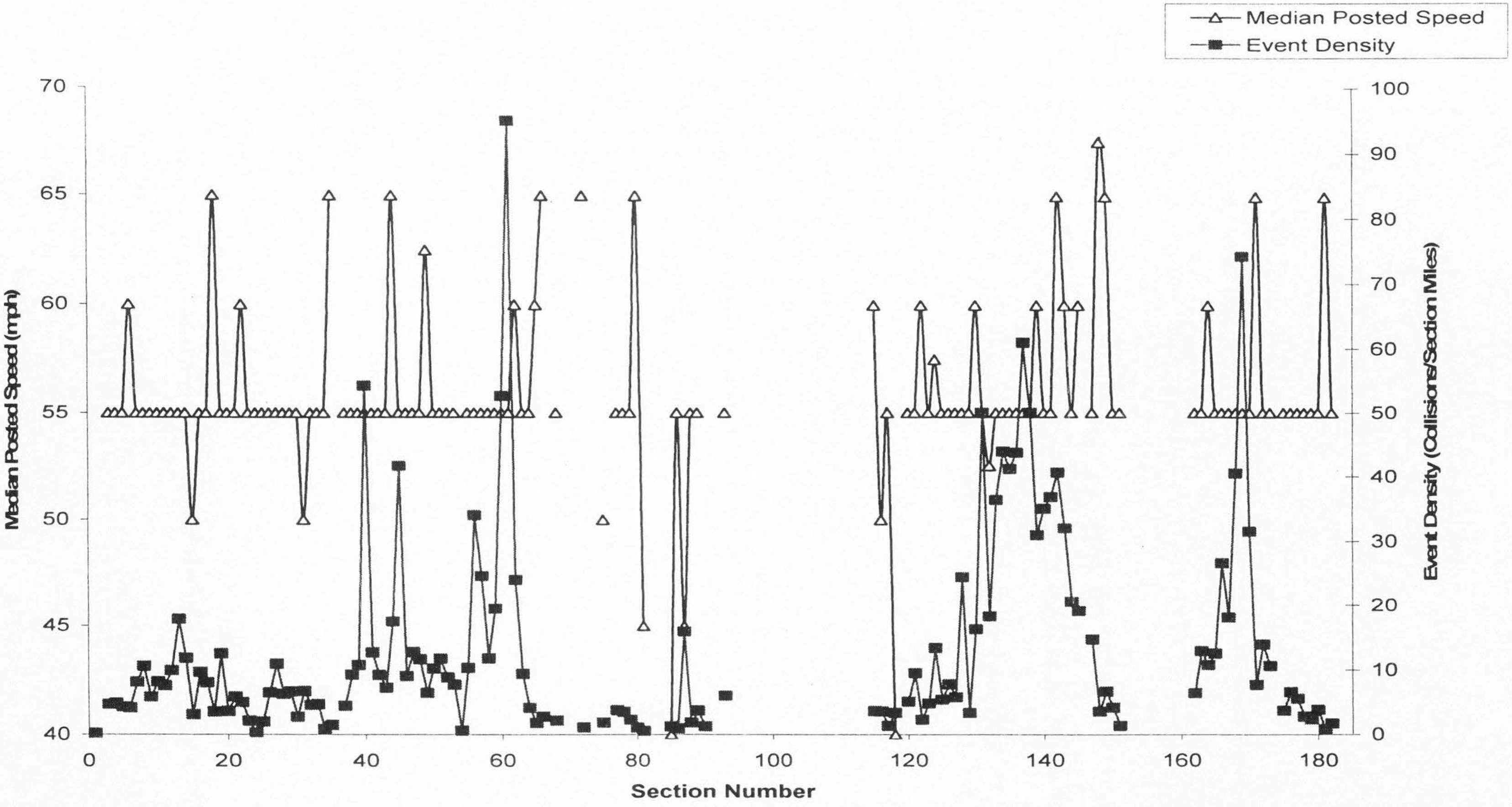


Figure 3-8. Median posted speed limit (mph) and event density vs. section number for Route 89, (spanning 12 counties from Kane to Rich), Utah, 1992-2002. These sections are not of equal length and were assigned based on how traffic volume is recorded by the Utah Department of Transportation. Event density is a rate: collisions per section length.

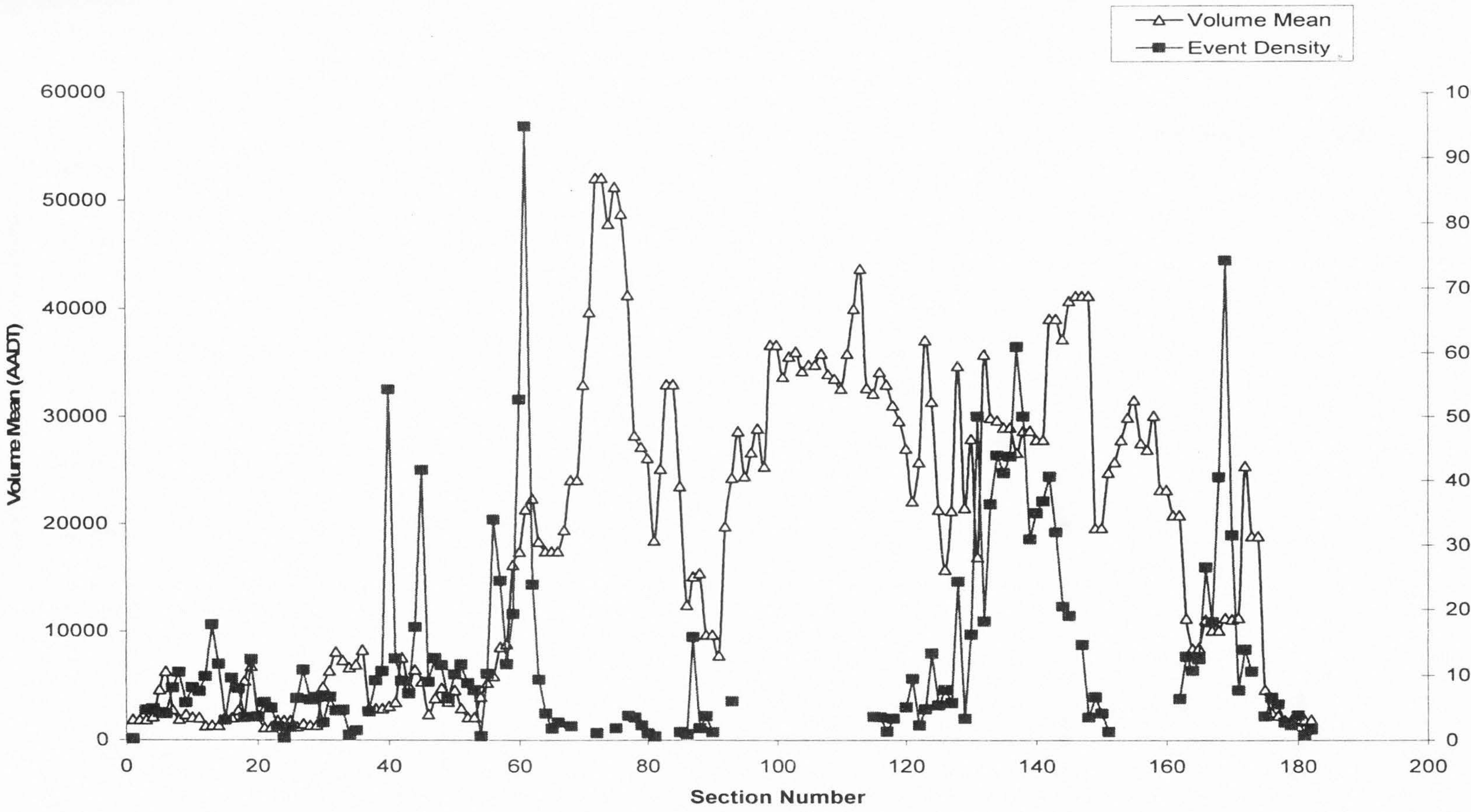


Figure 3-9. Traffic volume mean and event density vs. section number for Route 89, (spanning 12 counties from Kane to Rich), Utah, 1992-2002. These sections are not of equal length and were assigned based on how traffic volume is recorded by the Utah Department of Transportation. Event density is a rate: collisions per section length.

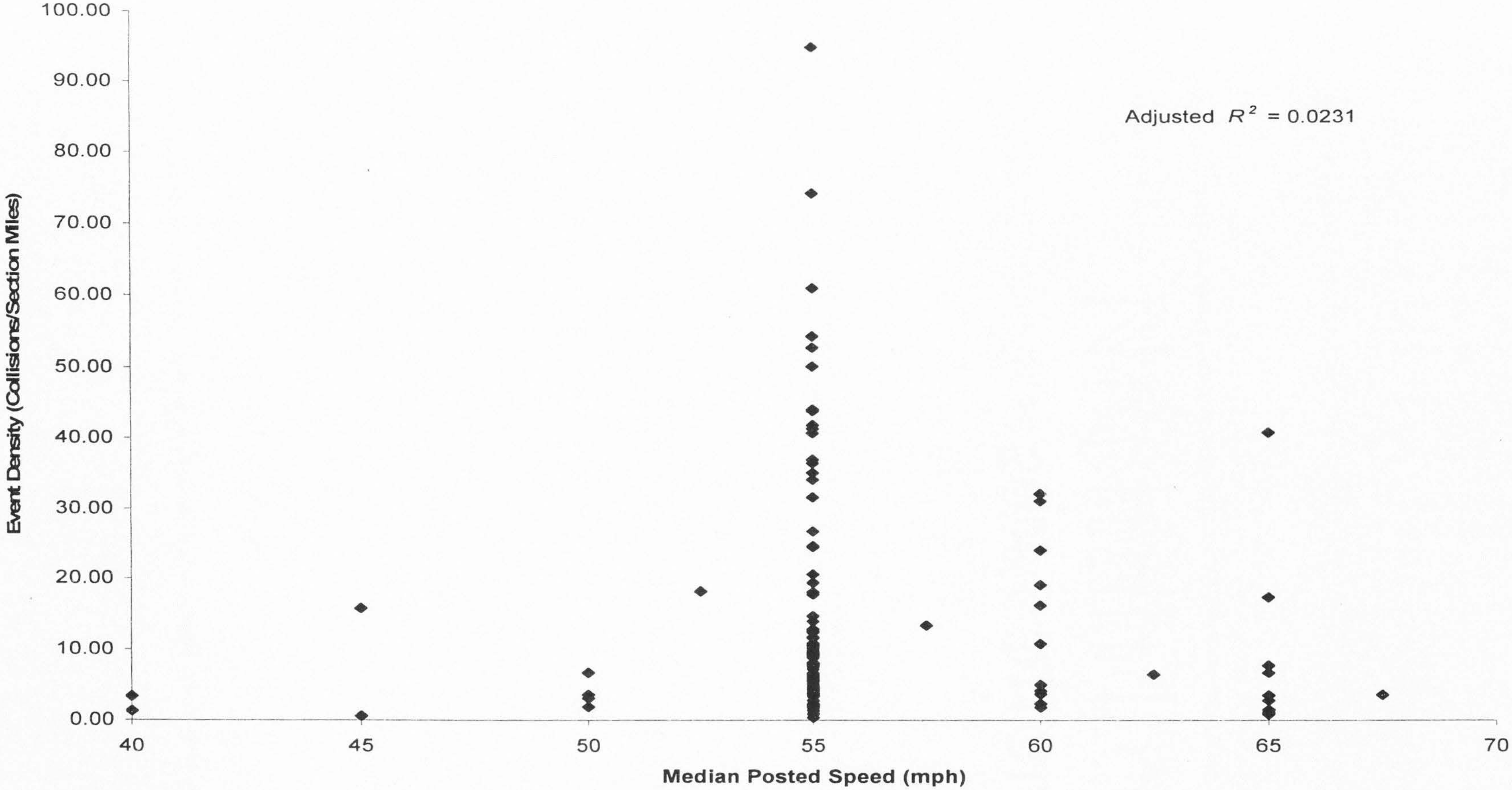


Figure 3-10. Event density vs. median posted speed for Route 89, (spanning 12 counties from Kane to Rich), Utah, 1992-2002. Event density is a rate (collisions per section length) shown as distributed across median posted speed (mph). The adjusted R^2 = 0.0231.

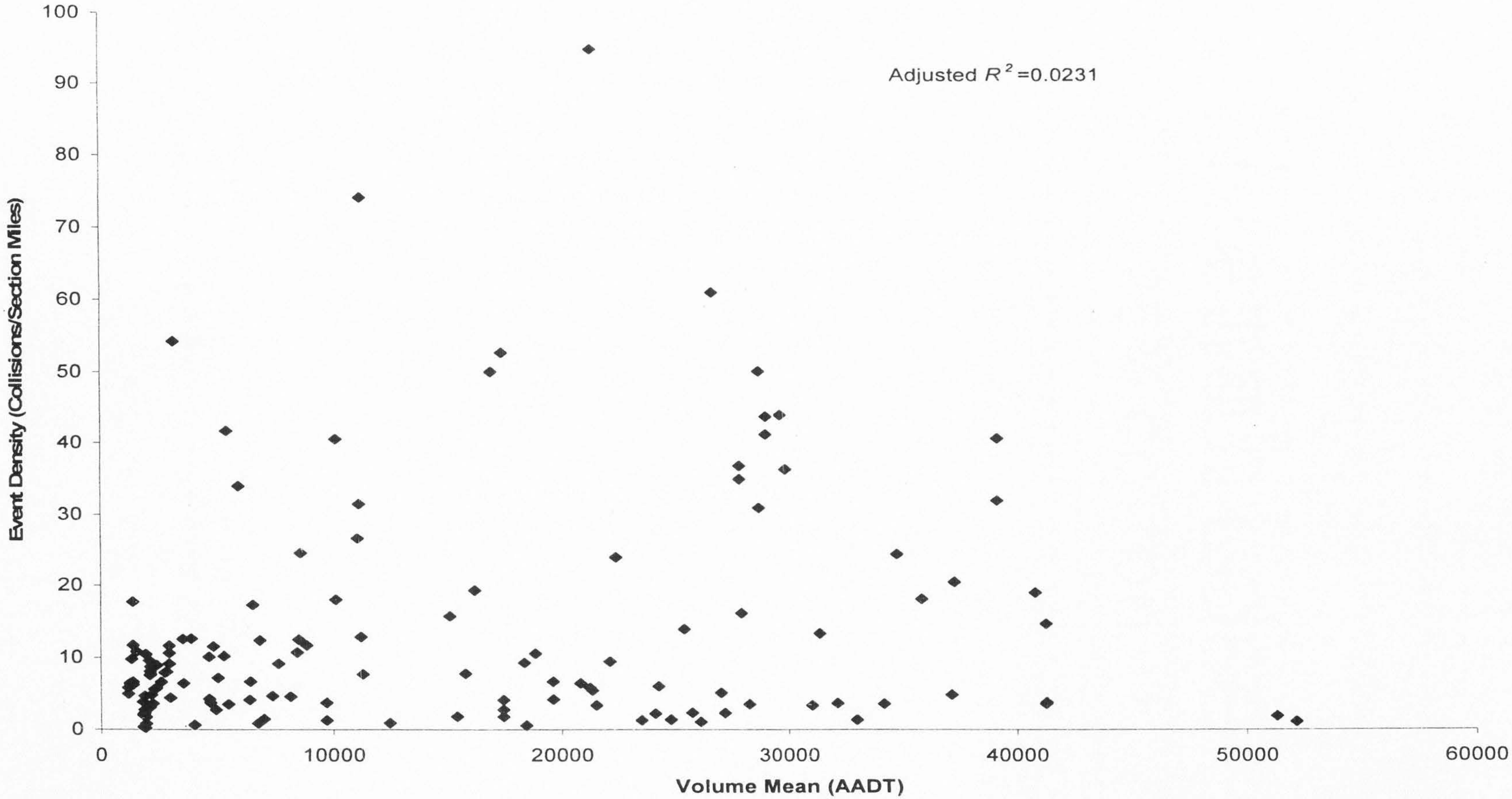


Figure 3-11. Event density vs. volume mean for Route 89, (spanning 12 counties from Kane to Rich), Utah, 1992-2002.Event density is a rate (collisions per section length) shown as distributed across mean volume (annual average daily traffic flow). The adjusted R^2=0.0231.

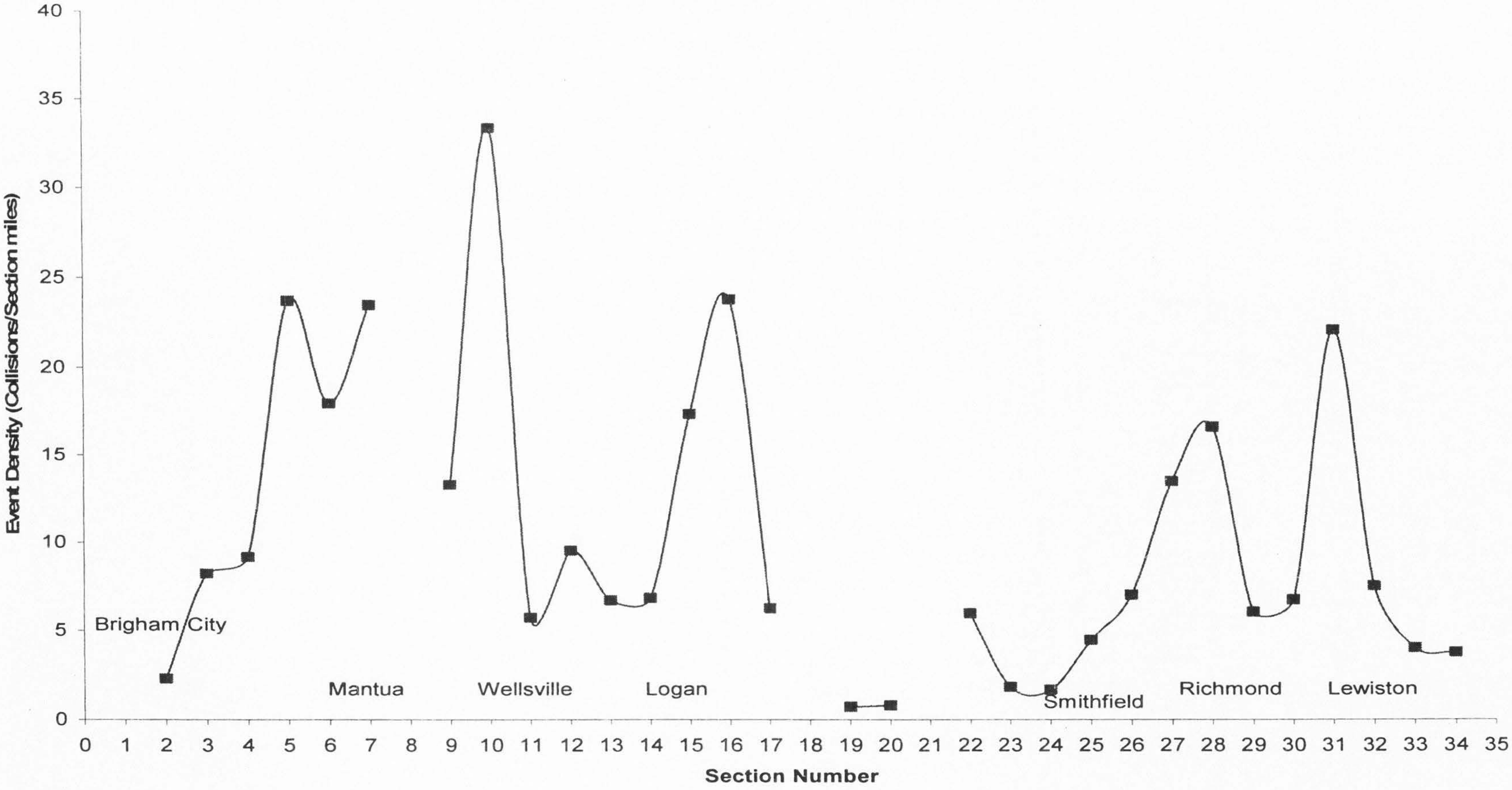


Figure 3-12. Event density vs. section number for Route 91 (Box Elder and Cache counties), Utah, 1992-2002.These sections are not of equal length and were assigned based on how traffic volume is recorded by the Utah Department of Transportation. Event density is a rate: collisions per section length.

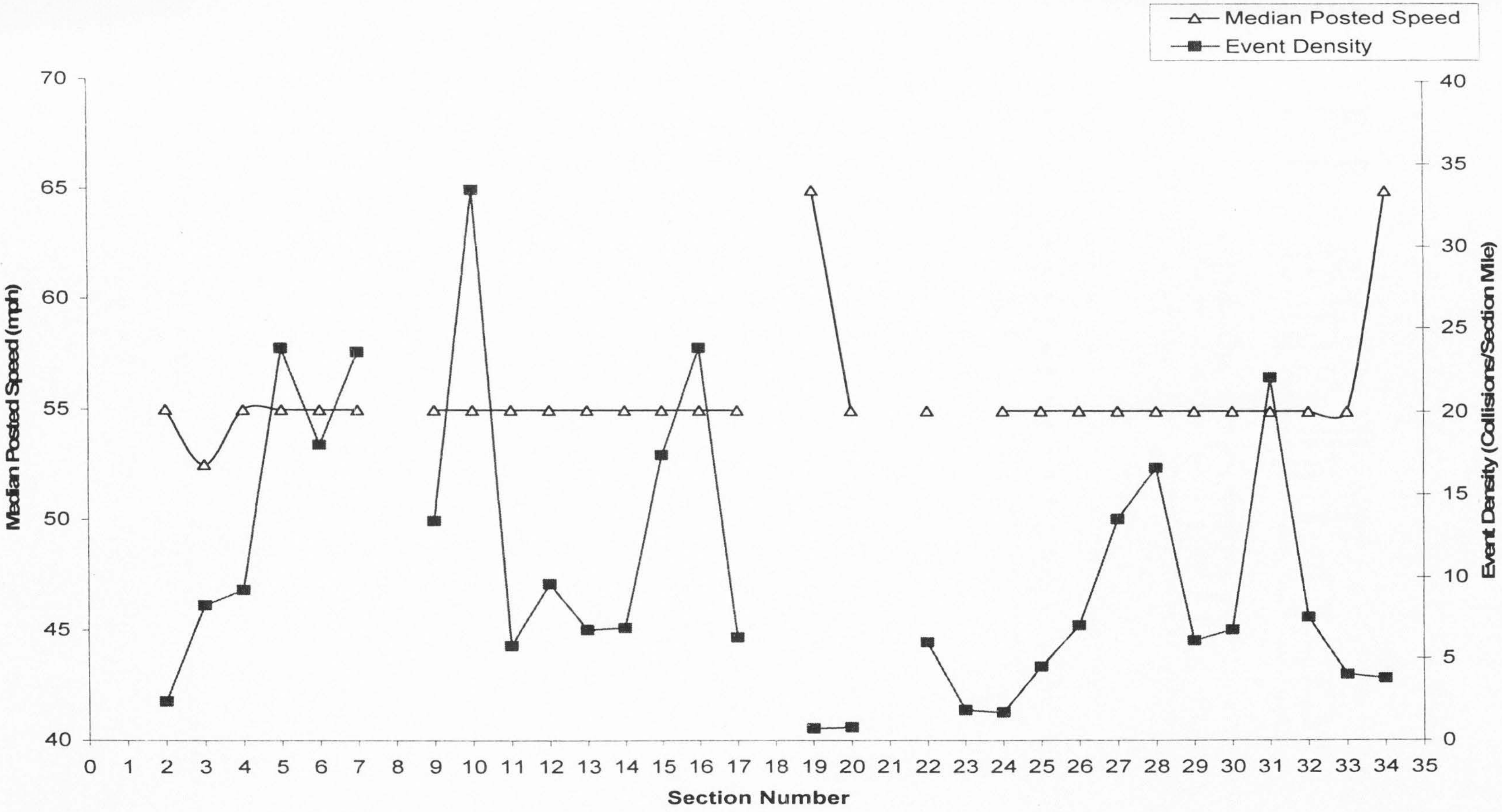


Figure 3-13. Median posted speed limit (mph) and event density vs. section number for Route 91, (Box Elder and Cache counties), Utah, 1992-2002. These sections are not of equal length and were assigned based on how traffic volume is recorded by the Utah Department of Transportation. Event density is a rate: collisions per section length.

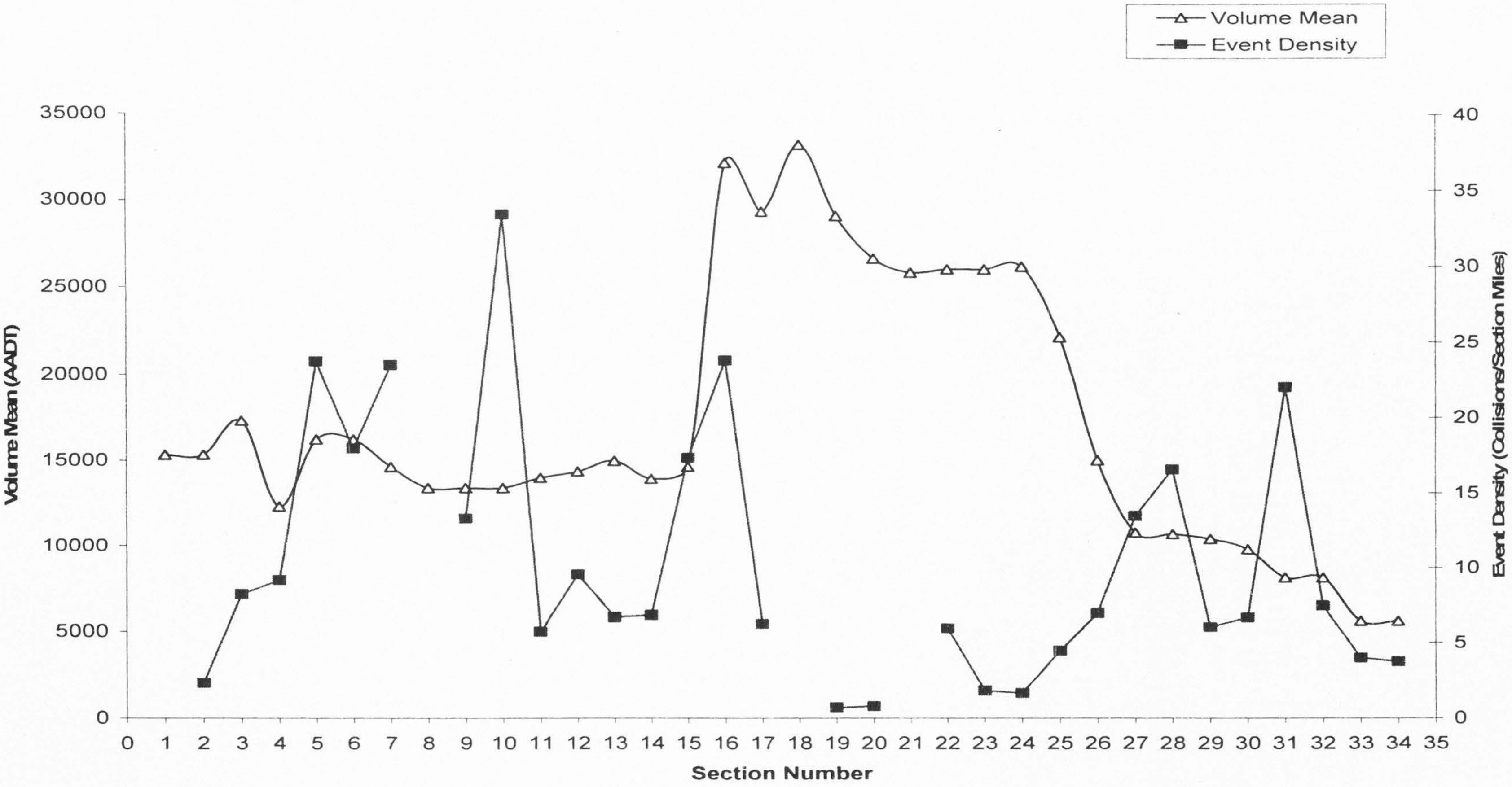


Figure 3-14. Traffic volume mean and event density vs. section number for Route 91, (Box Elder and Cache counties), Utah, 1992-2002. These sections are not of equal length and were assigned based on how traffic volume is recorded by the Utah Department of Transportation. Event density is a rate: collisions per section length.

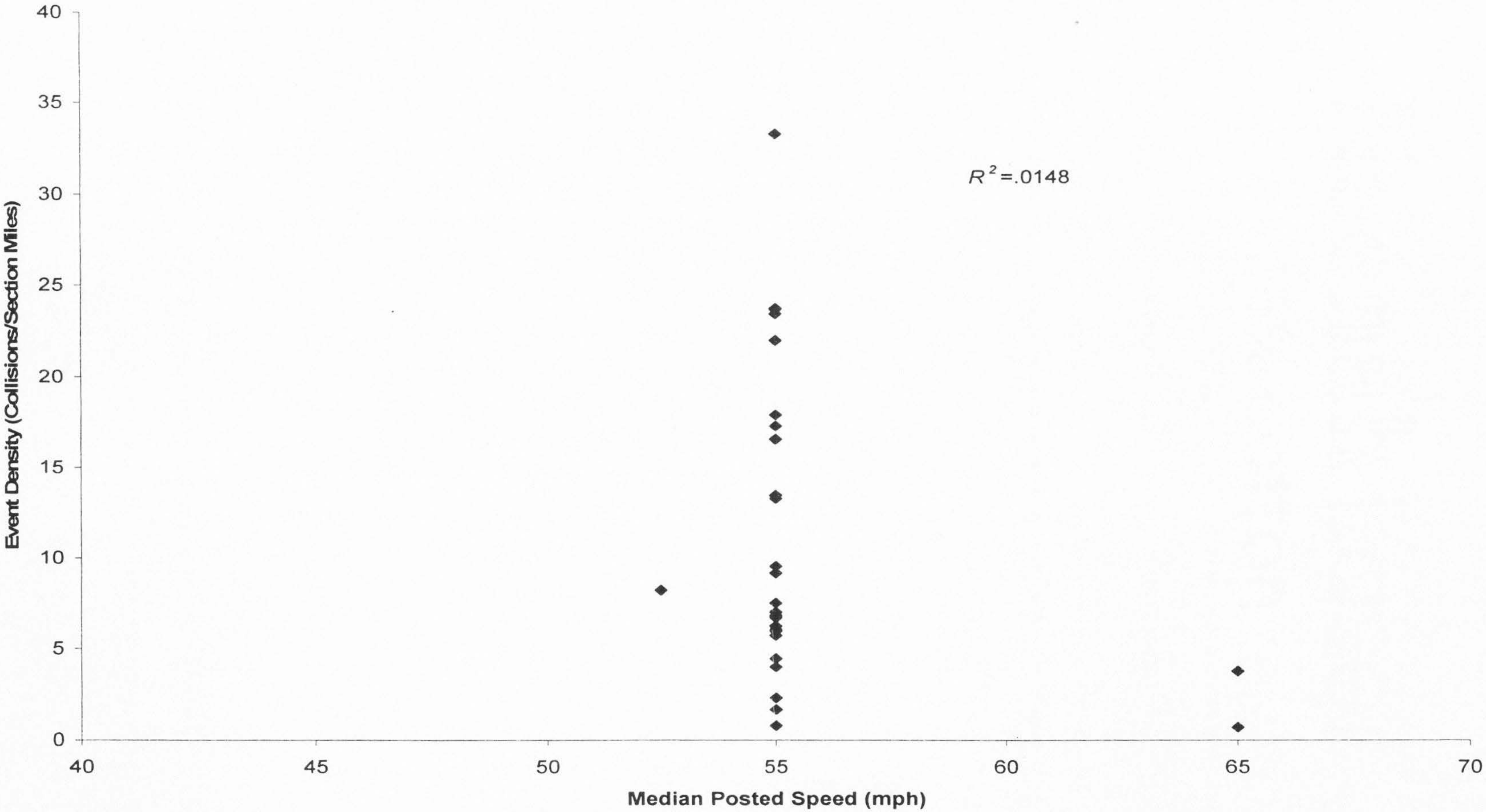


Figure 3-15. Event density vs. median posted speed for Route 91, (Box Elder and Cache counties), Utah, 1992-2002. Event density is a rate (collisions per section length) shown as distributed across median posted speed (mph). The adjusted $R^2 = 0.0148$.

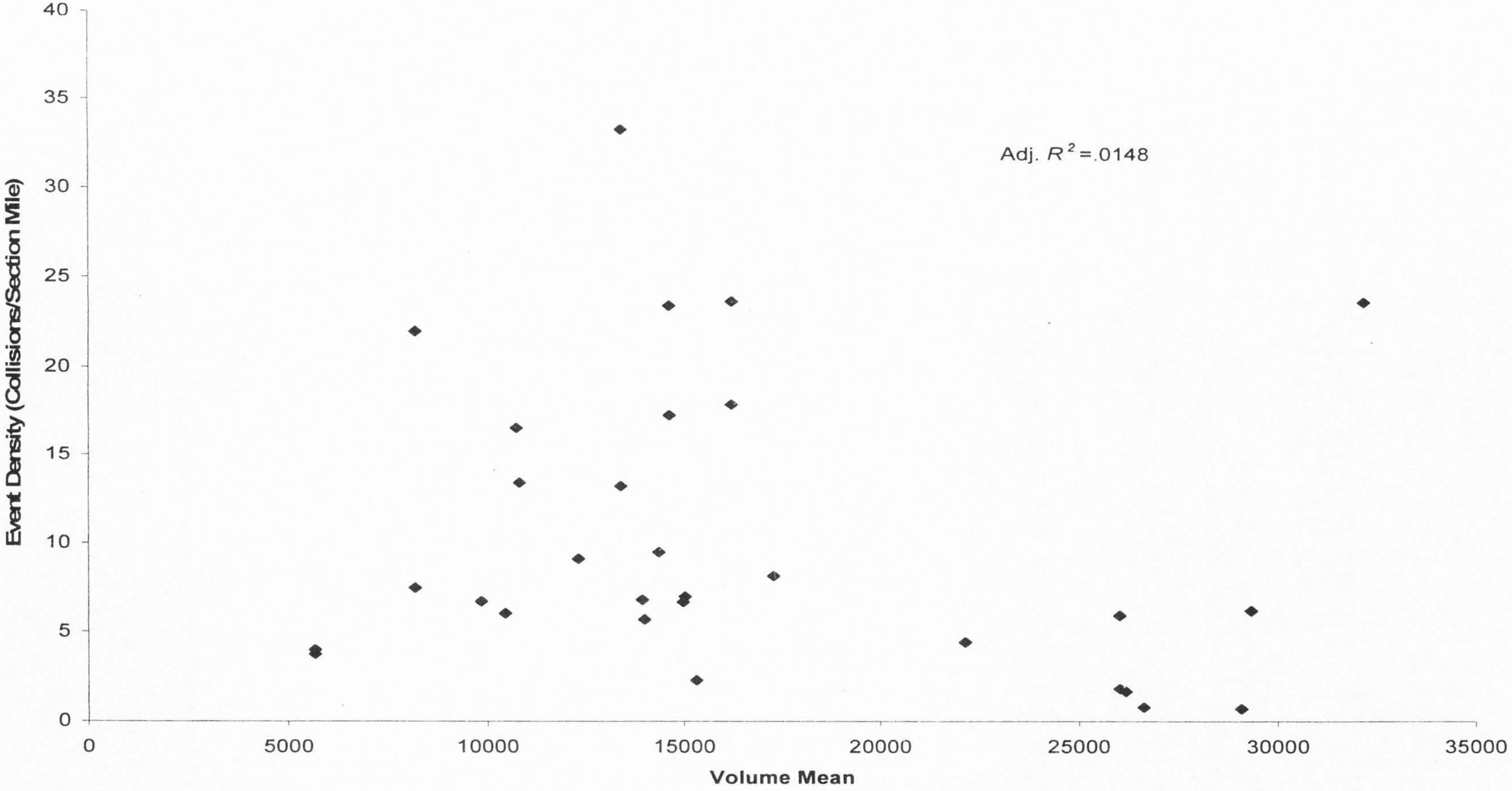


Figure 3-16. Event density vs. volume mean for Route 91, (Box Elder and Cache counties), Utah, 1992-2002. Event density is a rate (collisions per section length) shown as distributed across mean volume (annual average daily traffic flow). The adjusted R^2 =0.0148.

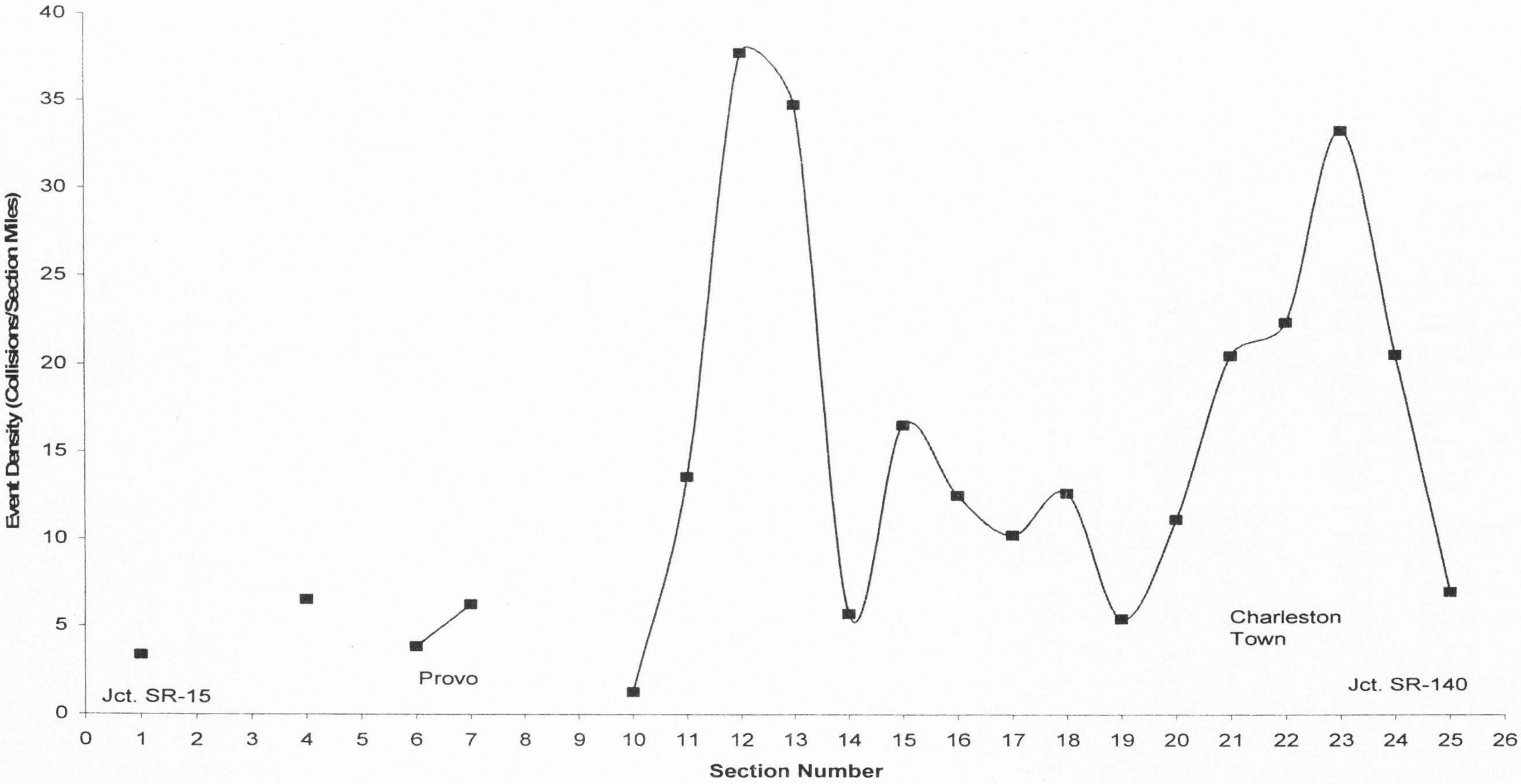


Figure 3-17. Event density vs. section number for Route 189 (Utah and Wasatch counties), Utah, 1992-2002.These sections are not of equal length and were assigned based on how traffic volume is recorded by the Utah Department of Transportation. Event density is a rate: collisions per section length.

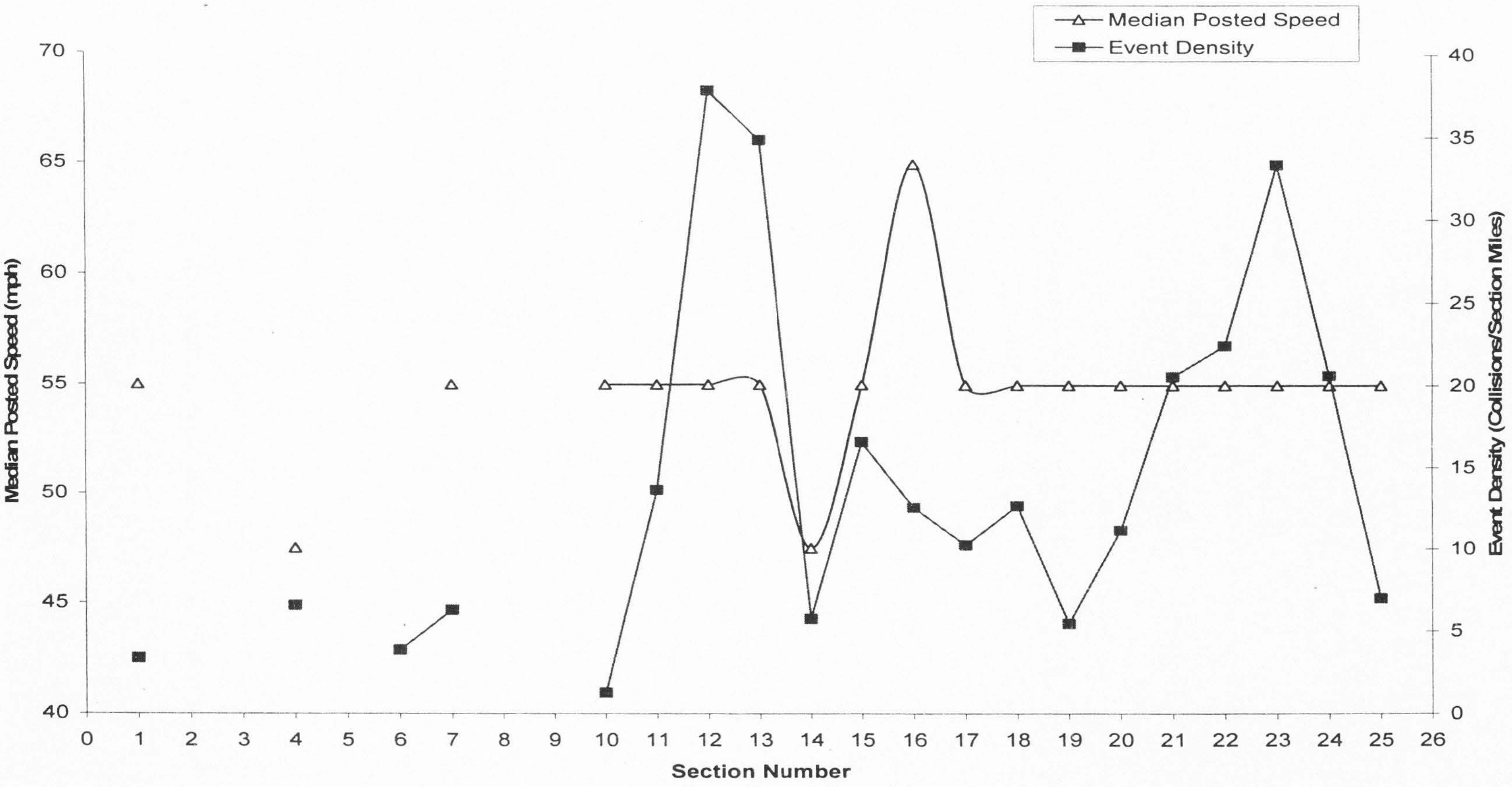


Figure 3-18. Median posted speed limit (mph) and event density vs. section number for Route 189, (Utah and Wasatch counties), Utah, 1992-2002. These sections are not of equal length and were assigned based on how traffic volume is recorded by the Utah Department of Transportation. Event density is a rate: collisions per section length.

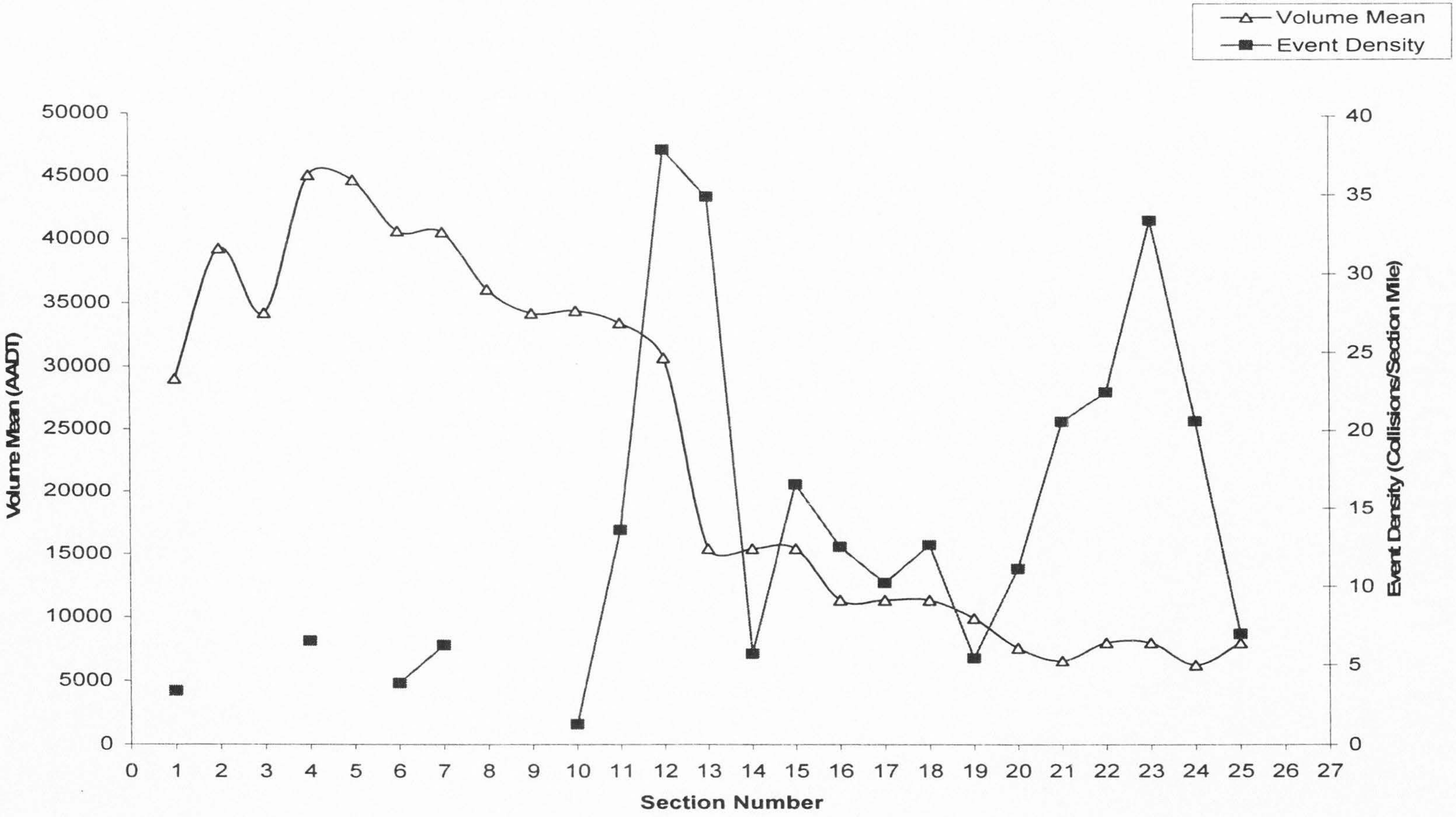


Figure 3-19. Traffic volume mean and event density vs. section number for Route 189, (Utah and Wasatch counties), Utah, 1992-2002. These sections are not of equal length and were assigned based on how traffic volume is recorded by the Utah Department of Transportation. Event density is a rate: collisions per section length.

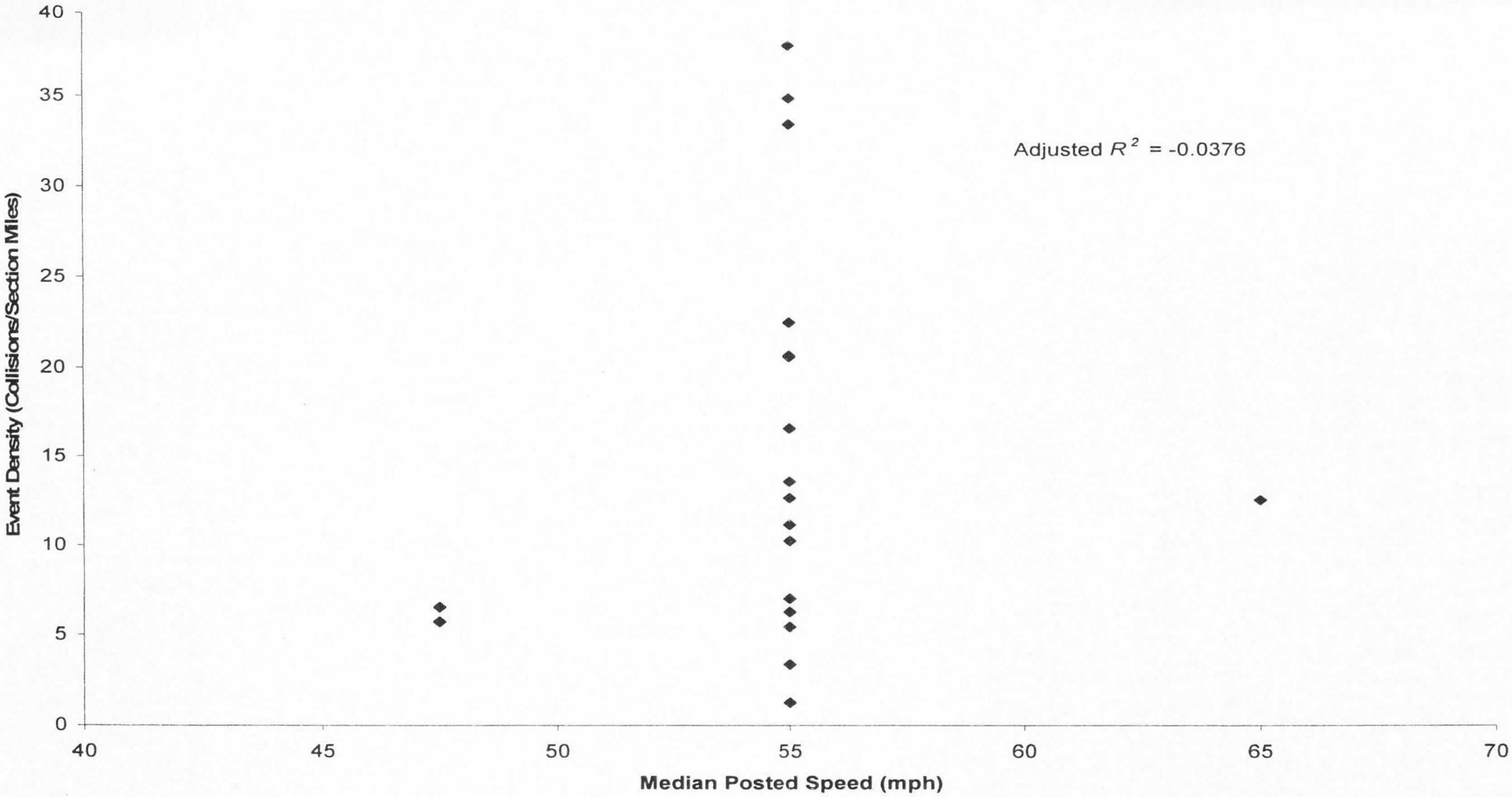


Figure 3-20. Event density vs. median posted speed for Route 189, (Utah and Wasatch counties), Utah, 1992-2002. Event density is a rate (collisions per section length) shown as distributed across median posted speed (mph). The adjusted R^2= 0.0231.

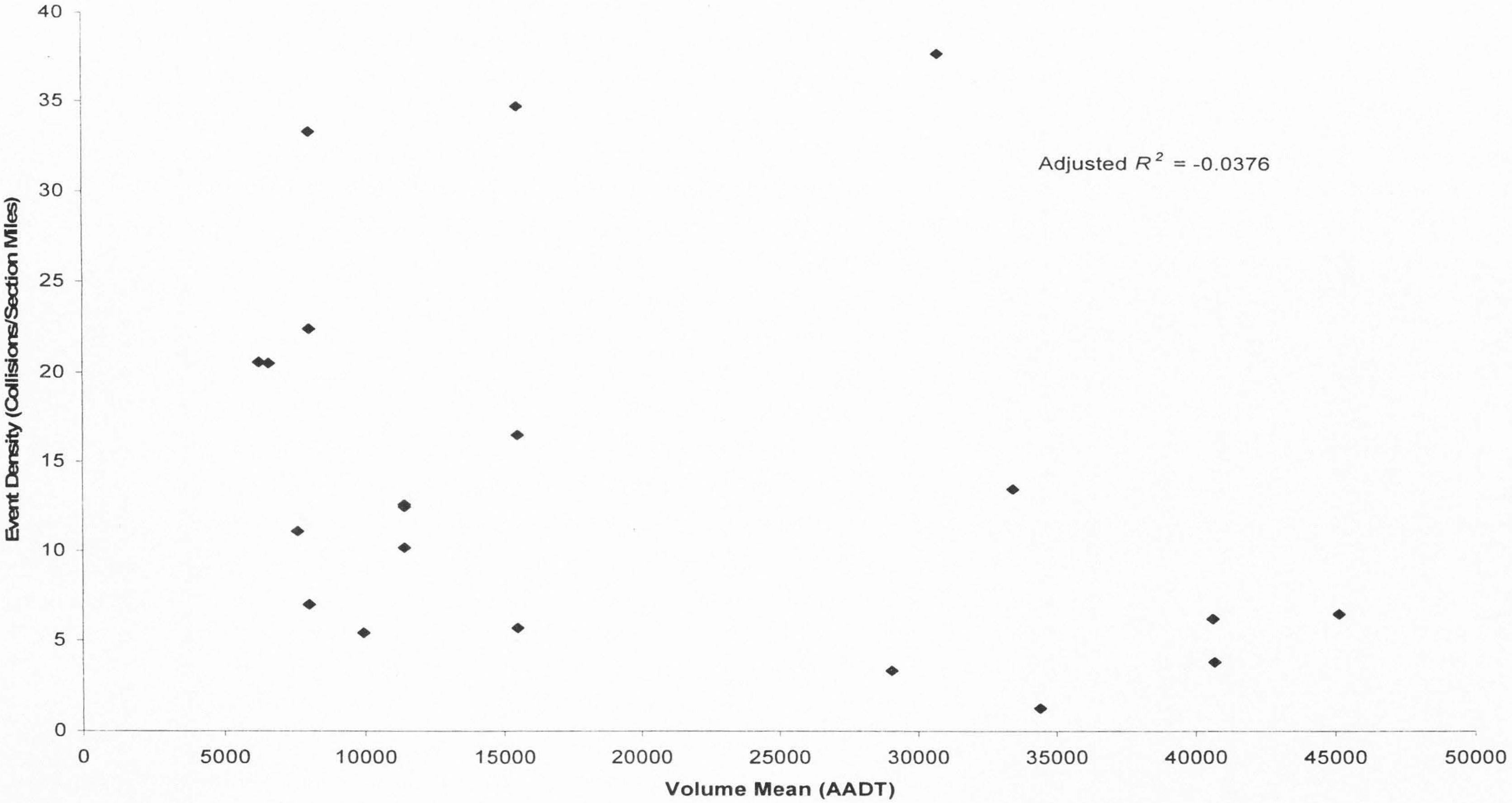


Figure 3-21. Event density vs. volume mean for Route 189, (Utah and Wasatch counties), Utah, 1992-2002. Event density is a rate (collisions per section length) shown as distributed across mean volume (annual average daily traffic flow). The adjusted R^2 =0.0231.

CHAPTER 4

AN ASSESSMENT OF COSTS ASSOCIATED WITH DEER-VEHICLE COLLISIONS: IT'S MORE THAN JUST ROAD KILL

Abstract: Conover et al. (1995) estimated that over 1 million deer-vehicle crashes (DVCs) may occur each year in the United States. Increases in deer-vehicle collisions have also been reported consistently in Europe (Groot Bruinderink & Hazebroek 1996; Staines et al. 2001). Collisions between large vertebrates (especially deer, elk, moose, and large carnivores) and vehicles are an increasing concern along roadways throughout the United States not only because of the ecological consequences for the species involved (viz. road mortality that may lead to decreases in population sizes), but also because of the potential for human injury and death, vehicle damage, loss of deer, and their associated economic costs. Research suggests that mitigation resulting in lower DVCs and as a result, decreased costs associated with property damage, human injury and death, and resource loss is cost effective (Reed et al. 1982; Wu 1998; Schwabe et al. 2002). To put this issue into a public safety perspective, we used data from Utah to summarize and analyze the costs of vehicle damage, human injury, human death, and deer loss that result from deer vehicle collisions on roadways. Our analyses demonstrates the magnitude of this issue on a broader scale by confirming that associated costs, damage, injuries, and loss of resources are significant aspects of DVCs that require attention and justify mitigation.

Our data consisted of 13,020 recorded deer vehicle collisions and 308,584 non-deer vehicle collisions, for a total of 321,604 collisions over 6 years. Deer-

vehicle collisions accounted for ~4.0 % of all collisions. From 1996 to 2001, we calculated an increase of ~12.8% ($163) in the average adjusted per crash value (AAPCV) with a minimum in 1996 of $1,271 and a maximum in 2001 of $1,434. From 1996-2001, we calculated the mean total cost of vehicle damage as $2,920,328 per year, while the total for the 6 years was $17,521,970.

There were 20,873 people involved in wildlife-vehicle collisions from 1996 to 2001. They 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 occupants, a total of 448 (2.1%) incurred an in-patient hospital or emergency department charge; charges for human injury totaled $1,002,401. Forty-four (0.2 %) were hospitalized for at least one night, accruing charges of $781, 324 while 404 (1.9%) visited the emergency department (ED), resulting in $221,077 in charges (Fig 4 -6).

There were 8 reported fatalities due to deer-vehicle collisions in Utah from 1996 to 2001. We used the DOT/FHWA statistic for the value of a human life ($3.0 million) to estimate that fatalities in Utah from 1996 to 2001 carry a value of ~ $24.0 million (adjusted to 2001). We found that the adjusted value of a deer increased each year from $209 in 1996 to $236 in 2001. From these values, we calculated the yearly monetary costs of deer loss and found that yearly costs were fairly constant ranging from a minimum of $403,013 in 1997 to a maximum of $489,823 in 2001. The overall calculated total cost for 6 years in Utah was $2,651,083 with a yearly mean of $441,847. This is a conservative estimate; deer hit by large trucks are seldom reported.

Despite the fact that in some areas road mortality may not have a large impact on the abundance or survival of ungulate populations, this problem is of economic importance, is a significant safety concern, and is also an important issue for conservation (Groot Bruinderink & Hazebroek 1996). Cost-benefit analyses have shown that mitigation efforts can have positive net economic gains while also increasing safety (Wu 1998; Schwabe et al. 2002; Bissonette et al. 2005). We suggest mitigation that is prioritized based on road kill data will help to address this issue.

Introduction

An estimated 6.1 million collisions involving light-vehicles, such as passenger cars, SUVs, vans, and pickup trucks, were reported to police in the United States during 2000. Four percent (~247, 000) involved a motor vehicle directly hitting an animal on the roadway (National Highway Traffic Safety Administration 2000). The Center for Disease Control (CDC 2004) estimated that during 2001 and 2002, 26,647 occupants per year were involved in collisions with animals ("predominantly deer") and were treated for nonfatal injuries. In 1980, vehicle collisions were responsible for killing ~200,000 deer in the United States (Williamson 1980; Schaefer & Penland 1985). Based on surveys from 36 states, Romin (1994) estimated ~538,000 deer were killed on roads in the United States in 1991. Conover et al. (1995) estimated that actually over 1 million deer-vehicle crashes (DVCs) may occur each year in the United States. Increases in deer-vehicle collisions have also been reported consistently in Europe (Groot Bruinderink & Hazebroek 1996; Staines et al. 2001). Even these estimates may be conservative because only about half of the deer vehicle collisions that occur are actually reported to authorities (Romin 1994; Romin & Bissonette 1996).

Collisions between large vertebrates (especially deer, elk, moose, and large carnivores) and vehicles are an increasing concern along roadways throughout the United States not only because of the ecological consequences for the species involved (viz. road mortality that may lead to decreases in population sizes), but also because of the potential for human injury and death, vehicle damage, loss of deer, and their associated economic costs. As the scope and frequency of DVCs increase, and the associated monetary costs grow, it is easy to understand why wildlife managers have begun to more fully integrate strategies to lessen the impacts that roads have on public safety as well as ecological integrity (animal mortality, habitat fragmentation, landscape connectivity and permeability) into management plans. For instance, a management objective of the Utah Division of Wildlife Resources (2003) focuses on minimizing human impacts on mule deer and critical habitat; strategies to do this include limiting the negative effects of roads by reclaiming unused roads, properly planning new roads, installing highway passage structures and closing roads during periods of stress for deer populations. Similarly, organizations concerned with traffic safety (viz., the Utah Department of Transportation (UDOT), Utah Division of Wildlife Resources (UDWR) are working to minimize injuries and fatalities by reducing wildlife-vehicle collisions through the active implementation of mitigation strategies. For example, in southwestern Utah just south of the confluence of Interstate highways I-70 and I-15, both agencies, in cooperation with sportsmen groups, have put in place exclusion fencing and earthen right-of-way escape ramps, coupled with the construction of two new underpasses, built exclusively for wildlife passage. Research suggests that mitigation resulting in lower DVCs and as a result, decreased costs associated with property damage, human injury and death, and resource loss is cost effective (Reed et al. 1982; Wu 1998; Schwabe et al. 2002). In this paper, we use data from Utah as a case study example to evaluate economic losses associated with DVCs from 1996 to 2001. We emphasize the fact that these DVCs are not only a conservation concern, but pose very significant human safety concerns.

Several estimates of vehicle damage costs have been reported. Hansen (1983) surveyed drivers in Michigan to determine that the average cost of property damage for a deer-vehicle accident in 1978 was ~\$569 (Consumer Price Index adjustment:[1] ~ \$1,666), including costs associated with repairs, substitute automobile costs, and towing. Reed et al. (1982) surveyed Colorado state patrol reports and insurance claims to derive an average value of ~\$500 (CPI adjustment: ~\$1,463.96) in property damage. Conover et al. (1995) used the mean of value ranges as reported from various studies in Michigan, New York, Pennsylvania, and West Virginia to estimate that the average cost for vehicle repair due to deer-vehicle collisions was ~\$1,577 per accident (CPI adjustment: ~\$1,975.39), resulting in a total damage to vehicles in excess of ~\$1 billion per year (CPI adjustment : ~\$1,252,600,000. Hartwig (1993) and Fehlberg (1994) estimated the average vehicle repair cost for deer-vehicle collisions in Europe at ~\$1,500 US dollars. Variations in these figures result from the

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[1] The CPI inflation calculator uses the average Consumer Price Index for a given calendar year. This data represents changes in prices of all goods and services purchased for consumption by urban households. This index value has been calculated every year since 1913. For 2004, the latest monthly (December) index value is used.

use of different definitions, study designs, data collection methods and variables. Also, costs change with each year and different cars do not cost the same to repair. Romin (1994) reported from unpublished data of the Farmers Insurance Bureau that Utah auto insurance big-game vehicle damage claims averaged $1,200 per collision. In our analysis, we CPI adjusted this amount to reflect inflation over the years and purposely used a conservative estimate of vehicle damage per crash (ranging from $1,271 in 1996 to $1,434 in 2001).

Vehicle collisions with deer and other larger animals cause injury to drivers and passengers. Although collisions with vehicles involve many species, larger wildlife species (deer, elk, moose, caribou, and large carnivores) pose the most risk to driver safety and result in higher human injury rates. Rue (1989) reported a 4 % human injury rate nationwide for deer-vehicle collisions and reported that 0.029% of deer vehicle collisions resulted in human fatality. Hartwig (1993) estimated that ~25 people were killed and ~2,500 people were injured each year in DVCs in Germany. Groot Bruinderink and Hazebroek (1996) reported that as many as 30,000 DVCs result in human injury each year in Europe.

Although various studies have assessed the number of people who suffer injuries because of deer-vehicle collisions, there is very little information regarding the costs that accrue because of these injuries (Schwabe et al. 2002). Economic analyses of injuries due to deer-vehicle collisions are not easily obtained because of the difficulty associated with assigning monetary values to human injuries and fatalities. For instance, Reed et al. (1982) chose to omit these from a cost-benefit analysis of deer-vehicle accident reduction methods, citing the challenges associated with quantifying injury and death in terms of money. However, to understand the full spectrum of the impacts of animal crashes and to put them into a broad and applicable perspective, it is both necessary and useful to assign a cost to these damages and losses. In this analysis, we use a unique dataset that links wildlife-vehicle collision information with data regarding occupant injuries and associated medical charges. This enabled us to accurately and objectively assign values to these outcomes, creating an analysis that for the first time, fills an existing gap in natural resource economics literature.

DVCs not only cause injury to humans and damage to vehicles, but also often result in a deer fatality, causing a further economic loss. Allen and McCullough (1976) reported that 92% of deer-vehicle collisions result in the death of the animal. Similar to estimates of vehicle damage, different methods were used to determine the values that should be assigned to individual animals. Conover (1997) stated that the value of a wildlife species is derived from the impact that it has on a "person's economic state, sense of well-being, or quality-of-life." Thus, he acknowledges that there are not only monetary values associated with a species, but also intangible values. Based on their impacts on people, deer can have both negative and positive values that contribute to their net value and to the loss assigned when one is killed. Conover (1997) argued that because deer in the U.S. are not owned by individuals but are the property of the collective society, it is difficult to establish monetary values for deer using traditional market system approaches. However, many approaches have been employed. Often, an analysis of the amount that individuals spend on activities related to the species of interest is used to provide an estimate of the positive monetary value of an animal. For instance, Adamowicz et al. (1991) found that deer in Alberta were worth $53 million based on a per person value of $119-210 of the benefits derived from hunting. In another instance, Reed et al. (1982) used a value of $350 based on damages that were awarded to the State of Colorado to compensate for the economic loss of a deer. For our analysis, we used a conservative estimate of the value of a mule deer ($236, CPI adjusted to 2001) that was determined using contingent valuation (Loomis et al. 1989). Contingent valuation is a method used to assess non-market values by asking people how much they would be willing to pay for specific environmental services or goods, contingent on a specific hypothetical scenario. Clearly, there is an important economic component to DVCs. By acknowledging the estimated costs associated with these crashes, we understand why managers seek to minimize them. Despite the fact that in some areas road mortality may not have a large impact on the abundance or survival of ungulate populations, this problem is of economic importance, is a significant safety concern, and is also an important issue for conservation (Groot Bruinderink & Hazebroek 1996).

To put this issue into a public safety perspective, we used data from Utah to summarize and analyze the costs of vehicle damage, human injury, human death, and deer loss that result from deer vehicle collisions on roadways. Our analyses demonstrate the magnitude of this issue on a broader scale by confirming that associated costs, damage, injuries, and loss of resources are significant aspects of DVCs that require attention and justify mitigation.

Methods

Study Area. The topography of Utah is diverse, consisting of mountainous, desert, rangeland, agricultural, wetland and urban regions. Elevations across the state range from 762 m (2,500 feet) in the Virgin River Valley in the southwest to 4,114 m (13, 498 feet) at Kings Peak in the Uinta Mountains. This varied terrain is accessed and divided by ~9500 km (~5,900 miles) included in 248 state routes and ~ 56,327 km (~35,000 miles) of city and county roads that are being used by a growing number of drivers (Appendix A, Figure A-1). From 1990 to 2001,[2] the number of licensed drivers in the state increased 43%, from 1,046,106 to 1,495,887. Vehicle Miles Traveled (VMT) increased from 14,646,000 to 23,452,000 (60.1%) over the same time period (Bureau of Transportation Statistics 2004). In addition, the population of Utah increased by 29.6 % (510,319 people) from 1990-2000 and is projected to continue this upward trend with an estimated increase of 554,501 people (24.8%) from 2000 to 2010. As the population increases, it is expected that licensed drivers and vehicle miles traveled will increase, making the issue of animal vehicle collisions an even larger safety and conservation priority. These data are representative of many parts of the world. For example, in Portugal, since 1986 the total mileage of roads has increased by ~ 20% (M. Santos Reis, U. Lisbon, personal communication).

Data Description. Our data set came from the Utah Crash Outcome Data Evaluation System (CODES) project. The Utah CODES project is based at the Intermountain Injury Control Research Center, University of Utah School of Medicine and is directed by J. Michael Dean MD, MBA and Larry Cook, M.Stat,

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[2] This represents the latest data available.

who provided us with the necessary data for our analysis. The data included wildlife-vehicle collision frequencies, associated human injuries and fatalities, and costs for crashes occurring within Utah from 1996 to 2001. The CODES database contains vehicle collisions for Utah from 1992 to 2002. At the time of this analysis, both emergency department and in-patient charges were available and linked for collisions occurring from 1996 to 2001. The CODES project is based on probabilistic record linkage, a method for combining multiple databases to study motor vehicle crashes in conjunction with other healthcare databases. The project relies on the following databases: the Utah Department of Transportation (UDOT) motor vehicle crash records completed by officers at the scene; the Utah Department of Health, Bureau of Emergency Medical Services records on emergency medical services runs; discharge records from emergency departments and hospitals collected from individual hospital organizations; vital statistics databases (i.e., death certificates and birth certificates); and driver license databases (i.e., moving citations and driver medical conditions).

Combining the information in these databases is necessary to create a comprehensive picture of the event and its consequences. For example, the motor vehicle crash database provides a number of variables that are of interest for the analysis of motor vehicle crashes (i.e., weather conditions, type of crash, the number of people and vehicles involved). This database also includes a police-assessed injury score coded on a five point scale ranging from 1 (not injured) to 5 (killed) and assigned to each passenger at the scene of a crash. However, more accurate measures of severity exist in other healthcare databases including the Glasgow Coma Score

(GCS) assessed by emergency medical services, and the Abbreviated Injury Score (AIS) and Injury Severity Score (ISS) calculated from emergency department and hospital discharge datasets. While healthcare databases contain more accurate severity rankings and injury mechanisms codes, there are no crash characteristics (as mentioned above) documented within them. Because the information within these databases was collected independently from different sources, researchers developed a probabilistic linkage method to join information from different databases. Comparing numerous common data fields, such as date of birth or gender, in two different files leads to the logical conclusion that two 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.

We used these linked data sets to develop our analysis of the economic costs associated with wildlife-vehicle collisions in Utah. Our analysis excluded large domestic animal collisions (e.g., livestock). Smaller wild animals-vehicle collisions are seldom reported. The CDC (2003) reported that deer are the most common large animals involved in vehicle collisions. Most reported large animal-vehicle collisions involving wildlife in Utah involved mule deer (*Odocoileus hemionus.*); with only a few involving elk or other larger animals (John Bissonette and Doug Anderson, personal communication). For this reason and given the nature of the Utah CODES data base, we focused on identifying patterns, trends and costs associated with motor vehicle collisions involving almost exclusively mule deer.

Estimates of Vehicle Damage. Romin (1994) reported that big-game vehicle damage claims averaged ~$1,200 per incident in Utah in 1992. In a mitigation cost-benefit analysis including a vehicle damage value, Bissonette et al.(2005) adjusted this vehicle damage claim amount to 1998 (~$1,320 per deer-vehicle collision). 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 wildlife-vehicle collisions in Utah. To take inflation into account and to accurately reflect the cost of vehicle damage during each year, we CPI adjusted the 1998 cost per crash value for each year (1996-2001). Using this adjusted cost per crash and the total number of crashes per year, we calculated the overall costs of vehicle damage per year; this allowed us to compare vehicle damage values across all 6 years.

Human Injury. To calculate the total and average in-patient and emergency department charges for each injury code, we used individual occupant data (n = 20,873) sorted by injury code. If occupants incur a charge from the emergency department or hospital, it is linked to their record, making it possible for costs to be assessed by injury severity. Injury codes, which are assigned to each occupant of a vehicle by the reporting officer at the site of the collision, include: 'no injury,' 'possible injury,' 'bruises/ abrasions,' 'broken bones/bleeding,' and 'fatal.' An occupant coded as 'no injury' shows no signs of bodily harm as a result of the collision, including confusion, excitement, anger, or internal injuries unknown to the person until after leaving the scene. 'Possible injury' is a reported or claimed injury that is neither incapacitating nor fatal, including momentary unconsciousness, claims of injury that are not evident, limping, complaint of pain, nausea or hysteria. 'Bruises/abrasions' include non-fatal and non-incapacitating injuries that are apparent to others at the scene of the collision, i.e., lump on the head, abrasions, and minor lacerations. Occupants coded as 'broken bones/bleeding' have non-fatal injuries which prevent them from continuing the activities they were capable of before the collision, e.g., walking or driving. These injuries can include severe lacerations, broken or limbs, skull fractures, crushed chest, internal injuries and unconsciousness. A 'fatal' injury is any injury sustained in or as the result of a collision that causes the death of the injured person. Because 'fatal' was included as an occupant injury code within the CODES database, we include these collisions and occupants in our assessment of number of collisions and injuries. However, our full economic analysis of fatalities will be considered separately (see Human Fatalities).

We did not adjust values by the CPI when comparing total and average emergency department and inpatient charges by injury class. We wanted to show the distribution of injuries across classes as reported in the database from 1996 to 2001. To compare costs by year and injury class, we used adjusted reported values to reflect costs in 2001. Standardizing these values allows us to differentiate between changes due to inflation and actual increases in medical charges.

Human Fatalities. To guide public policy and health and safety regulations, governmental agencies have attempted to define the value of a life for over thirty years (U.S. Department of Transportation 2002). In preparing economic evaluations, the U.S. Department of Transportation (DOT) has defined the term "value of a statistical life" (VSL) as the value for safety measures that reduce the statistically predicted number of accidental fatalities by one. The basis for this comprehensive standard amount originated from an attempt by the Federal Highway Administration to standardize values used; it represents willingness-to-pay (WTP) by citizens for an averted fatality and does not differ according to age, health, income, or specific type of risk. In 2001, adjusting the value of life by the Gross Domestic Product (GDP) implicit price deflator,[3] the DOT recommended the use of a value of $3.0 million (U.S Department of Transportation 2002). Because only three fatalities had dates associated with them, we used this value in our analysis for all eight fatalities to coincide with the last year of data available in the CODES database.

Deer Loss. To calculate the number of deer killed per year in Utah from 1996 to 2001, we estimated that 92% of collisions result in at least one deer dying based on (Allen & 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 is surrounded by a history of controversy and debate (Langford & Cocheba 1978). Difference in age, sex and condition can affect how humans value deer. Schwabe et al. (2002) explained that a variety of methods have been used within deer-vehicle collision and natural resource economics literature, resulting in a range of values with a minimum of $35 (Livengood 1983) and a maximum of $1,313 (Romin & Bissonette 1996). Despite the fact that each estimate was derived from costs associated with hunting, there is still a wide range in values. This exists because prices have been estimated for different deer species in distinct parts of the United

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[3] 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.

States, using varied market valuation techniques (Schwabe et al. 2002). Other studies have not focused on hunting, but have instead determined an associated economic value by evaluating the subjective values that people place on a resource (Fausold & Lilieholm 1999). Schwabe and Schuhmann (2002) argued that estimating the impacts of deer loss due to collisions should involve measuring the true value of deer, not only the expenditures associated with hunting. They suggest that economic analyses should focus on the benefits received from a successful hunt instead of the costs incurred to bag a deer. They state that such benefits are represented by costs reported in literature using non market valuation techniques. For example, Loomis et al. (1989) used contingent valuation to estimate the value of an average mule deer at $236 (adjusted to 2001). We used this value based on the value of a deer over and above the cost to a hunter of obtaining a permit, traveling to the site, etc., in our analysis because it is conservative and appears to accurately represent the value that humans place on deer, not only the costs associated with hunting one. This value reflects the consumer surplus or net willingness-to-pay of individuals and is a measure of what hunters gain by being able to hunt. To accurately represent and compare the changes in deer value over the years, we CPI adjusted this value for each year of our data.

Results

Patterns and Trends in Deer-vehicle Collisions in Utah (1996-2001). The CODES database contained a total of 13,020 recorded deer vehicle collisions and 308,584 non-deer vehicle collisions, for a total of 321,604 collisions over 6 years.

Deer-vehicle collisions accounted for ~4.0 % of all collisions. In Utah, wildlife collision rates remained fairly constant over 6 years with a mean value of 2,170 collisions per year, a maximum of 2,256 and a minimum of 2,047 collisions per year (Fig, 4-1). Non DVC rates were also constant with a mean of 51,431 collisions per year, a maximum of 52,747 and a minimum of 50,274 collisions per year (Fig. 4-1).

Higher numbers of DVCs occurred from October through December (Fig.4-2); 4,220 or ~1/3 of all collisions occurred within a 1/4 of the year. In addition to a pulse of crashes in the fall, 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 other 6 months ranging from 791 (6.1%) to 978 (7.5%) collisions. Most DVCs occurred from 1900 to 2400 hr (Fig. 4-3). In these 6 hours there were 7,079 collisions totaling 54.4% of all crashes. An increase occurred in the early morning hours (0600 to 0800hr) with 2,261 crashes or 17.4% of the total number of crashes. The most crashes within an hour (1,557, 12%) occurred from 2200 to 2259 hr while the least collisions (99, 0.8%) occurred from 1400 to 1459 hr.

Estimates of Vehicle Damage. From 1996 to 2001, we calculated an increase of ~12.8% ($163) in the average adjusted per crash value (AAPCV) with a minimum in 1996 of $1,271 and a maximum in 2001 of $1,434. The overall total costs per year associated with vehicle damage correlated with the number of collisions occurring per year; 1997, the year with the least amount of collisions had the lowest total cost of vehicle damage ($2,661,100) while 2001, the year with the most collisions occurring had the highest total costs associated with vehicle damage

($3,235,104) (Fig. 4-4). From 1996-2001, we calculated the mean total cost of vehicle damage as $2,920,328 per year, while the total for the 6 years was $17,521,970.

Human Injury. There were 20,873 people involved in wildlife-vehicle collisions from 1996 to 2001. They 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' (Fig.4-5). Of the 20,873 occupants, a total of 448 (2.1%) incurred an in-patient hospital or emergency department charge; charges for human injury totaled $1,002,401. Forty-four (0.2 %) were hospitalized for at least one night, accruing charges of $781,324 while 404 (1.9%) visited the emergency department (ED), resulting in $221,077 in charges (Fig 4-6).

Distribution across injury classes (Fig. 4-5) does not correlate with cost due to the disparity in charges associated with certain types of injuries (Fig.4-7). Second to 'fatal', the injury code 'broken bone and bleeding' had the least common occurrence (1.2% of all reported wildlife-vehicle collisions from 1996-2001). Despite a low number of overall incidences, occupants classified within this injury code contributed to 28% (114) of all emergency department visits and 79.5% (35) of all in-patient visits. This injury code was the most costly with 40.7% ($90,112) of total emergency department costs and 93.9% ($733,481) of overall total inpatient costs (Fig 4-7). Those classified within 'bruises or abrasions' had 29.4% (119) of emergency department visits, 11.4% (5) of in-patient visits, and accrued 24.0% ($52,978) of emergency department costs and 3.7% ($28,940) of in-patient costs. Occupants classified as 'possible injury' were responsible for 22.2% (90) of emergency department visits and 2.3% (1) of inpatient visits, totaling 18.1% ($40,013) of emergency department costs and 0.7% ($5,851) of in-patient costs. Those with 'no injury' had 19.3% (78) of emergency department visits, 6.8% (3) of in-patient visits and contributed to 15.4% of emergency department costs ($34,059) and 1.7% ($13,052) of in-patient costs. Occupants classified as 'fatal' had no in-patient costs and contributed to 1.8% ($3,915) of all emergency department costs (Fig. 4-7).

We reported the average charges across injury classes to illustrate the impact that injury severity and type of treatment (in-patient or emergency department) can have on charges incurred. For 'no injury' to 'broken bone/bleeding' emergency department average costs range from $437 to $790 with increasing severity, while in-patient average charges range from $4,351 to $20,957. Per crash, in-patient costs are from ~10 times (no injury) to ~26.5 times (broken bone or bleeding) higher than emergency department costs. With increasing injury code severity, average costs also increase. Emergency department average charges showed a ~1.8 times increase from 'no injury' to 'broken bone or bleeding', while in-patient average charges showed a ~4.8 times increase across these same categories.

An analysis of injury class costs by year adjusted to 2001 values allowed for a comparison across years and injury codes (Fig. 4-8). Because charges were adjusted, we expected that the total adjusted charges within an injury class would be proportional to the number of people that fell within that injury code per year. However, we did not always find this result. An analysis of adjusted totals and means revealed that there is a great deal of variation within the in-patient 'broken bone and bleeding' category independent of the number of people within a category. For example, data shows that in 1996 there were four people in that category totaling adjusted charges of $62,490 with an adjusted mean of $15,128. We would expect that adjusted charges for the 12 people injured as severely in 2000 would equal roughly 3 times the total value or ~$187,470 with a similar mean of ~$15,622. However, the adjusted total charge for 12 people within this category was actually $354,408 or ~5.7 times the total value, resulting in a mean of $29,534 (1.5 times the mean).

We find a similar occurrence within the 'no injury' in-patient charges when looking at the only 2 years with charges. In 1996, one person accrued a charge of $2,146 while in 1998, 2 people accrued charges of $12,116. A comparison of means adjusted for 2001 shows a ~282% increase from 1996 (mean = $2,146) to 1998 (mean= $6,058). Similarly, when looking at emergency department charges in the 'possible injury' class, we find a disparity among charges despite the fact that both 1997 and 1999 show 19 people in this class. For 1997, we calculated a total adjusted value of $11,077 (mean =$583), while for 1999, we calculated a total adjusted value of $6,421 (mean =$338). These variations may be due to changing medical costs and/or variation in the severity of injuries and/or treatment needs of people assigned to the same injury code.

Human Fatality. There were 8 reported fatalities due to deer-vehicle collisions in Utah from 1996 to 2001. The CODES database reported only three with emergency department charges totaling $4,270 (2001 adjusted dollars). To provide a more complete and accurate assessment of costs associated with deer-vehicle collision fatalities, we used the DOT/FHWA statistic for the value of a human life

($3.0 million) to estimate that fatalities in Utah from 1996 to 2001 carry a value of ~ $24.0 million (adjusted to 2001).

Deer Loss. We calculated 92% of each reported collision count per year to estimate the number of deer killed; these remained fairly constant ranging from 1,883 deer in 1997 to 2,076 in 2,001 for a total of ~11,978 deer and a mean of 1,996 deer killed per year

(Fig 4-9).

We found that the adjusted value of a deer increased each year from $209 in 1996 to $236 in 2001 (Fig. 4-9). From these values, we calculated the yearly monetary costs of deer loss and found that yearly costs were fairly constant ranging from a minimum of $403,013 in 1997 to a maximum of $489,823 in 2001. These values correlated with the low (1,979) and high (2,076) numbers of deer killed, however, this pattern was not always consistent; in 2000, the second lowest number of deer were killed (1,965) resulting in the fourth highest cost ($450,012). The overall calculated total cost for 6 years in Utah was $2,651,083 with a yearly mean of $441,847 (Fig. 4-9). This is a conservative estimate; deer hit by large trucks are seldom 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 per year cost of ~$7,529,242 and an overall per crash value of ~$3,470. Contributions to total costs varied widely: estimated human fatality costs of $24 million accounted for 53%; vehicle damage costs of $17,521,970 accounted for

39%; deer loss valued at $2,651,083 totaled 6%, and human injury costs of $1,002,401 accounted for 2% of total costs.

Discussion

In Europe, it is estimated that collisions with hoofed animals kill ~300 people, injure ~30,000 people, and cost ~$ 1 billion in property damage each year (Staines et al. 2001). Conover et al. (1995) estimated that over 1 million deer-vehicle crashes 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. Utah had an average of ~2,170 deer-vehicle collisions each year accounting for ~4.0% of all vehicle collisions that occur each year. When property damage, human injury and death, and wildlife loss are included, we estimated overall costs of ~$7,529,242 per year in Utah. If only 1/6 (Decker et al. 1990) to ½ of all deer-vehicle collisions are actually reported (Romin 1994), the impacts of DVCs could be greater than what we calculated (Romin & Bissonette 1996)

Statewide data collection that includes wildlife as a variable allows assessments of the real costs of DVCs. Data to inform mitigation efforts to reduce wildlife-vehicle collisions benefits from the inclusion of information on species sex and age. For modeling purposes, more accurate spatial location data are valuable. Accurate location of carcass data and/or animal vehicle collisions data to at least the 0.1 mile marker or by GPS location would enable the development of reliable models that attempt to correlate environmental variables with areas of high road kill. Nationally, more uniform data collection and data sets utilizing probabilistic linkage would enable states to utilize existing economic data more effectively. NHTSA has funded the following states to create CODES databases to link statewide crash and injury data, making similar analyses possible: 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 to link statewide crash and injury data. Those states that link police crash reports, hospital discharge records, and ambulance reports may have better descriptions of circumstances and outcomes of motor vehicle crashes and may be able to more completely and accurately analyze comprehensive costs associated with DVC. The CODES database we used covered occupants who were treated in either a hospital or the emergency 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. We were unable to address these in our analyses. The inclusion of current insurance claim databases may add to the economic costs of DVC.

Mitigation to reduce wildlife-vehicle collisions is not inexpensive, but it can be practical and cost effective in Utah; the majority of crashes are concentrated on 10.5 % of the available roadway (1000 km of ~9500 km) (Bissonette and Kassar, unpublished data). In Utah, a small percentage of the people (2.1%) involved in deer-vehicle collisions are responsible for 100% of the costs associated with injuries ($1,002,401).

Cost-benefit analyses have shown that mitigation efforts can have positive net economic gains while also increasing safety (Wu1998))(Schwabe et al. 2002b; Bissonette et al. 2005). Research suggests that the collisions might best be mitigated by in the installation of underpasses or overpasses with associated exclusion fencing and ROW escape ramps at certain key travel or migration corridors (Reed et al. 1975; Ward 1982; Foster & Humphrey 1995). There are few, if any circumstances, when fencing should be installed without crossing and ROW escape ramps.

Our data support the findings of the CDC (2004): more people were injured in deer-vehicle collisions during the fall and the dawn and dusk hours when animals are more active. We suggest that mitigation measures, including driver education and outreach, should take into account the temporal patterns associated with DVCs. Placing crossings based on the analysis of collision data should increase the efficacy of the crossing structures, thereby decreasing wildlife-vehicle collisions and increasing public safety.

The Center for Disease Control (CDC; 2003) reported that nonfatal wildlife-vehicle related injuries accounted for <1.0% of the ~3 million people treated in U.S. emergency departments annually due to motor-vehicle related injuries. However, the CDC (2003) also argued that wildlife-vehicle collisions and associated consequences, including property damage, wildlife 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 animal-vehicle collisions make this an important issue in Utah and across the country.

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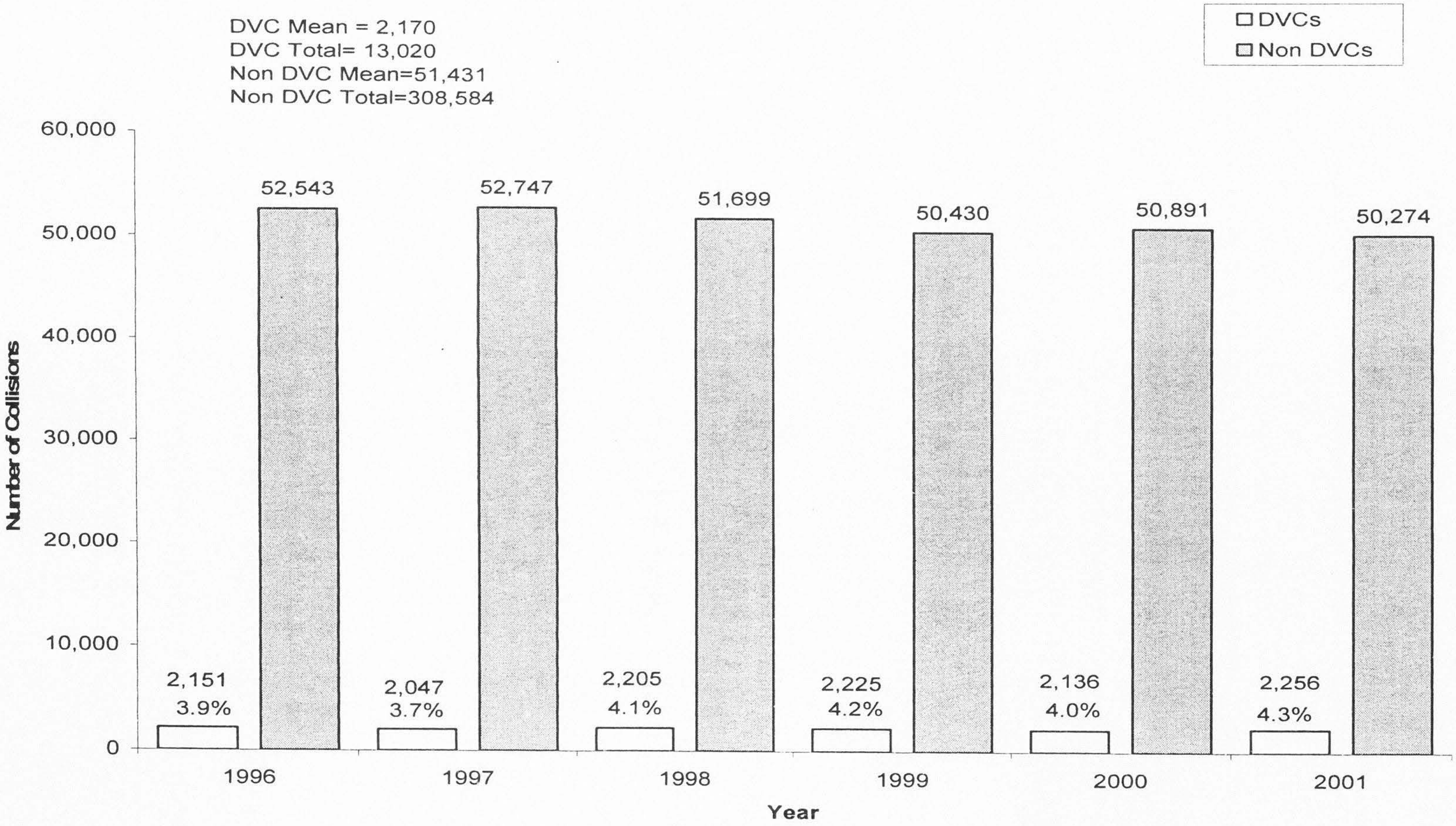


Figure 4-1. Deer-vehicle collisions (DVCs) and non DVCs by year, Utah, 1996-2001. Shown are the percent of total collisions made up by DVCs.

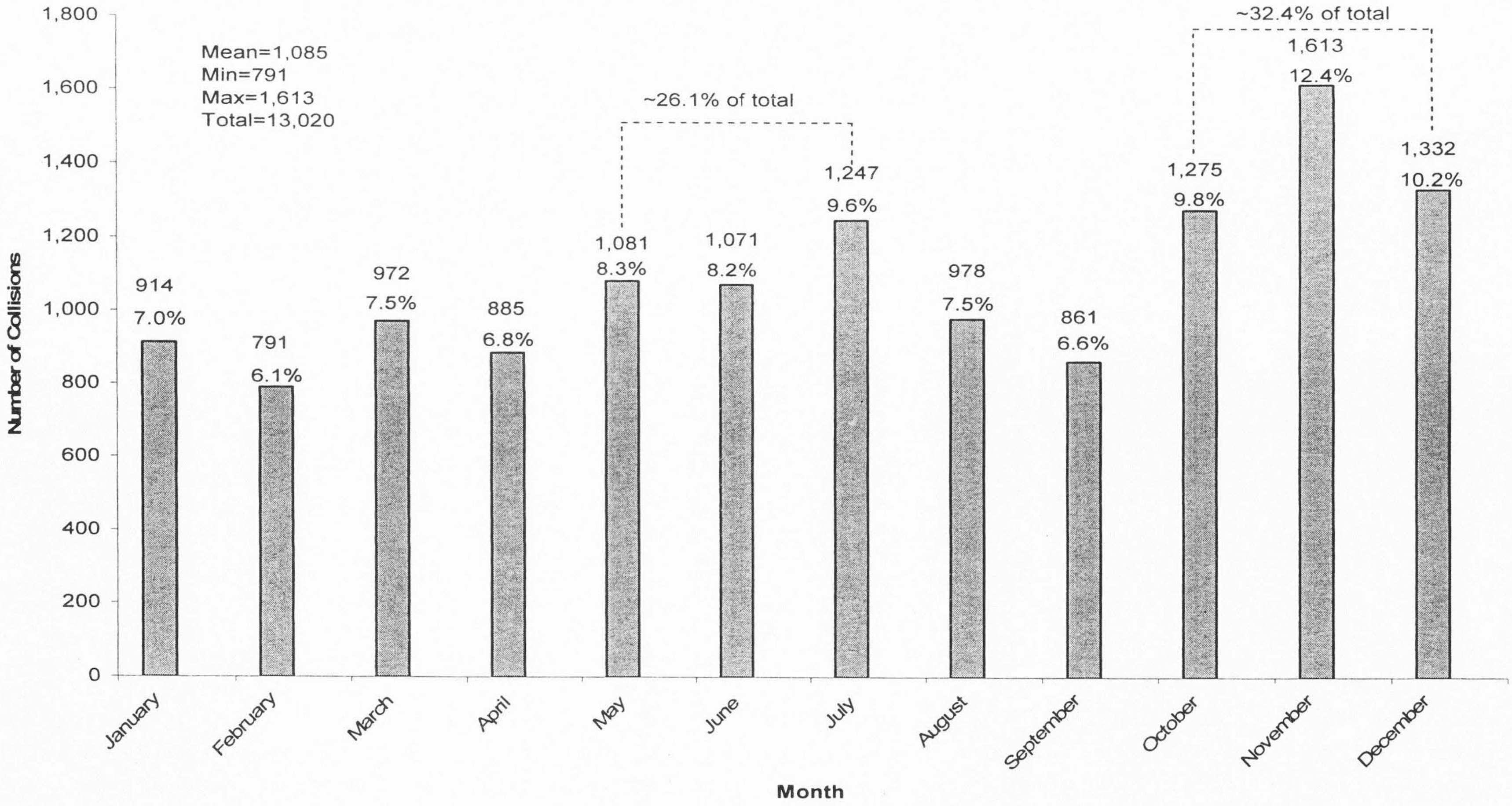


Figure 4-2. Trends in deer-vehicle collisions by month, Utah, 1996-2001.

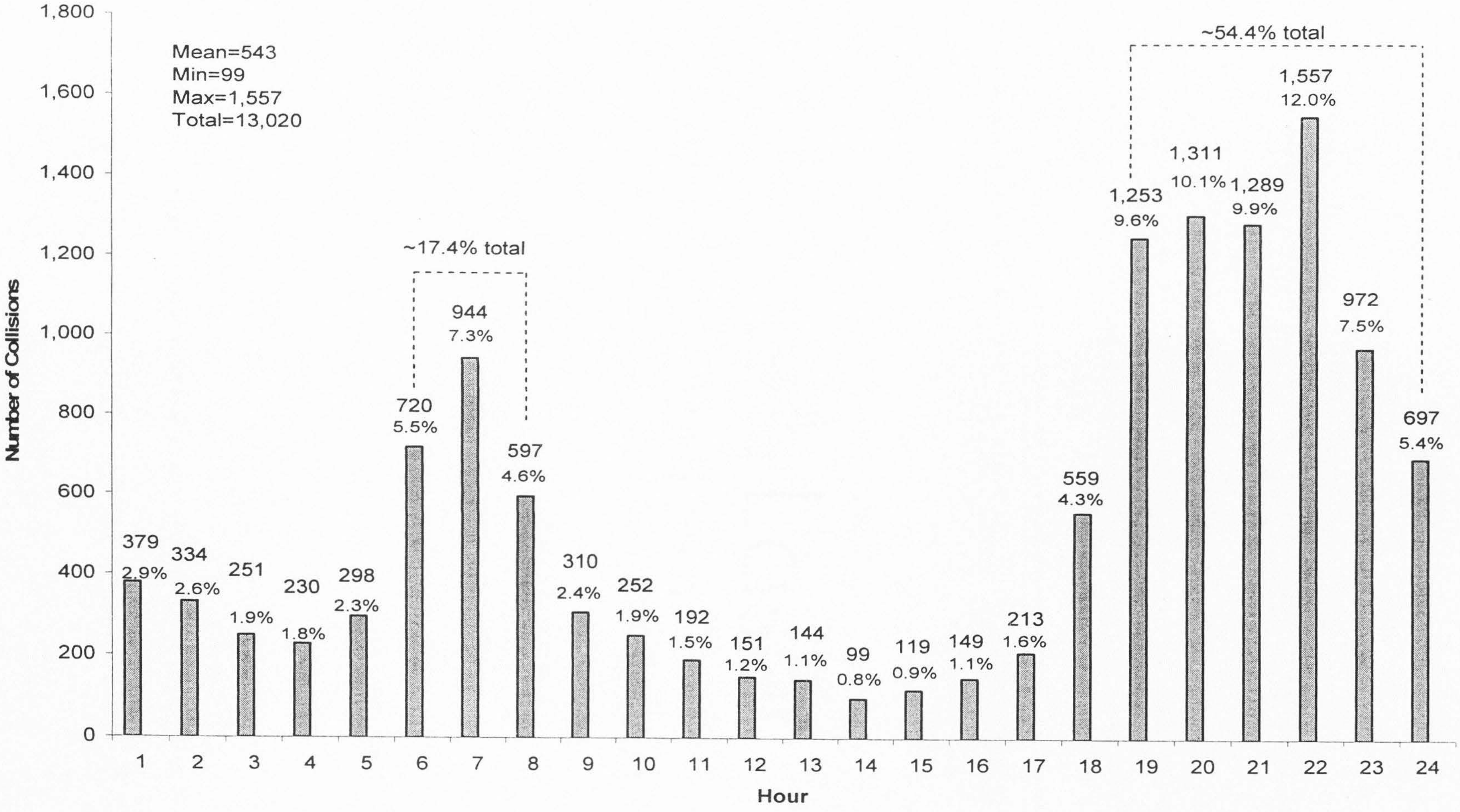


Figure 4-3. Trends in deer-vehicle collisions by hour, Utah, 1996-2001.

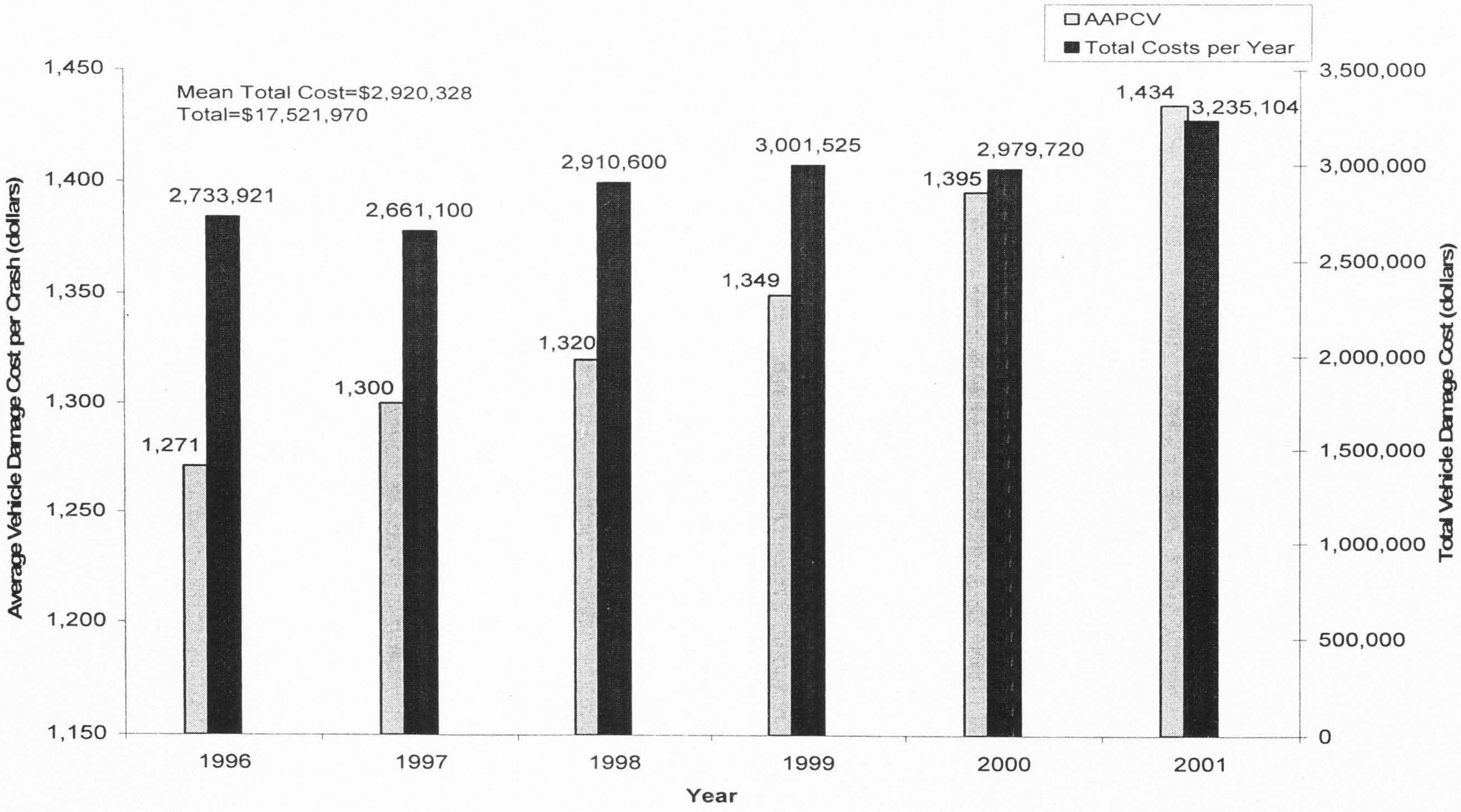


Figure 4-4. Deer-vehicle damage costs by year, Utah, 1996-2001. The adjusted average per crash value (AAPCV) has been adjusted to accurately represent the value for each year.

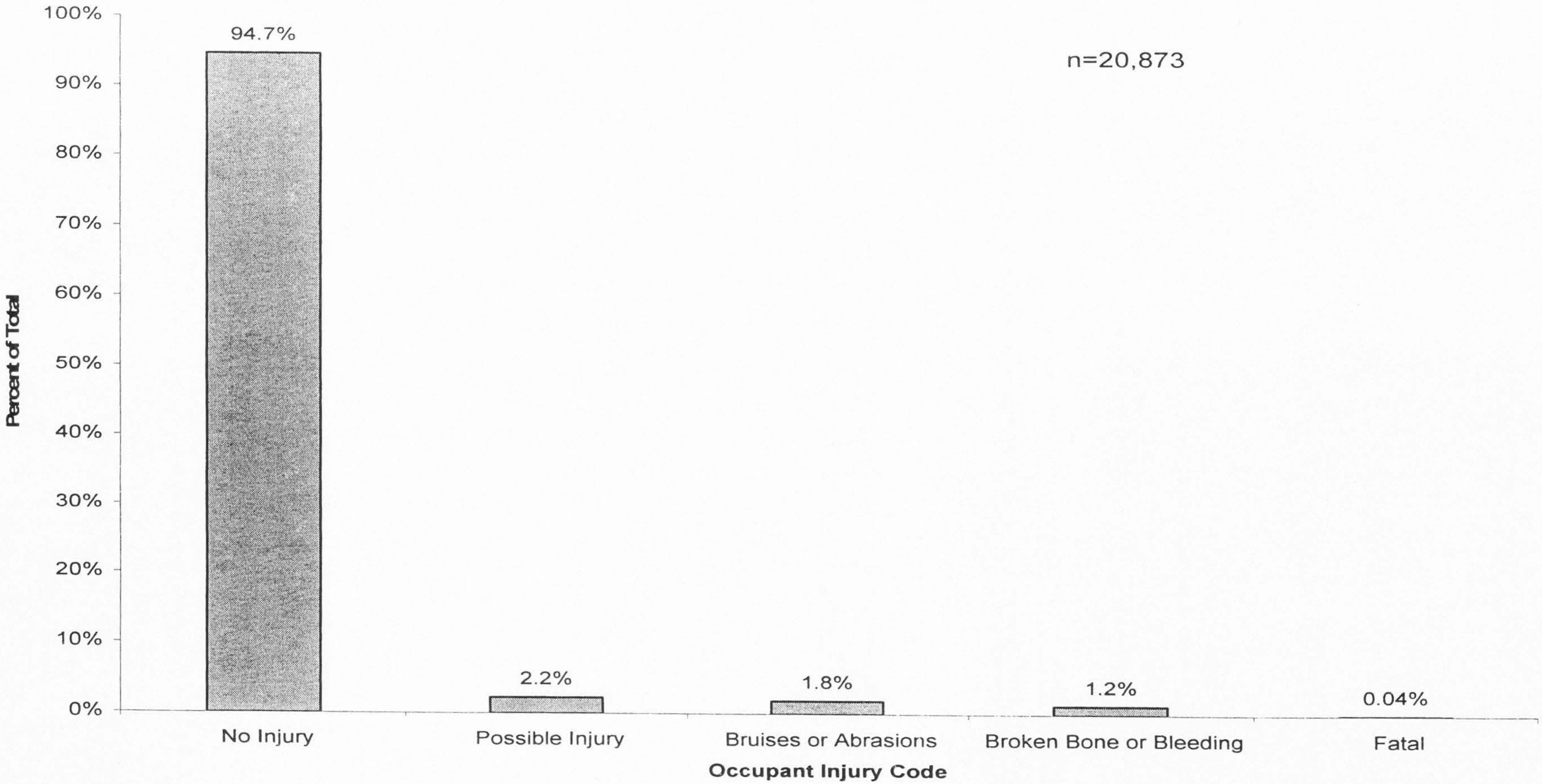


Figure 4-5. Trends in injuries associated with deer-vehicle collisions, Utah, 1996-2001. Occupant injury codes are assigned at the scene of the collision by the reporting officer.

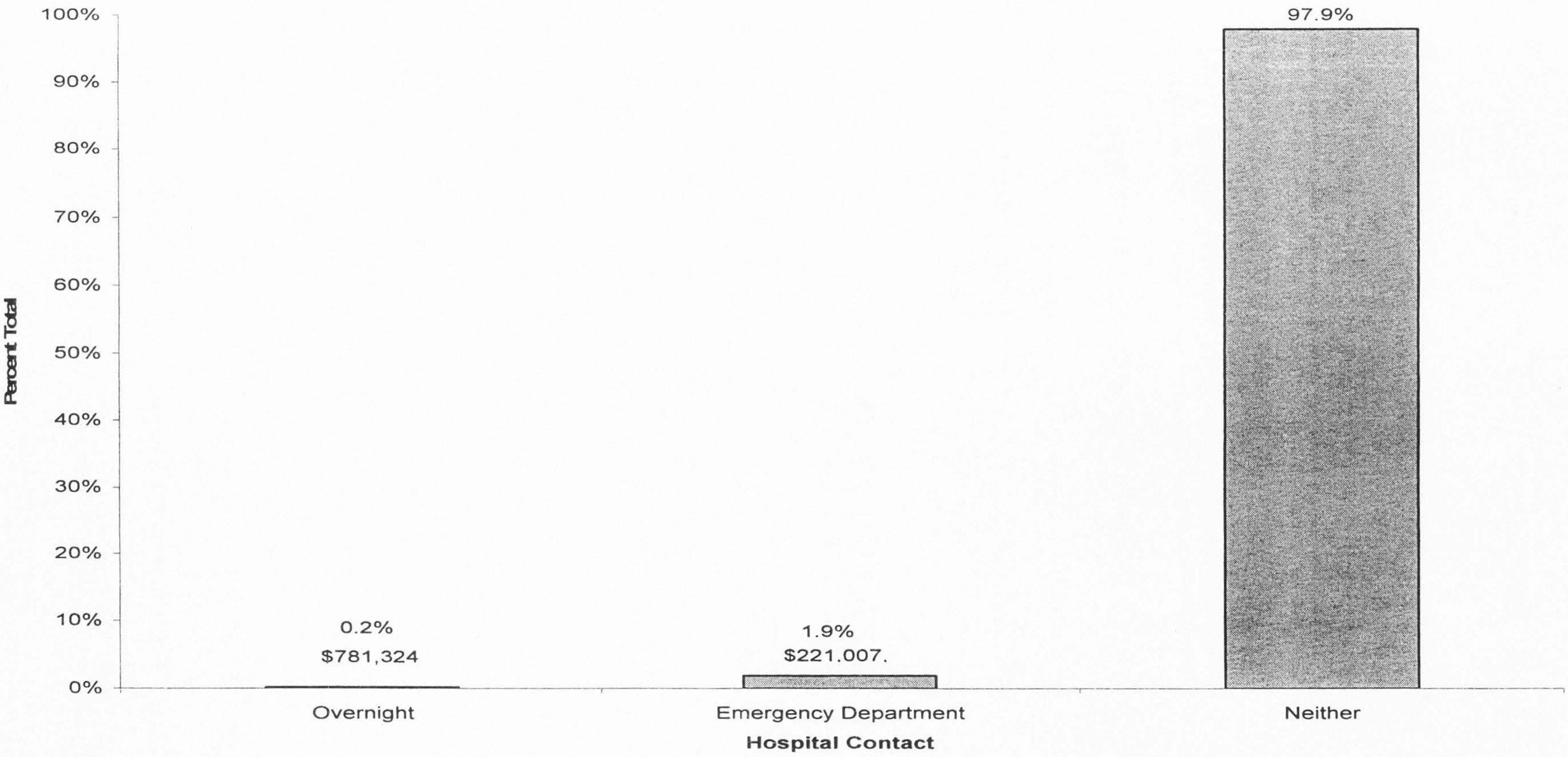
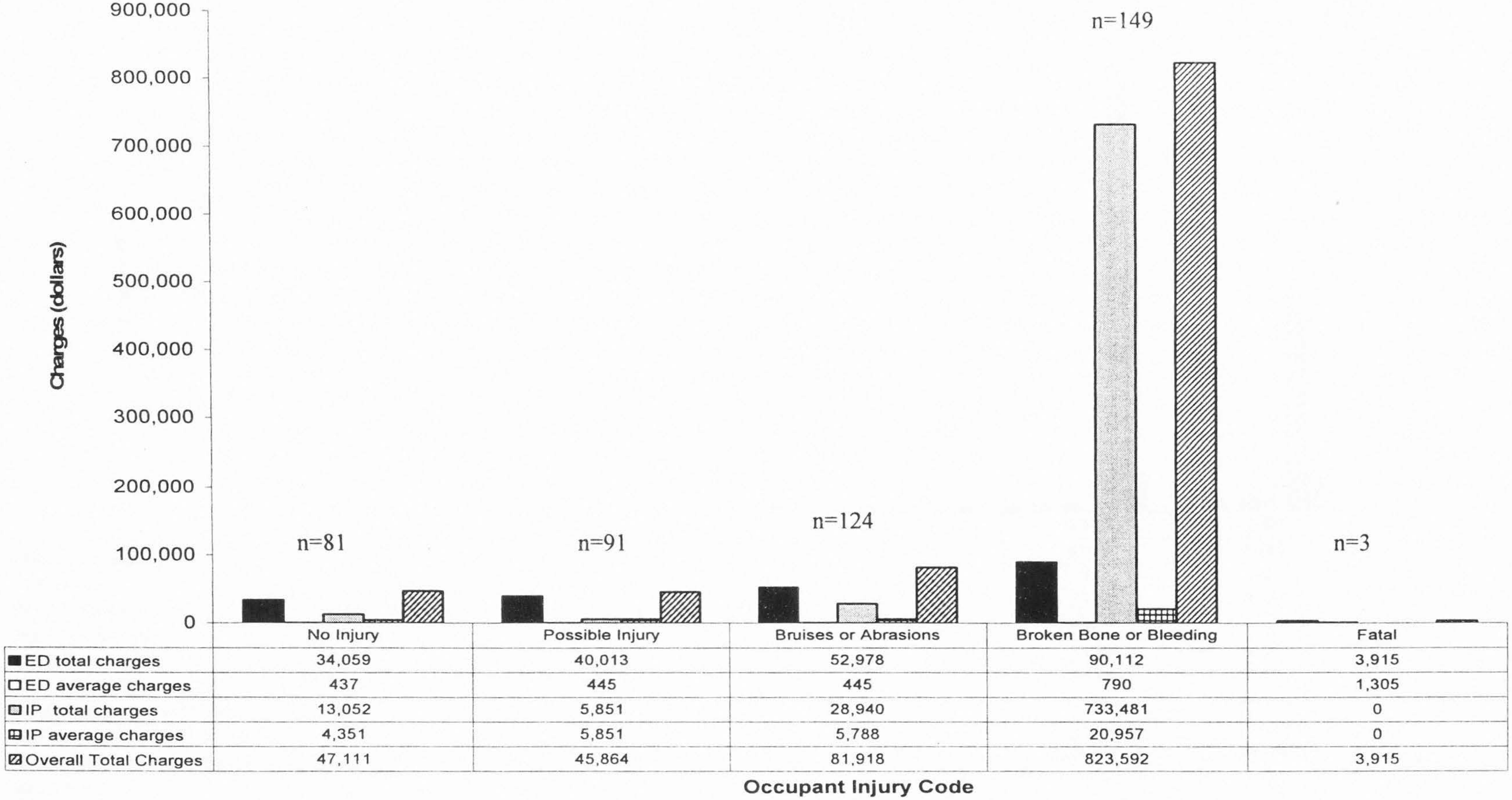
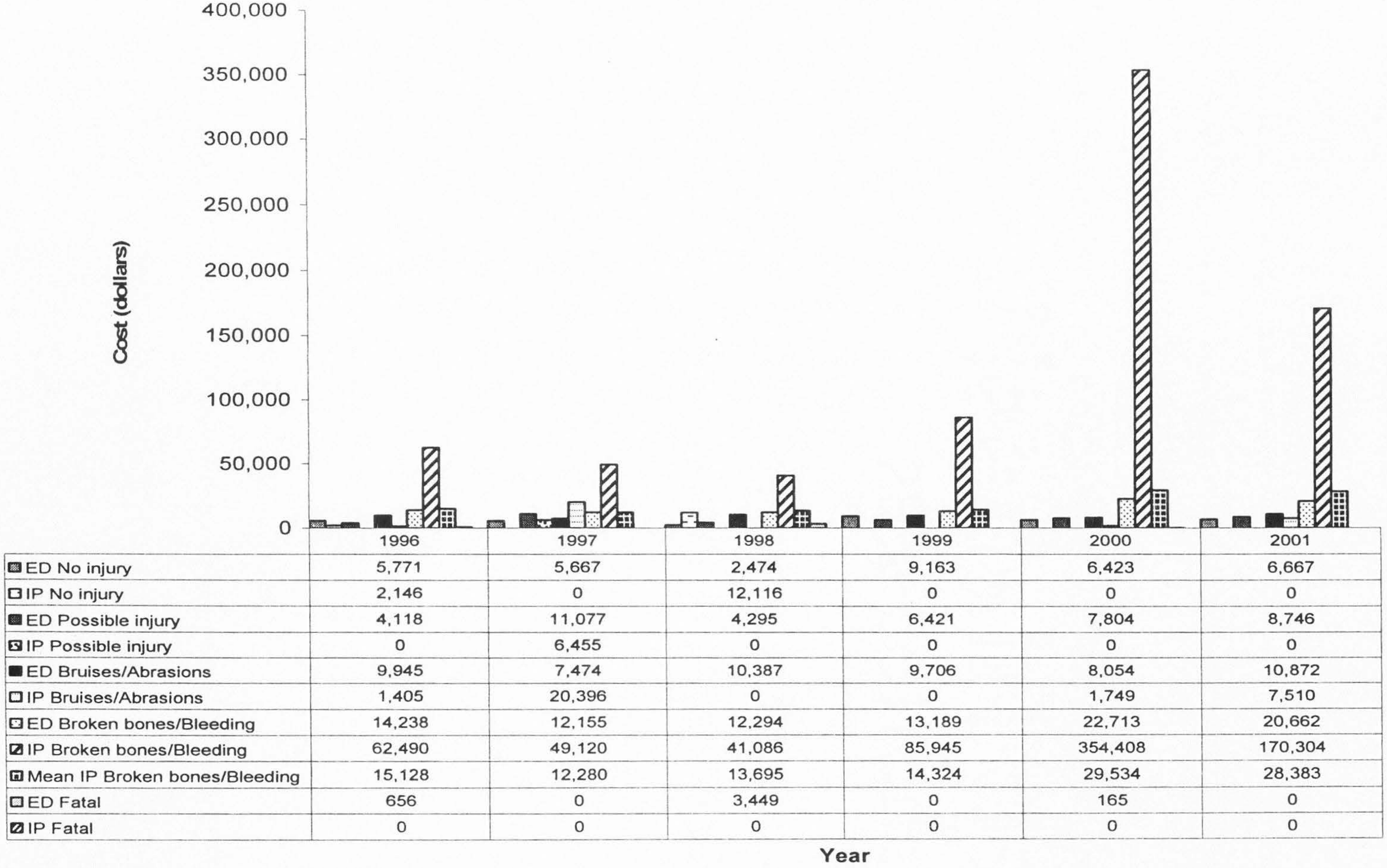


Figure 4-.6 Percent of occupants in deer-vehicle collisions who were either hospitalized overnight or who visited the emergency department and were not admitted to that same hospital, Utah, 1996-2001. Costs associated with these are shown with the percentage who received treatment.



	No Injury	Possible Injury	Bruises or Abrasions	Broken Bone or Bleeding	Fatal
■ ED total charges	34,059	40,013	52,978	90,112	3,915
☐ ED average charges	437	445	445	790	1,305
☐ IP total charges	13,052	5,851	28,940	733,481	0
⊞ IP average charges	4,351	5,851	5,788	20,957	0
▨ Overall Total Charges	47,111	45,864	81,918	823,592	3,915

Figure 4-7. Summary of medical charges resulting from deer-vehicle collisions, 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 overnight).



	1996	1997	1998	1999	2000	2001
▩ ED No injury	5,771	5,667	2,474	9,163	6,423	6,667
☐ IP No injury	2,146	0	12,116	0	0	0
■ ED Possible injury	4,118	11,077	4,295	6,421	7,804	8,746
⊠ IP Possible injury	0	6,455	0	0	0	0
■ ED Bruises/Abrasions	9,945	7,474	10,387	9,706	8,054	10,872
☐ IP Bruises/Abrasions	1,405	20,396	0	0	1,749	7,510
▦ ED Broken bones/Bleeding	14,238	12,155	12,294	13,189	22,713	20,662
▨ IP Broken bones/Bleeding	62,490	49,120	41,086	85,945	354,408	170,304
⊞ Mean IP Broken bones/Bleeding	15,128	12,280	13,695	14,324	29,534	28,383
☐ ED Fatal	656	0	3,449	0	165	0
▨ IP Fatal	0	0	0	0	0	0

Figure 4-8. Summary of medical charges due to deer-vehicle collisions, sorted by year and by injury class, Utah, 1996-2001. ED=emergency department; IP=inpatient (≥ 1 overnight).

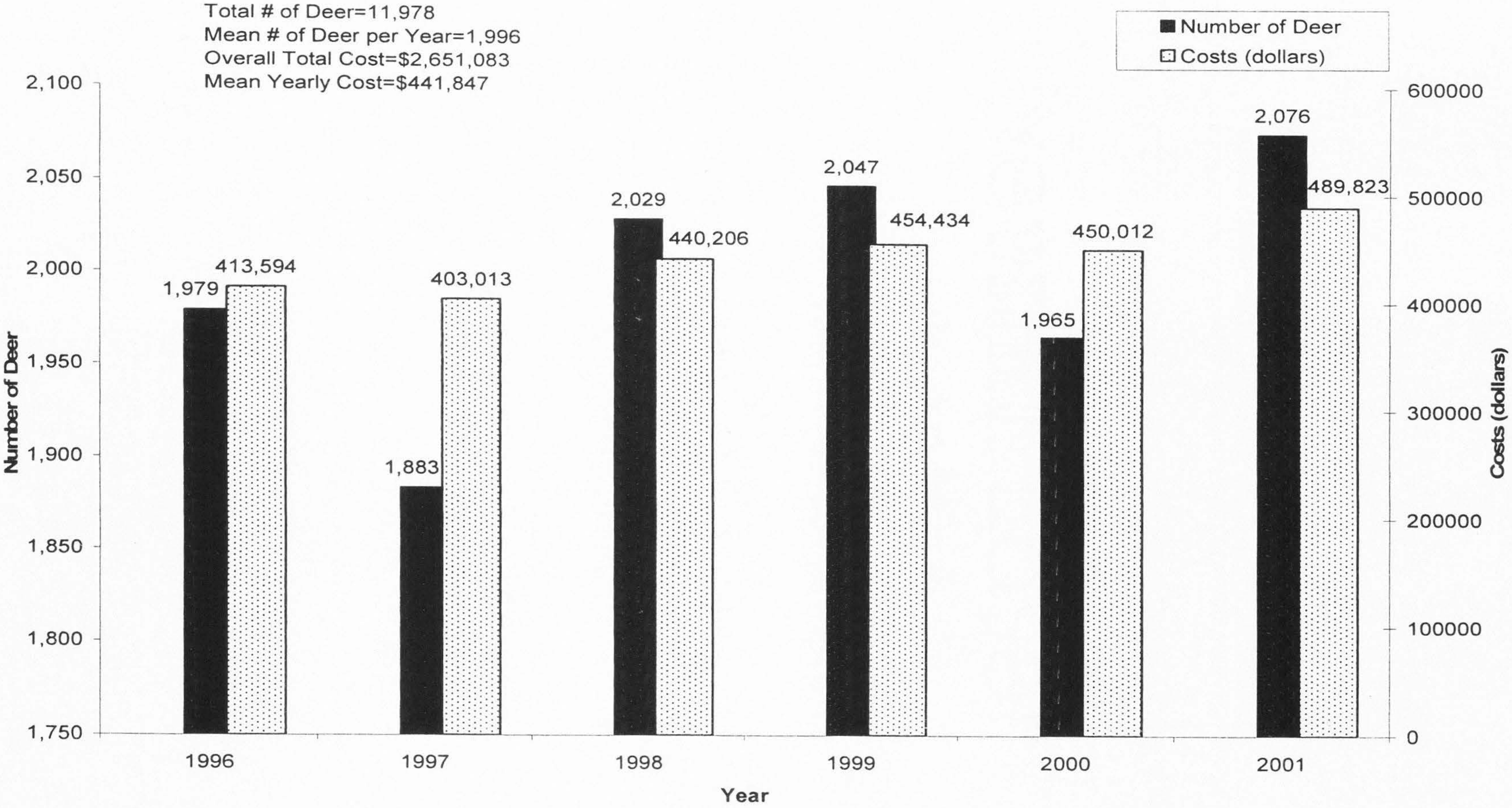


Figure 4-9. Summary of costs associated with deer losses due to vehicle collisions, Utah, 1996-2001.

CHAPTER 5

CONCLUSION

Ecological processes and patterns impact the roaded landscape and effect interactions between wildlife and vehicles. Quantifying the effects of roads on animals is an important step in determining the long-term decisions that scientists, engineers, and managers make regarding road planning, engineering, and mitigation. This case study analysis of wildlife-vehicle collisions in Utah quantified these effects by investigating patterns and trends in collision locations, causal relationships, and associated costs based on 11 years of data. This investigation was guided by three main objectives: (1) to determine if wildlife vehicle collisions were concentrated spatially and if so, identify the location of these hotspots; (2) to examine if it was possible to relate the presence of hotspots to simple road geometrics, viz., posted speed limit and traffic volume; and (3) to estimate the economic costs associated with deer-vehicle collisions in Utah.

I studied deer-vehicle collisions occurring on the 248 state routes in Utah from 1992 to 2002 using the Utah Department of Transportation (UDOT) vehicle crash database. To bridge the gap that exists between available information and the practical way it is being used, I analyzed 11 years of relevant data to identify “hotspots” of deer kill. I tracked trends and patterns in deer-vehicle collisions throughout the years, evaluated entire routes for frequency of deer kills, and identified “hotspots,” defined as segments of road with high concentrations of collisions per mile. I found that although the number of deer-vehicle collisions did not vary much from year to year (1992-2002), seasonal patterns and daily temporal patterns were pronounced. A small number of the routes had a disproportionately high concentration of the collisions, suggesting that mitigation may be practical and cost effective in Utah. Because the research suggested that certain road segments were more susceptible to wildlife mortality than others, it is clear that animal-vehicle collisions could be significantly reduced and road safety enhanced if mitigation were prioritized based on the spatial and temporal patterns of deer mortality hotspots. Temporally, if managers focused on mitigation efforts that directly address times of day and year (e.g., flashing signs on sections of roads during migration, heavy enforcement of reduced speed limits) that are correlated with increased numbers of collisions, mitigation may be more effective. Spatially, mitigation will be informed and most effective if managers recognize that hotspots actually consist of two components: (1) a core area and (2) a mitigation zone. The core area can be defined as the section of the route where collisions per mile (or deer kills) are most concentrated. The mitigation zone is the additional area bordering the core where mitigation is needed to address the "end of the fence problem" by creating a buffer to account for animal movement and behavior. By "end of the fence problem" I refer to the movement of deer beyond the core hotspot. When only a core hotspot is fenced (without associated crossings and right-of-way (ROW) escape structures) deer and other large animals are prone to move along the fence and cross at the end of the fence. If mitigation includes the "mitigation zone" and the installation of crossing and ROW escape ramps, the "end of the fence" (EOF) problem can be largely reduced or eliminated. To determine the length of this mitigation zone on the actual landscape, further local evaluation needs to be done because this will vary based on the characteristics of the hotspot, the surrounding terrain, and the input of managers and biologists within the region.

Research suggests that the collisions might be best mitigated by the installations of underpasses or overpasses at certain key travel or migration corridors, thereby providing animals an opportunity to bypass the road. At the same time, passage over or under the road decreases habitat fragmentation (Reed et al. 1975; Ward 1982; Foster & Humphrey 1995). The use of deer-proof fences in conjunction with deer right-of way escape ramps has also been shown to reduce deer-mortality by providing an effective way for animals to exit the right-of-way (Hammer 2001). Placing crossings based on the analysis of road kill data should increase the effectiveness of the crossing structures by decreasing wildlife-vehicle collisions while restoring connectivity and preventing further fragmentation of habitat.

To make this analysis more complete and useful to managers in the applied sense of implementing mitigation, it is desirable to not only identify the road segments that are most susceptible to deer-vehicle collisions, but also to analyze what it is about these areas and their relationship to deer that result in a larger number of deer-vehicle collisions. I began this process by investigating correlations between higher concentrations of deer-vehicle collisions and two road variables, traffic volume and posted speed limit. I found that although these are commonly cited as correlated, trends in the literature varied, and the results showed no relationship between traffic volume and/or posted speed limit and the number of wildlife-vehicle collisions that occurred on 4 test routes. I suggest five possible hypotheses to explain these results: (1) lack of a causal relationship, (2) data problems, (3) variations within scale and resolution of the data, (4) speed and volume explain only a small part of the variance of the relationship, and (5) some combination of 2, 3 or 4.

In terms of the processes followed and the data needed, my analysis suggests that there are inherent differences between identifying hotspots and models that relate the presence of hotspots to explanatory variables. For the first objective of *defining hotspots of road kill for mitigation action*, my analysis using existing data accurate to the mile marker produced excellent results and can be done for most states, provinces, and countries that have this data. Use of hotspot analyses to prioritize mitigation measures will have quick beneficial effects on restoring landscape permeability. However, I argue that the second objective, developing reliable and accurate *predictive models* of animal-vehicle crashes using explanatory environmental and/or roadway variables was not possible due to the type and extent of data that I had. I suggest that such a task requires that: (1) road kill data is spatially explicit, (2) data regarding explanatory variables and road kill are recorded at appropriate scale extents and resolutions, (3) data is recorded accurately and completely, (4) the model considers not only road geometrics but also environmental variables, and (5) the model considers both driver behavior and animal behavior.

My research suggests that data to inform mitigation efforts to reduce wildlife-vehicle collisions would benefit from the inclusion of information on species, sex, age, and more accurate spatial location. Accurate location of carcass data and/or animal vehicle collisions data by GPS location would enable the development of reliable models that attempt to correlate environmental variables with areas of high road kill. Significant improvement in recording spatial location of wildlife-vehicle crashes would greatly enhance the utility of the data base. Currently, animal-vehicle collisions with damage to the vehicle < $1,000 and with no human injury are seldom if ever recorded. Inclusion of these data in the database would significantly improve any analysis of hotspots of wildlife kill.

This analysis suggests that knowing where to concentrate mitigation efforts may help in curbing wildlife-vehicle collisions and thus, decrease their negative impacts. However, for more effective mitigation techniques to be implemented, it is necessary to not only identify the road segments that are most susceptible to deer-vehicle collisions, but also to analyze what it is about these areas and their relationship to deer that result in a larger number of deer-vehicle collisions. Forman and Deblinger (1998) concluded that "rate of collisions is related to deer density, traditional pathways, and natural habitat quality." Ecologists may need to explore the spatial and temporal components of deer vehicle collisions to determine why they may consistently occur at certain locations. Road kill and crash data can be used in a connectivity analysis using GIS satellite imagery that shows animal migration routes and distribution ranges in relation to hotspots; an analysis of deer populations by road segment may aid in determining if high numbers of animals killed at hotspots are related to population densities. Studies that put hotspots into an ecological context by exploring a full suite of environmental and roadway characteristics would be most helpful.

Action to mitigate and reduce deer crashes can be more easily justified and accomplished when it is possible to target certain areas for mitigation and when deer-vehicle crashes are tied to real costs, including those related to ecological integrity, environmental impacts, and human safety. Thus, I evaluated the economic impacts of deer loss, vehicle damage, human injury, and human death. My economic analysis shows that deer-vehicle collisions are indeed a safety concern and are costly, averaging ~$7,529,242 per year and ~$3,470 per crash in Utah.

Economic analyses of deer-vehicle hotspots can inform mitigation and managerial decision-making. This research has detailed some of the challenges facing landscape ecologists in creating predictive road kill models and has outlined what is needed to find it there is a causal link between where collisions are concentrated and explanatory variables. Research that explores the development of accurate models that contain the relevant road and environmental variables is needed. Successful development of these tools will allow for further development and efficacy of mitigation techniques.

In the United States and in Utah, the number of wildlife-vehicle accidents has been increasing. Yet, in most states, a determination of high kill areas by road segment has not been done or is incomplete. Further, few have attempted to relate spatially explicit road kill numbers with the real costs that are associated with deer-vehicle accidents at the state and provincial level. By doing both of these, this study was intended to have an impact locally and globally. Locally, knowledge of the location of deer-vehicle collision hotspots and associated temporal patterns will allow the Utah Department of Transportation and Utah Division of Wildlife Resources to prioritize areas for mitigation and to tailor mitigation efforts to high road-kill routes and highway segments, thereby increasing their efficacy. Globally, these data have broader implications. They are an example for conservation agencies and transportation departments of how long-term data can be used to set priorities for mitigation that can improve public safety. Additionally, this type of analysis can be linked to ecological connectivity analyses to prioritize mitigation that can increase permeability, maintain landscape connectivity and minimize fragmentation.

Effective mitigation planning will address both conservation issues and safety concerns by finding ways to maintain connectivity and avoid fragmentation of wildlife habitat. If agencies work together, a decreased number of wildlife-vehicle collisions, a lessening of wildlife mortality of animal populations, and positive safety benefits will result. Similarly, if we develop accurate predictive models, we may be able to take a proactive approach to preventing collisions. I conclude that the ideal transportation system accounts for the preservation of natural landscape processes and biodiversity while also providing necessary, safe and efficient mobility for humans. To meet these goals, planning must be proactive by considering broad ecological processes in conjunction with societal needs and costs.

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APPENDICES

Appendix A.

Supplementary Maps

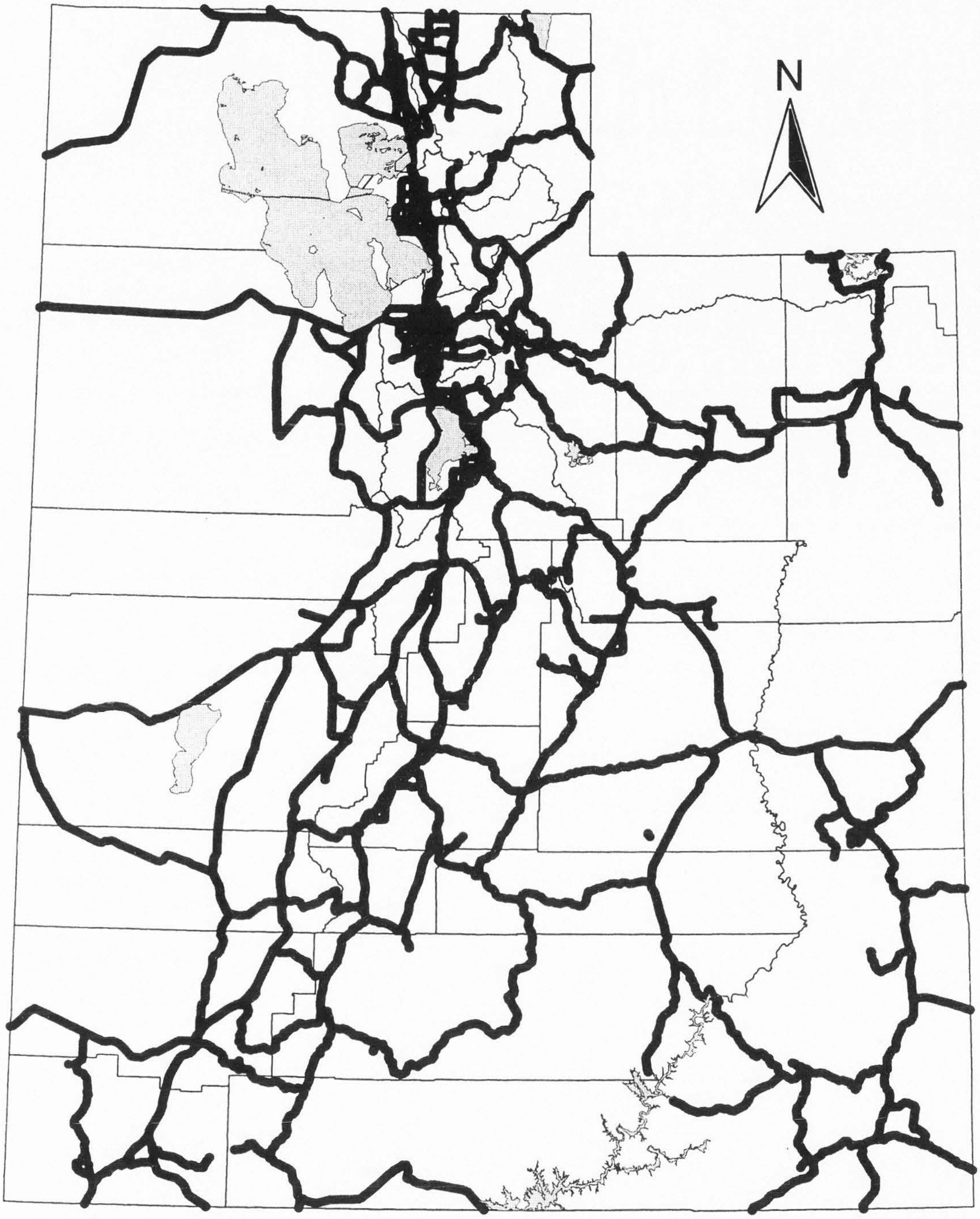

Figure A-1. Map of state routes in Utah. There are 248 state routes (~5,900 mi) of road in Utah that were analyzed in this study.

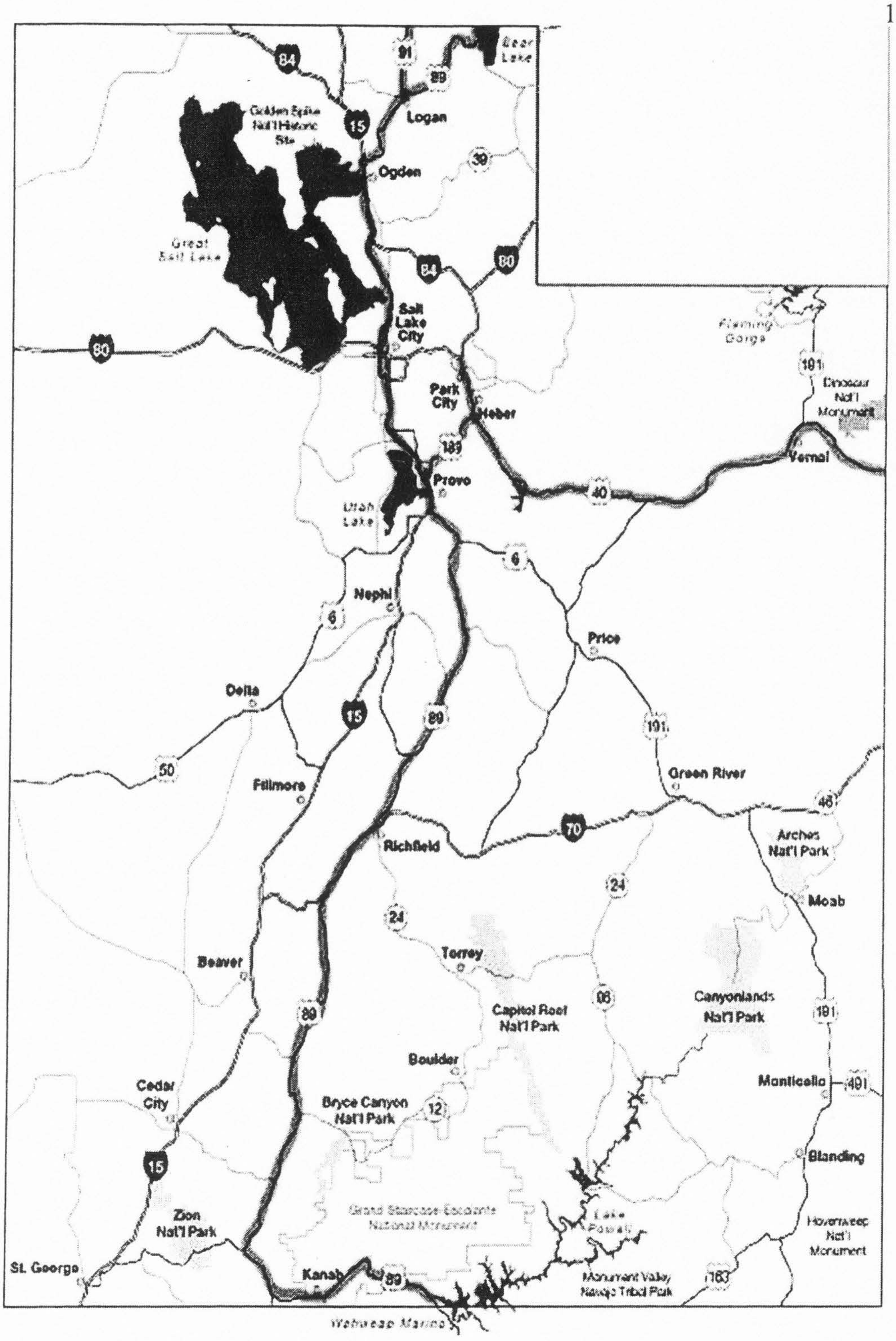

Figure A-2. Map of Utah. The four highlighted routes (Route 40, 89, 91, 189) were used in the analysis of describing hotspots using road geometrics (Chapter 3).

Appendix B.

Annual average daily traffic flow data for Routes 40, 89, 91, 189 Utah, (1992-2002)

Table B.1. Route 40 annual average daily traffic flow (AADT) by volume-defined section and by year, 1992-2002.

Route	Section Number	Mileposts (begin-end)	Y2002	Y2001	Y2000	Y1999	Y1998	Y1997	Y1996	Y1995	Y1994	Y1993	Y1992
40	1	0 - 1.24	21145	20725	18953	18295	17260	16220	16865	16225	15490	14340	13500
40	2	1.24 - 3.96	20262	19865	18165	17525	16530	15535	16870	16225	15490	14340	13500
40	3	3.96 - 6.04	16245	15925	14565	14050	13255	12460	11805	11490	9495	8770	8255
40	4	6.04 - 8.19	16245	15925	14565	14050	13255	12460	11805	11490	9495	8770	8255
40	5	8.19 - 13.21	15279	15810	14465	13955	13165	12373	11955	11490	9495	8770	8255
40	6	13.21 - 16.38	12250	12680	11595	11185	10550	9916	9675	9310	8855	8175	7695
40	7	16.38 - 17.01	22731	23195	21210	20460	19300	18138	17870	17195	15180	14020	13200
40	8	17.01 - 17.94	22731	23195	21210	20460	19300	18138	17870	17195	15180	14020	13200
40	9	17.94 - 20.51	7500	9180	8395	8095	7635	7175	7140	6870	6190	5715	5380
40	10	20.51 - 33.2	4380	4760	4740	4645	4285	4180	4135	4045	3665	3500	3425
40	11	33.2 - 40.28	4380	4760	4740	4645	4285	4180	4135	4045	3665	3500	3425
40	12	40.28 - 58.67	3520	3555	3455	3105	2985	2878	2850	2740	2615	2890	2720
40	13	58.67 - 68.25	3895	3935	3825	3437	3305	3191	3160	3040	2900	3020	2850
40	14	68.25 - 85.92	3400	4095	3980	3577	3440	3320	3280	3155	3010	3070	2895
40	15	85.92 - 86.57	3452	3640	3535	3185	3065	2958	2845	2735	2610	2610	2455
40	16	86.57 - 87.23	3505	4940	4800	4315	3735	3603	3465	3330	3180	3060	2880
40	17	87.23 - 96.63	4905	3985	3870	3475	3345	3226	2910	2800	2670	2465	2240
40	18	96.63 - 105.00	4370	4415	4290	3855	3710	3582	3445	3315	3165	2920	2770
40	19	105.00 - 105.46	4775	4825	4650	4180	4020	3884	3735	3590	3485	3215	3025
40	20	105.46 - 109.59	5420	5475	5320	4780	4780	4612	4435	4265	4070	3755	3535
40	21	109.59 - 111.39	7475	7690	7360	7310	7785	7620	7070	6855	6710	5645	5315
40	22	111.39 - 114.62	7475	7690	7360	7310	7785	7620	7070	6855	6710	6425	6070
40	23	114.62 - 115.24	8910	9166	8780	8715	9279	9080	8425	8165	7990	7650	7225
40	24	115.24 - 118.43	6017	6140	5875	5830	6205	6070	5635	5460	5340	5110	4825
40	25	118.43 - 121.44	6017	6140	5875	5830	6205	6070	5635	5460	5340	5110	4825
40	26	121.44 - 130.48	3055	3140	3005	2980	3170	3100	2875	2875	2810	2690	2540
40	27	130.48 - 141.39	4400	4525	4320	4290	4210	4115	3820	3960	3875	3500	3175

40	28	141.39 - 141.47	4400	4525	4320	4290	4210	4115	3820	3960	3875	3500	3175
40	29	141.47 - 144.31	26185	26460	25723	25545	24585	23735	23180	23180	22750	21675	21175
40	30	144.31 - 145.89	26945	27230	26468	26285	25297	25814	24330	23875	23430	22325	22325
40	31	145.89 - 145.98	26945	27230	26468	26285	25297	25814	24330	23875	23430	22325	22325
40	32	145.98 - 148.28	9480	9580	9320	8375	10786	11007	10375	10180	9720	8975	9160
40	33	148.28 - 148.52	4565	6100	5930	5330	5130	5368	5060	4865	4770	4405	4495
40	34	148.52 - 157.18	4505	6035	5865	5270	5072	5262	4960	4770	4770	4405	4495
40	35	157.18 - 168.79	1765	1780	1730	1730	1663	1639	1545	1545	1545	1425	1340
40	36	168.79 - 174.78	1666	1633	1520	1533	1465	1459	1375	1460	1460	1400	1290

Table B-2. Route 89 annual average daily traffic flow (AADT) by volume-defined section and by year, 1992-2002.

Route	Section Number	Mileposts (begin-end)	Y2002	Y2001	Y2000	Y1999	Y1998	Y1997	Y1996	Y1995	Y1994	Y1993	Y1992
89	1	0 - 5.03	2645	2530	2585	1900	1785	1742	1675	1615	1585	1510	1430
89	2	5.03 - 8.87	2150	2055	2100	2080	1955	1910	1835	1775	1745	1660	1575
89	3	8.87 - 54.93	2150	2055	2100	2080	1955	1910	1835	1775	1745	1660	1575
89	4	54.93 - 61.59	2285	2185	2230	2473	2325	2267	2180	2105	2065	1960	1860
89	5	61.59 - 64.18	5305	5105	5050	5035	4860	4732	4550	4375	4175	4070	3875
89	6	64.18 - 65.40	7195	6925	6850	6830	6830	6650	6395	6150	5870	5420	5100
89	7	65.40 - 81.62	3595	2920	2890	2880	2960	2880	2770	2665	2665	2460	2375
89	8	81.62 - 85.25	2000	1925	1905	1900	2020	1965	1965	1890	2035	1880	1815
89	9	85.25 - 86.99	2685	2585	2555	2545	2470	2405	2405	2310	2310	2050	1975
89	10	86.99 - 89.71	2085	2005	1980	2370	2285	2225	2270	2180	2080	1940	1870
89	11	89.71 - 90.51	1630	2030	2005	2335	2255	2193	2285	2195	2095	2095	2020
89	12	90.51 - 104.20	1210	1165	1150	1450	1400	1360	1450	1395	1330	1425	1290
89	13	104.20 - 108.32	1485	1430	1415	1410	1360	1360	1450	1395	1330	1425	1290
89	14	108.32 - 116.36	1435	1380	1365	1360	1360	1425	1475	1415	1330	1425	1290
89	15	116.36 - 117.01	1635	1570	2340	2330	2250	2250	2320	2230	2125	2125	2050
89	16	117.01 - 124.85	1925	1849	2255	2250	2250	2187	2255	2170	2070	1910	1840
89	17	124.85 - 131.17	2992	2905	3045	3035	2930	2770	2770	2665	2545	2350	2270
89	18	131.17 - 131.74	6190	5960	5895	5880	5675	5525	5525	5315	5075	4685	4520
89	19	131.74 - 132.63	7725	7435	7355	7335	7080	6895	6895	6635	6335	5850	5650
89	20	132.63 - 141.81	2415	2345	2321	2315	2275	2215	2215	2215	2215	2020	1950
89	21	141.81 - 156.98	1240	1200	1235	1235	1175	1155	1170	1195	1205	1140	1075
89	22	156.98 - 160.81	1240	1200	1235	1235	1175	1155	1170	1195	1205	1140	1075
89	23	160.81 - 163.17	2045	1975	1945	1940	1850	1820	1840	1740	1755	1655	1560
89	24	163.17 - 165.81	2045	1975	1945	1940	1850	1820	1840	1740	1755	1655	1560
89	25	165.81 - 167.85	2045	1975	1945	1940	1850	1820	1840	1740	1755	1655	1560
89	26	167.85 - 179.07	1355	1310	1350	1345	1405	1380	1395	1105	1105	1040	1005
89	27	179.07 - 181.38	1460	1385	1420	1490	1686	1670	1670	1620	1620	1515	1435
89	28	181.38 - 185.58	1460	1385	1420	1490	1425	1415	1415	1420	1395	1285	1215
89	29	185.58 - 193.31	1460	1385	1420	1490	1425	1415	1415	1420	1395	1285	1215

89	30	193.32 - 194.78	5545	5560	5855	5370	5175	4915	4645	4650	4430	4180	3915
89	31	194.78 - 195.08	8696	8705	9165	8405	5790	5500	5195	5195	4945	4665	4400
89	32	195.08 - 195.74	9680	9700	10210	9365	8350	7925	7485	7145	6970	6580	6160
89	33	195.74 - 200.67	8370	8390	8834	8105	7805	7410	7000	6795	6470	6130	5735
89	34	200.67 - 206.49	7630	7645	8050	7385	7115	6755	6380	6195	6015	5675	5310
89	35	206.49 - 207.86	7850	7865	8280	7595	7315	6965	6580	6450	6380	6020	5635
89	36	207.86 - 209.50	4616	4405	10850	10360	9980	9480	8955	8855	8770	8275	6840
89	37	209.50 - 211.09	3395	3235	3205	3239	3130	3045	2930	2830	2795	2590	2355
89	38	211.09 - 215.90	3245	3095	3065	3100	2990	2910	2800	2955	2920	2710	2615
89	39	215.90 - 217.31	3245	3095	3065	3100	2990	2910	2800	2955	2920	2710	2615
89	40	217.31 - 217.90	3285	3130	2875	3505	3385	3295	3170	3170	3130	2980	2875
89	41	217.90 - 222.92	3470	3310	3280	4180	4036	3930	3780	3655	3290	3050	2945
89	42	222.92 - 224.67	8425	8035	7960	8050	7770	7565	7275	7650	7560	7015	6770
89	43	224.67 - 230.24	3775	4930	4885	4940	5480	5335	5130	5505	5440	5045	4870
89	44	230.24 - 231.74	7275	6940	6875	6955	6715	6560	6310	6310	6370	5910	5705
89	45	231.74 - 235.53	6060	5780	5725	5790	5590	5640	5425	5245	5105	4735	4570
89	46	235.53 - 244.92	2845	2485	2460	2670	2575	2505	2410	2330	2300	2000	1930
89	47	244.92 - 246.11	4510	4300	4260	4305	4153	3975	3825	3600	3510	3255	3140
89	48	246.11 - 246.63	8270	7885	4205	4250	4765	4560	4385	3915	3870	3590	3520
89	49	246.63 - 251.47	4375	4170	4130	4175	4030	3735	3590	2960	2810	2605	2515
89	50	251.47 - 252.26	5440	5190	5140	5200	5020	4885	4700	4200	4015	3725	3595
89	51	252.26 - 252.69	3170	3020	2990	3435	3315	3225	3100	2810	2625	2435	2350
89	52	252.69 - 265.38	2410	2470	2525	2675	2430	2155	2060	1980	1800	1595	1515
89	53	265.38 - 281.20	2410	2470	2525	2675	2430	2155	2060	1980	1800	1595	1515
89	54	281.20 - 282.74	5715	5352	5321	5359	3715	3376	3265	3230	3045	2900	2830
89	55	282.74 - 283.62	7415	6945	6898	6947	4816	4565	4415	4225	4145	3950	3855
89	56	283.62 - 284.62	7140	6690	6645	6696	5880	5810	5675	5430	5330	5075	4955
89	57	284.62 - 285.68	9910	9285	9220	9290	8585	8480	8290	8200	8045	7740	7560
89	58	285.68 - 286.62	13870	12995	8585	8650	7995	7897	7720	7720	7575	7270	7100
89	59	286.62 - 286.93	19855	16890	16775	16905	15625	15440	15080	15710	15420	15420	15065
89	60	286.93 - 287.31	19455	18225	18105	18245	16865	16665	16275	17085	16765	17080	16685
89	61	287.31 - 287.70	25100	23515	24425	24615	19695	19460	19005	19595	19230	20405	19935
89	62	287.70 - 288.62	27464	25740	25570	25770	20770	20525	20045	20455	20075	20075	19610

89	63	288.62 - 289.05	21320	19975	19840	19995	18480	18259	17390	17745	17415	16595	14925
89	64	289.05 - 290.75	20080	18810	18685	18830	17404	17080	15565	17230	17160	16350	14700
89	65	290.75 - 291.87	20080	18810	18685	18830	17404	17080	15565	17230	17160	16350	14700
89	66	291.87 - 292.23	20080	18810	18685	18830	17404	17080	15565	17230	17160	16350	14700
89	67	292.23 - 292.88	22294	20895	20755	20919	19370	19142	18585	18955	18605	17725	16565
89	68	292.88 - 293.34	27770	26015	25840	26045	24073	23625	23075	23075	22645	21575	21075
89	69	293.34 - 293.61	27770	26015	25840	26045	24073	23625	23075	23075	22645	21575	21075
89	70	293.61 - 294.33	38022	35635	35400	35680	32980	32590	31830	31495	30940	29480	28800
89	71	294.33 - 294.77	45805	42915	42630	42965	39715	39245	38335	37935	37230	35475	34655
89	72	294.77 - 295.69	60085	56295	55925	56365	52100	51585	50385	49855	48930	46625	45550
89	73	295.69 - 296.61	60085	56295	55925	56365	52100	51585	50385	49855	48930	46625	45550
89	74	296.61 - 297.26	56130	52590	52242	51470	47575	47015	45920	45440	44600	42500	41520
89	75	297.26 - 298.33	60100	56310	55936	55110	50940	50340	49170	48655	47755	45505	44455
89	76	298.33 - 299.39	50780	47575	54693	53885	49805	49220	48075	47570	46690	44895	43860
89	77	299.39 - 300.45	49255	46150	45845	43980	40650	40170	39235	38825	38105	36310	35470
89	78	300.45 - 301.02	35725	33470	33249	32950	30457	26485	25870	25600	23705	21750	21245
89	79	301.02 - 302.33	33805	31670	34580	34855	32215	24215	23650	23400	20890	19905	19445
89	80	302.33 - 303.28	35707	33465	33245	33505	30970	22525	22000	21770	18630	17750	17340
89	81	303.28 - 305.04	24155	22630	22480	22655	20938	16751	16375	16200	14085	13420	13110
89	82	305.04 - 305.93	31950	29935	29735	29970	27700	23505	22960	22720	19935	18995	18555
89	83	305.93 - 306.16	40519	37975	37725	38025	35145	31950	31205	30875	27570	26270	25665
89	84	306.16 - 306.54	40519	37975	37725	38025	35145	31950	31205	30875	27570	26270	25665
89	85	306.54 - 307.32	27850	26090	25915	26120	24140	23555	23005	22765	20420	19455	19005
89	86	307.32 - 308.4	13955	13075	14060	14169	13120	12965	12660	12650	10455	10005	9775
89	87	308.4 - 308.59	18425	17260	17145	15985	14775	14600	14260	14110	13845	12950	12835
89	88	308.59 - 309.14	18731	17555	17440	16610	15350	15170	14815	14110	13845	12950	12835
89	89	309.14 - 310.49	11100	10400	10329	10760	9945	9825	9825	8775	9145	8335	8260
89	90	310.49 - 311.27	11100	10400	10329	10760	9945	9825	9825	8775	9145	8335	8260
89	91	311.27 - 311.49	10070	9435	9370	9780	8010	7915	7915	6185	5960	5715	5665
89	92	311.49 - 312.05	20825	21250	18355	23199	22095	20770	19000	18205	18555	17680	17525
89	93	312.05 - 313.05	26350	26888	30192	31967	28290	26595	24330	18205	18555	17680	17525
89	94	313.05 - 314.54	31725	32390	38295	40070	32665	30704	29660	19990	20390	19430	19260
89	95	314.54 - 315.06	22605	24495	31570	31817	26080	24515	22425	20990	21975	20940	20755

89	96	315.06 - 315.53	23335	27891	34610	34885	28595	26880	24590	23875	23430	22490	22295
89	97	315.53 - 315.93	28455	30836	37555	37850	30245	28430	26010	25735	25260	24070	23020
89	98	315.93 - 316.54	28675	31078	26065	26272	26272	24715	22610	22610	24650	23485	21745
89	99	316.54 - 316.92	28900	31320	41060	41382	42585	40030	36620	37755	37055	35310	31360
89	100	316.92 - 317.31	28900	31320	41060	41382	42585	40030	36620	37755	37055	35310	31360
89	101	317.31 - 317.81	25970	29980	37475	37770	38620	36305	33215	33720	33720	32130	31850
89	102	317.81 - 318.07	28730	31135	40290	40610	41453	37685	35135	35135	36220	32810	32525
89	103	318.07 - 318.84	28730	31135	40290	40610	41453	37685	35135	35135	36220	35300	34995
89	104	318.84 - 319.74	28920	31344	39180	39490	40310	34845	31880	31545	34175	32565	32280
89	105	319.74 - 320.31	27405	31896	39870	40185	41020	35230	32230	31890	35675	33995	33700
89	106	320.31 - 320.49	27405	31896	39870	40185	41020	35230	32230	31890	35675	33995	33700
89	107	320.49 - 321.00	29900	32404	40505	40827	41661	36545	33435	33085	36760	35025	34720
89	108	321.00 - 321.14	27720	30040	37550	37845	38630	34370	31445	31115	36265	34555	34255
89	109	321.14 - 321.87	27655	29972	37465	37758	38529	33650	30785	30460	35420	33750	33460
89	110	321.87 - 322.75	25940	28112	35140	35415	37615	32795	30000	29685	35880	34190	33895
89	111	322.75 - 323.63	29825	32324	40405	40722	43722	36280	33285	33300	36185	34495	34195
89	112	323.63 - 324.02	34190	37055	44100	46431	51431	41595	38055	38055	38055	36260	35205
89	113	324.02 - 324.51	34035	40000	50000	54500	58500	44528	41615	41180	40415	38510	38015
89	114	324.51 - 325.07	28360	30737	37485	36518	39518	33929	31710	31375	30795	29620	29360
89	115	325.07 - 325.62	27175	29700	35243	35963	38963	33881	31635	31200	30445	29880	29620
89	116	325.62 - 326.18	26890	30160	37000	40722	42481	36940	34460	33830	32220	30860	30455
89	117	326.18 - 326.93	24170	27103	34055	34323	35385	33397	36820	36820	35065	33580	32295
89	118	326.93 - 327.53	24575	27558	34510	34780	35465	33458	31270	32235	30700	29400	27475
89	119	327.53 - 327.68	23988	26654	32505	32761	33430	31425	29315	31250	29760	28500	25590
89	120	327.68 - 328.27	23960	22446	28725	28950	29915	28120	25725	25855	29645	28435	24945
89	121	328.27 - 329.01	18385	17225	25250	25447	26235	24663	22565	22725	21910	21015	17730
89	122	329.01 - 329.88	29890	28005	27818	28015	28595	26882	24595	24345	23470	22350	18780
89	123	329.88 - 331.96	43590	40840	40570	40890	41725	39225	35885	34520	33280	31275	26710
89	124	331.97 - 332.12	36980	34645	34417	34660	32035	31658	28965	29500	28440	27085	26850
89	125	332.12 - 332.49	25020	23440	23285	23450	21674	22345	20500	19670	18960	18185	18025
89	126	332.49 - 333.52	17520	16415	16305	16430	15185	16472	15395	14770	14885	14275	15900
89	127	333.52 - 334.04	23850	22345	22195	22370	20678	22235	20800	19965	19760	18950	20400
89	128	334.04 - 334.45	40365	37820	37570	37835	34970	34970	33305	32970	31795	30495	30230

89	129	334.45 - 335.65	26750	25060	24895	25090	23190	22915	22380	18220	17565	16845	13590
89	130	335.65 - 336.33	33310	31210	31005	31250	28885	28545	27880	27595	26605	25515	15040
89	131	336.33 - 336.73	18640	17465	21430	21598	19635	19405	18955	13305	12825	12300	10700
89	132	336.74 - 337.07	43640	40885	40615	40935	35860	35435	34610	34245	33610	30375	24050
89	133	337.07 - 337.84	34215	32055	31845	33363	30330	29970	28010	27715	27200	24955	28995
89	134	337.84 - 338.66	33495	31380	31174	32815	30330	29970	28010	27715	27200	24955	28995
89	135	338.66 - 339.00	33130	31040	30835	32895	30405	30045	27565	27275	26770	24475	24260
89	136	339.00 - 340.03	33130	31040	30835	32895	30405	30045	27565	27275	26770	24475	24260
89	137	340.03 - 341.18	32500	30290	29715	27581	26268	26454	24270	23775	24085	23515	24205
89	138	341.18 - 342.04	32410	30205	29630	29810	28954	30905	27560	26785	26785	26150	26205
89	139	342.04 - 342.46	32410	30205	29630	29810	28954	30905	27560	26785	26785	26150	26205
89	140	342.46 - 344.26	32505	30295	29720	29905	29050	29150	25995	24885	25210	24620	24675
89	141	344.26 - 345.59	32505	30295	29720	29905	29050	29150	25995	24885	25210	24620	24675
89	142	345.59 - 345.91	45590	42490	41680	41935	40735	40875	36450	35045	35500	34660	35450
89	143	345.91 - 346.16	45590	42490	41680	41935	40735	40875	36450	35045	35500	34660	35450
89	144	346.16 - 347.67	40585	37825	37105	37335	36265	39275	35025	33530	38240	37335	37335
89	145	347.67 - 347.88	47955	44695	43845	44115	42850	40890	36465	34910	38240	37335	37335
89	146	347.88 - 347.93	49265	46155	45850	46210	42712	41071	37680	37285	37285	35525	34705
89	147	347.93 - 348.68	49265	46155	45850	46210	42712	41071	37680	37285	37285	35525	34705
89	148	348.68 - 349.8	49265	46155	45850	46210	42712	41071	37680	37285	37285	35525	34705
89	149	349.8 - 349.95	23905	22395	22245	22420	20722	19993	19060	18325	18750	17865	10180
89	150	349.95 - 350.67	23905	22395	22245	22420	20722	19993	19060	18325	18750	17865	10180
89	151	350.67 - 353.58	30385	26940	27405	28005	25735	24710	23540	21560	22070	21925	20130
89	152	353.58 - 353.77	32785	29070	29575	27780	27780	26675	22495	21630	22140	21995	21150
89	153	353.77 - 354.29	32785	29070	29575	27780	27780	26660	25415	26295	26940	26765	26675
89	154	354.29 - 354.43	34480	31100	31635	32330	29712	28515	27165	28100	28790	28600	28500
89	155	354.43 - 355.3	36960	34630	34400	34672	31956	30580	29870	29555	29555	28160	26370
89	156	355.3 - 355.88	32250	30215	30015	30249	27880	26680	26060	25800	25320	24125	24005
89	157	355.88 - 356.78	31605	29610	29415	29645	27400	25985	25380	25115	25025	23845	22615
89	158	356.78 - 357.81	35280	33055	32835	33095	30300	29945	29250	28850	28765	27410	22150
89	159	357.81 - 358.38	26960	25260	25090	25285	23370	23095	22555	22320	21905	20870	18150
89	160	358.38 - 358.74	26960	25260	25090	25285	23370	23095	22555	22320	21905	20870	18150
89	161	358.74 - 360.83	24330	22795	22645	22825	21095	20845	20360	20145	19770	18835	15400

89	162	360.83 - 361.61	24330	22795	22645	22825	21095	20845	20360	20145	19770	18835	15400
89	163	361.61 - 363.79	10295	12540	12455	12550	11600	11460	11190	11075	10675	10235	9220
89	164	363.79 - 364.07	8480	7945	7890	8075	9391	9145	8930	8840	8670	7880	7695
89	165	364.07 - 364.55	9735	9285	9200	9340	9015	8775	8440	8160	8065	6920	6810
89	166	364.55 - 367.63	12590	12010	11895	12030	11615	11310	10880	10520	10400	9300	9155
89	167	367.63 - 370.01	11580	11045	10940	11065	10685	10016	9820	9495	9385	8705	8570
89	168	370.01 - 371.12	11580	11045	10940	11065	10685	10016	9820	9495	9385	8705	8570
89	169	371.12 - 372.05	12620	12035	11920	12055	11641	11130	11080	10715	10715	9940	9785
89	170	372.05 - 374.62	12385	11815	11705	11840	11430	11130	11080	10715	10715	9940	9785
89	171	374.62 - 374.75	12995	12175	12095	12190	11265	11130	11080	10715	10715	9940	9785
89	172	374.75 - 375.54	29225	27380	27200	27415	25340	25040	24455	24200	23850	22725	22200
89	173	375.54 - 377.62	21865	20485	20350	20510	18955	18730	18295	18115	17780	16940	15400
89	174	377.62 - 377.65	21865	20485	20350	20510	18955	18730	18295	18115	17780	16940	15400
89	175	377.65 - 387.27	7000	6555	6510	6560	3860	3815	3725	3625	3555	3350	3065
89	176	387.27 - 396.5	3210	2950	2867	2867	2705	2610	2505	2410	2300	2180	1975
89	177	396.5 - 402.57	2615	2640	2565	2565	2420	2335	2240	2155	2155	1950	1770
89	178	402.57 - 407.61	2110	2130	2130	2130	2010	1870	1795	1710	1715	1635	1490
89	179	407.61 - 410.2	2110	2130	2130	2130	2010	1870	1795	1710	1715	1635	1490
89	180	410.2 - 414.64	2247	2270	2270	2095	1910	1670	1575	1490	1495	1425	1385
89	181	414.64 - 415.84	2320	2385	2385	2150	2065	1835	1800	1705	1685	1515	1485
89	182	415.84 - 418.71	2320	2385	2385	2150	2065	1835	1800	1705	1685	1515	1480

Table B-3. Route 91 annual average daily traffic flow (AADT) by volume-defined section and by year, 1992-2002.

Route	Section Number	Mileposts (begin-end)	Y2002	Y2001	Y2000	Y1999	Y1998	Y1997	Y1996	Y1995	Y1994	Y1993	Y1992
91	1	0 - 0.48	18000	17390	16710	16675	15864	15095	14150	15095	14755	12810	11895
91	2	0.48 - 1.35	18000	17390	16710	16675	15864	15095	14150	15095	14755	12810	11895
91	3	1.35 - 1.96	20315	15740	15770	15735	19840	18880	17700	18835	17715	15380	14280
91	4	1.96 - 3.82	14145	13665	13690	13660	12995	12365	11590	12330	11595	10065	9345
91	5	3.82 - 4.96	17085	16510	18380	18340	17450	16605	15565	16560	15575	13555	12585
91	6	4.96 - 5.63	17085	16510	18380	18340	17450	16605	15565	16560	15575	13555	12585
91	7	5.63 - 7.72	14650	15740	15551	15520	16065	15285	14330	15245	14335	12445	11555
91	8	7.75 - 10	15380	14860	14885	14850	14130	13445	12605	13425	12625	10960	10175
91	9	10 - 16.59	15380	14860	14885	14850	14130	13445	12605	13425	12625	10960	10175
91	10	16.59 – 16.86	15380	14860	14885	14850	14130	13445	12605	13425	12625	10960	10175
91	11	16.86 – 19.13	16380	15825	15855	15820	15050	14320	13425	13425	12625	10960	10175
91	12	19.13 – 19.55	17065	16488	16522	16490	15690	14929	14005	13275	12485	10840	10065
91	13	19.55 – 21.34	18115	17505	17540	17505	16655	15850	14865	13275	12485	10840	10065
91	14	21.34 – 24.27	16805	15745	15638	15607	14655	14479	13660	13275	12485	10840	10065
91	15	24.27 - 25.6	17680	16570	16457	16295	15060	14882	14040	13890	13630	11295	11035
91	16	25.6 - 26.19	40745	38175	37920	34395	31485	31116	30035	29720	29170	26835	23920
91	17	26.19 – 26.83	35995	33725	33500	33500	28595	28260	27305	27020	26520	24400	23835
91	18	26.83 – 27.09	40490	37935	34545	34815	32180	33270	32315	31975	31380	28530	27870
91	19	27.09 – 28.51	31839	29840	29640	29875	27612	28320	27660	27370	31405	28550	27850
91	20	28.51 – 29.78	30240	28330	28140	28360	26215	26705	26105	25830	26410	23580	23035
91	21	29.78 – 30.59	29935	28045	27155	27370	25298	25815	25215	24950	25460	22730	22205
91	22	30.59 – 31.26	30420	28500	28310	28535	26375	26375	25760	25490	25015	21000	20515
91	23	31.26 – 31.81	30420	28500	28310	28535	26375	26375	25760	25490	25015	21000	20515
91	24	31.81 – 32.41	30785	28840	28650	28875	26690	26375	25760	25490	25015	21000	20515
91	25	32.41 – 33.98	26215	24560	24395	24585	22725	22455	21930	20975	20585	18380	16780
91	26	33.98 – 34.98	17955	16820	16707	16380	15140	14700	14355	14205	13940	12675	12380
91	27	34.98 - 35.5	13300	12460	12375	11495	10624	10315	9915	9815	9460	8840	10300
91	28	35.5 - 38.64	12705	12120	12005	11220	10835	10550	10150	9815	9460	8840	10300

91	29	38.64 – 39.96	12595	12015	11900	10930	10555	10275	9885	9560	9450	8075	9665
91	30	39.96 – 41.15	10550	10230	9705	10860	10725	10465	9965	9685	9310	8350	8350
91	31	41.15 – 43.24	8265	8015	7965	9240	9125	8905	8405	8195	7880	7065	6915
91	32	43.24 – 43.64	8265	8015	7965	9240	9125	8905	8405	8195	7880	7065	6915
91	33	43.64 – 43.89	6425	6230	6195	6227	6150	5770	5540	5410	5195	4665	4565
91	34	43.89 – 45.22	6425	6230	6195	6227	6150	5770	5540	5410	5195	4665	4565

Table B-4. Route 189 annual average daily traffic flow (AADT) by volume-defined section and by year, 1992-2002.

Route	Section Number	Mileposts (begin-end)	Y2002	Y2001	Y2000	Y1999	Y1998	Y1997	Y1996	Y1995	Y1994	Y1993	Y1992
189	1	0 - 1.49	29953	30627	30445	32014	29643	30095	29865	28700	27330	25945	24855
189	2	1.49 - 1.67	40562	41475	41202	43325	40045	40655	40340	38760	36910	35155	33680
189	3	1.67 - 1.95	33645	34415	34185	35980	34962	35495	34670	34670	34030	32425	31675
189	4	1.95 - 2.41	47015	48095	47775	48150	44506	45225	44175	44175	44175	42095	41125
189	5	2.41 - 2.69	46146	47185	46875	47245	43669	44335	43305	44645	44645	42540	41560
189	6	2.69 - 2.95	45030	46060	45756	43665	37331	37900	37020	39820	39820	37945	37070
189	7	2.95 - 3.11	44470	45491	45220	43156	38533	39120	38210	39390	39235	37395	36530
189	8	3.11 - 3.48	37726	38575	38320	38620	35695	36245	35400	35400	35100	33440	32670
189	9	3.48 - 4	37620	38484	38255	38555	35635	35635	34805	34440	32800	25335	24750
189	10	4 - 4.77	38070	38942	38710	39015	36060	35635	34805	34440	32800	25335	24750
189	11	4.77 - 5.36	36830	37675	37675	37970	35095	34680	33875	33520	30630	25260	24675
189	12	5.36 - 5.81	33325	34095	34605	35310	32700	31200	30475	30155	26425	25180	24600
189	13	5.81 - 6.04	16400	16775	16665	16795	15810	15625	15625	15300	14440	13625	13310
189	14	6.04 - 6.39	16400	16775	16665	16795	15810	15625	15625	15300	14440	13625	13310
189	15	6.39 - 7.48	16400	16775	16665	16795	15810	15625	15625	15300	14440	13625	13310
189	16	7.48 - 7.72	16040	16705	12545	11276	10490	10125	10500	10155	9860	9130	8680
189	17	7.72 - 9.19	16040	16705	12545	11276	10490	10125	10500	10155	9860	9130	8680
189	18	9.19 - 11.17	16040	16705	12545	11276	10490	10125	10500	10155	9860	9130	8680
189	19	11.17 - 14.3	11670	12160	11460	10592	9918	9630	9990	9135	8840	8175	7775
189	20	14.3 - 14.57	8805	8475	8385	8365	7730	7580	7775	7335	7100	6175	5810
189	21	14.57 - 21.05	7615	7330	7254	7240	6690	6610	6780	6490	6195	5245	4935
189	22	21.05 - 24.93	10735	10335	10120	10095	7390	7301	7375	7095	6775	5645	5315
189	23	24.93 - 25.17	10735	10335	10120	10095	7390	7301	7375	7095	6775	5645	5315
189	24	25.17 - 26.19	8510	7980	7895	7911	5775	5707	5765	5545	5295	4285	4035
189	25	26.19 - 29.2	10650	10250	10140	10160	7355	7266	7340	7060	6740	5620	5460

Table B-4. Route 189 annual average daily traffic flow (AADT) by volume-defined section and by year, 1992-2002.

Route	Section Number	Mileposts (begin-end)	Y2002	Y2001	Y2000	Y1999	Y1998	Y1997	Y1996	Y1995	Y1994	Y1993	Y1992
189	1	0 - 1.49	29953	30627	30445	32014	29643	30095	29865	28700	27330	25945	24855
189	2	1.49 - 1.67	40562	41475	41202	43325	40045	40655	40340	38760	36910	35155	33680
189	3	1.67 - 1.95	33645	34415	34185	35980	34962	35495	34670	34670	34030	32425	31675
189	4	1.95 - 2.41	47015	48095	47775	48150	44506	45225	44175	44175	44175	42095	41125
189	5	2.41 - 2.69	46146	47185	46875	47245	43669	44335	43305	44645	44645	42540	41560
189	6	2.69 - 2.95	45030	46060	45756	43665	37331	37900	37020	39820	39820	37945	37070
189	7	2.95 - 3.11	44470	45491	45220	43156	38533	39120	38210	39390	39235	37395	36530
189	8	3.11 - 3.48	37726	38575	38320	38620	35695	36245	35400	35400	35100	33440	32670
189	9	3.48 - 4	37620	38484	38255	38555	35635	35635	34805	34440	32800	25335	24750
189	10	4 - 4.77	38070	38942	38710	39015	36060	35635	34805	34440	32800	25335	24750
189	11	4.77 - 5.36	36830	37675	37675	37970	35095	34680	33875	33520	30630	25260	24675
189	12	5.36 - 5.81	33325	34095	34605	35310	32700	31200	30475	30155	26425	25180	24600
189	13	5.81 - 6.04	16400	16775	16665	16795	15810	15625	15625	15300	14440	13625	13310
189	14	6.04 - 6.39	16400	16775	16665	16795	15810	15625	15625	15300	14440	13625	13310
189	15	6.39 - 7.48	16400	16775	16665	16795	15810	15625	15625	15300	14440	13625	13310
189	16	7.48 - 7.72	16040	16705	12545	11276	10490	10125	10500	10155	9860	9130	8680
189	17	7.72 - 9.19	16040	16705	12545	11276	10490	10125	10500	10155	9860	9130	8680
189	18	9.19 - 11.17	16040	16705	12545	11276	10490	10125	10500	10155	9860	9130	8680
189	19	11.17 - 14.3	11670	12160	11460	10592	9918	9630	9990	9135	8840	8175	7775
189	20	14.3 - 14.57	8805	8475	8385	8365	7730	7580	7775	7335	7100	6175	5810
189	21	14.57 - 21.05	7615	7330	7254	7240	6690	6610	6780	6490	6195	5245	4935
189	22	21.05 - 24.93	10735	10335	10120	10095	7390	7301	7375	7095	6775	5645	5315
189	23	24.93 - 25.17	10735	10335	10120	10095	7390	7301	7375	7095	6775	5645	5315
189	24	25.17 - 26.19	8510	7980	7895	7911	5775	5707	5765	5545	5295	4285	4035
189	25	26.19 - 29.2	10650	10250	10140	10160	7355	7266	7340	7060	6740	5620	5460