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# Mitigation Measures and Recommendations in the USA to Reduce Environmental Impacts of Transportation Infrastructure on Wildlife

**Fengxiang Qiao, Boya You, Qing Li* and Lei Yu**

*Innovative Transportation Research Institute, Texas Southern University, 3100 Cleburne Street, Houston, Texas, 77004, USA*

## Abstract

Serious and adverse conservation consequences of transportation infrastructure have not only altered the landscape but have also become a source of pollution to impact the entire environment and the living styles of wildlife in the planet. The design, construction, operation and management of transportation infrastructure should therefore consider their environmental and ecological impacts from the point of views of conservation biology and environmental science. This paper summarizes the mitigation measures in the USA to avoid, minimize and mitigate negative environmental and ecological impacts of transportation infrastructure on wildlife movements, including wildlife crossing structures and fencing. The review of existing efforts to enhance wildlife crossings in the USA and federal/state level guidelines and recommendations are presented, together with the cost-benefit analyses. It is recommended that each local transportation agency proposes implementation steps to examine the current practices to reduce the negative impacts of transportation infrastructure on wildlife and make recommendations on how to systematically incorporate the successful design practices into their local transportation projects.

**Keywords:** Environmental impacts; Ecological impacts; Wildlife; Transportation infrastructure; Mitigation measures; Cost-benefit analyses

## Impact of Transportation Infrastructure on Wildlife

On July 7, 2017, some passengers at the New York John F Kennedy (JFK) International Airport encountered a flight delay due to the slow marching of about 40 diamondback terrapins (a kind of turtles) crossing the tarmac of the airport [1], which is the busiest international air passenger gateway into North America [2]. This situation is similar to what Schweber [3] described in Figure 1 and is definitely one of the typical examples illustrating the impacts of transportation infrastructure on wildlife.

There is an increasing need of transportation infrastructure in peoples' daily lives with the development of transportation related technologies and the evolution of civilization of human beings in the recent centuries. About 20% of land area in the United States is directly and ecologically impacted by roads [4,5], including habitat fragmentation/isolation, connectivity loss, quality changes, barrier effects, mortality/road kill, direct and indirect effects to threatened and endangered species, etc. [5,6]. Serious and adverse conservation consequences have not only altered the landscape but also become a source of pollution to impact the entire environment and the living styles of wildlife in the planet [4]. For example, habitat fragmentation by highways led to inbreeding among the mountain lions in the Santa Monica Mountains in Greater Los Angeles [7]. So the design, construction, operation, and management of transportation infrastructure should consider their environmental and ecological impacts from the perspective of conservation biology and environmental science.

Figure 1: A diamondback terrapin walks on a service road alongside a runway at New York JFK International Airport after overcoming black plastic tubing intended to keep it out [3] Photo Credit to: Dave Sanders.

Part of the transportation infrastructure such as roadsides, railway margins, and waterways sometimes serve as linear habitats for wildlife, particularly small mammals and insects [8,9]. For example, birds may feed on the grit on roads and mountain goats are attracted by roadside vegetation. In this way, road construction creates high quality edge habitat [10]. However, in most cases, roads create barriers and serve as an inhospitable environment for most. For example, road construction and expansion reduce the area of natural habitat and landscape connectivity by transforming natural habitat into pavement, which will significantly affect the movement of animals that regularly move to different habitats [11]. Animals were prevented from crossing the road to meet their daily, seasonal and basic biological needs because of the high traffic volume and high-speed vehicles. Besides, noise and artificial lighting effects, such as traffic noise and the light from vehicles, can reduce bird population densities [12] and noise levels have been shown to affect animal use of wildlife crossing structures [13].

***Corresponding author:** Qing Li, Post-doctoral Fellow, Innovative Transportation Research Institute, Texas Southern University, 3100 Cleburne Street, Houston, Texas, 77004, USA, Tel: 713-313-7532; E-mail: liq@tsu.edu

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Additionally, road kill (wildlife-vehicle mortality) is responsible for the reduction in wildlife population. State Farm's insurance claims State of Texas in the USA has the highest number of wildlife-vehicle collision (WVCs) involving deer, elk and moose from 2012 to 2013 [14]. A report presents that the annual cost of reported WVCs in South Dakota is $107.9 million and the wildlife values are over $29.6 million each year [15]. In 2010, the costs of 4,668 WVCs to Pennsylvania were $14,484,804 [16].

## Mitigation Measures

Mitigation measures have been developed and applied to avoid, minimize and mitigate negative impacts of transportation on wildlife movements. The most commonly applied mitigation measures to reduce WVCs are wildlife crossing structures and fencing.

### Wildlife crossing structures

Wildlife crossing structures are designed to increase permeability and habitat connectivity across roads and reduce motor vehicle collisions with wildlife, consequently reducing the likelihood of damage to motor vehicles [17]. Wildlife crossing structures include underpass tunnels, viaducts, overpasses, amphibian tunnels and culverts [16]. Wildlife crossing structures should have the following biological functions: 1) reducing mortality and increase movement; 2) meeting biological requirements (e.g. finding food, cover and mates); 3) dispersal from maternal or natal ranges and recolonization after long absences; 4) redistribution of populations in response to environmental changes and natural disturbances; 5) long-term maintenance of meta-populations, community stability, and ecosystem processes.

The design of the wildlife crossing structure is associated with landscape and wildlife species groups. The wildlife species groups are defined and documented in the Wildlife Crossing Structure Handbook are shown in Table 1, while the general design specifications of wildlife crossing structures are in Table 2.

It is noticeable that bird species as an important member wildlife family have been neglected from the crossing structure. The inclusion of birds in the list ensures transportation project design and construction to respect and leave intact the natural environment, particularly vegetation, water systems and wetland, along the roads to be built. Most of the structures are for wildlife only; however there are indeed some can also serve for seasonal drainage and human activities. Each of them has different dimensional specifications.

| Wildlife Species Group | Description |
|---|---|
| Large mammals, e.g. Deer, elk, bears, pronghorn | Species with large area requirements and potential migratory behavior; large enough to be a motorist safety concern; traffic-related mortality cause substantial impacts to local populations; susceptible to habitat fragmentation by roads. |
| High mobility medium-sized mammals, e.g. Bobcat, fisher, fox | Species that range widely; fragmentation effects of roads may impact local populations. |
| Low mobility medium-sized mammals, e.g. Raccoon, skunk, hare, groundhog | Species with smaller area requirements; common road-related mortality; relatively abundant populations. |
| Semi-arboreal mammals, e.g. Red squirrel, flying squirrel | Species that are associated with riparian habitats for movement and life requisites; common road-related mortality. |
| Small mammals, e.g. Ground squirrels, mice, voles | Species that are common road-related mortality; relatively abundant populations. |
| Amphibians, e.g. Frogs, toads, turtles | Species with special habitat requirement; relatively abundant populations at the local scale; populations are highly susceptible to road mortality. |
| Reptiles, e.g. Snakes, lizards | Species with special habitat requirement; road environment tends to attract individuals; relatively abundant populations. |

**Table 1:** Wildlife species groups [5].

| Type | Usage | Species and Groups | Minimum Dimensions | Recommended Dimensions |
|---|---|---|---|---|
| Landscape bridge | Wildlife only | All wildlife species. Amphibians (if adapted) | W: 230 ft | W: >330 ft |
| Wildlife overpass | Wildlife only | Large mammals, High-mobility medium-sized mammals, Low mobility medium-sized mammals, Small mammals Reptiles, Amphibians (if adapted) | W: 130-165 ft | W: 165-230 ft |
| Multi-use overpass | Wildlife and human activities | Large mammals, High-mobility medium-sized mammals, Low mobility medium-sized mammals, Small mammals Reptiles, Amphibians (if adapted) | W: 32 ft | W: 50-130 ft |
| Canopy crossing | Wildlife only | Semi-arboreal mammals | - | - |
| Viaduct or flyover | Multi-purpose | All wildlife species | * | * |
| Large mammal underpass | Wildlife only | Large mammals, High-mobility medium-sized mammals, Low mobility mediumsized mammals, Semi-arboreal and semiaquatic mammals (adapted), Small mammals, Amphibians (adapted), Reptiles | W: 23 ft<br>Ht: 13 ft | W: >32 ft<br>Ht: >13 ft |
| Multi-use underpass | Wildlife and human activities | Large mammals, High-mobility mediumsized mammals, Low mobility mediumsized mammals, Semi-arboreal and semiaquatic mammals (adapted), Small mammals, Amphibians (adapted), Reptiles | W: 16.5 ft<br>Ht: 8.2 ft | W: >23 ft<br>Ht: >11.5 ft |
| Underpass with waterflow | Wildlife and drainage | Large mammals, High-mobility mediumsized mammals, Low mobility mediumsized mammals, Semi-arboreal mammals (adapted), Semi-aquatic mammals, Small mammals and amphibians, Semi-arboreal mammals and reptiles (adapted) | W**: 6.5 ft path<br>Ht: 10 ft | W**: >10 ft path<br>Ht: >13 ft |
| Small to medium-sized mammal underpass | Wildlife and seasonal drainage | High-mobility medium-sized mammals (adapted), Low mobility mediumsized mammals, Semi-aquatic mammals (adapted), Small mammals, Amphibians (adapted), Reptiles | W: 1.5 ft<br>Clearance: 3 ft | W: >3 ft<br>Clearance: >4 ft |
| Amphibian and reptile tunnel | Wildlife only | Amphibians; Low mobility medium-sized mammals (adapted); Semi-aquatic (adapted), Small mammals and reptiles (adapted) | + | + |

*The dimension is Larger than the largest wildlife underpass structures; ** The width depends on the width of hydrologic channel in crossing; + Dimensions vary depending on target species or taxa or local conditions. Tunnels range from 1-3 feet in diameter

**Table 2:** Minimum and recommended dimensions of wildlife overpass/underpass designs [5].

## Fencing

Fencing is a common and robust mitigation measure to reduce WVCs with large mammals [18,19], to keep selected species away from roadways and sometimes guide wildlife to safe crossing structures [5]. The fences are typically implemented at the 'hotspots' of WVCs and need to extend further than the hotspot to prevent 'fence end run' [20]. Both the home range for the target species and the length of the 'hotspot' are considered in fence's design [21,22]. Fences are typically installed on both sides of a roadway with both ends ending opposite of each other to prevent animals to be kept on roads by a one-side fence. Fencing is typically implemented in conjunction with wildlife crossing structures because fencing alone may increase barrier effects and incidentally impedes wildlife access to critical resources such as water, forage and cover [23-25].

Construction Guidelines for Wildlife Fencing and Associated Escape and Lateral Access Control Measures (AASHTO) reviewed current state of knowledge and practice regarding the design, implementation and maintenance of wildlife fencing. Fence material and dimensions are discussed in the guidelines, regarding three species groups: large mammals, medium mammals and reptiles and amphibians. Arizona Game and Fish Department published guidelines for wildlife compatible fencing to assist landowner, project manager and land management agencies in designing fences with least impact to wildlife [25]. Specific recommendations of fencing are documented in this report for different species including pronghorn, bighorn sheep, deer, elk, etc. Guidelines of effectiveness measurements and maintenance of fences can be found in roadway design manual published by Pennsylvania Department of Transportation (PennDOT) in the USA.

## Structure Selection and Placement

Four basic principles regarding wildlife crossing structure placement are: topographic features, multiple species, adjacent land management and larger corridor network [5]. Wildlife crossings should be placed where movement corridors are associated with dominant topographic features. Sections of roadways can be ignored where terrain and land cover are unsuitable for wildlife and their movement. Besides, crossings should be designed to accommodate multiple species. Most importantly, wildlife crossings must connect to larger corridor networks, but not 'ecological dead ends' [5]. Different approaches used by transportation agencies to locate wildlife crossing structures are summarized in Table 3. Each of them has different needs of data and models.

It should be noted that there is no simple formula to determine the spacing of wildlife crossings because each site is different and design should be landscape- and species-specific. For example, water frogs prefer the tunnels to the grass while agile frogs prefer grass [26]. Thus, crossing success highly depends on the material and design of tunnel. Moreover, improper design may lead to negative effects.

Planning resources for wildlife crossing structures site selection include but not limited to:

- Maps (aerial photos, land cover-vegetation maps, topographic maps, land ownership maps and wildlife habitat maps)
- Data (wildlife movement model data, wildlife ecology field data, wildlife road-kill data, and road network data)

Detailed descriptions of each resource and how it can be used for project-level and systems-level planning can be found in Chapter 3 of the Wildlife Crossing Structure Handbook.

## The USA Federal and State Level Guidelines and Recommendations

### Overall views of existing efforts to enhance wildlife crossings in the USA

In the USA, the Wildlife Crossing Structure Handbook provides key design and ecological criteria, construction and maintenance guidelines, effective monitoring techniques and solutions to wildlife-

| Approach | | Description |
|---|---|---|
| Physical data | Road-kill data | Use of road-kill data alone provides a very limited scope of wildlife movement areas and should be combined with habitat linkage mapping or movement models. |
| | Radio and satellite telemetry | Telemetry has been commonly used to describe successful road crossing locations usually through intensive monitoring of wildlife movements. Satellite methods allow for more frequent and more accurate relocation data while the animal is collared when compared to radio-based methods. |
| | Capture-mark-recapture | By live-trapping and marking individuals and monitoring their movements via translocation or natural movements across roads, the distribution and population density of wildlife can be identified. |
| | Road surveys | In areas that receive regular snowfall, transects adjacent and parallel to the road or road surveys carried out while driving slowly along the road edge are two commonly used techniques to identify animal crossing locations. |
| | Track beds | Beds of sand or other tracking medium laid out along sections of roadway to intercept animal movements across roads have been used to estimate the number of animal crossings before road expansion and constructing wildlife crossings. |
| | Camera detection | Camera systems along roads have their own inherent operating problems and have not proven to be a reliable method of obtaining information on where animals actually cross roads. |
| | Genetic sampling | Non-invasive genetic sampling of hair for DNA analysis may be practical if used in a high-density grid pattern and/or focusing efforts at a smaller scale of resolution (e.g. medium-sized mammals). |
| GIS-Based movement model | GIS-Based movement model | Landscape-scale GIS-based models have been used to identify key habitat linkages, evaluate habitat fragmentation and discover areas where highways are permeable to wildlife movement. |
| No data | Expert-based habitat model | Expert information may consist of models based on the opinion of experts or qualitative models based on the best available information obtained from the literature. |
| | Rapid assessment | This process differs from the expert-based habitat model in that there is no quantitative analysis of expert opinion or modeling. |
| | Local knowledge | Long-term residents can provide information about where and how wildlife moves across the land. In landscapes where crossing locations are limited, local knowledge can help guide the planning of wildlife crossings. |
| | Compatibility of adjacent land use | Wildlife crossings will only be as effective as the management strategies developed around them that incorporate all the key landscape elements (humans, terrain, natural resources and transportation). |

**Table 3:** Summary of wildlife crossing structures placement approaches.

vehicle interactions by offering effective and safe wildlife crossing examples. This handbook defines a series of criteria, which can be used for future project prioritization. Three key questions during the planning process are identified in the handbook: 1) where should wildlife crossing structures go; 2) what should they look like; and 3) how will they perform [5]. Correspondingly, project and program level considerations are identified for planning, placement and design of wildlife crossing structures.

Many states in the USA do not have a standardized process of data collection, analyses, and project prioritizations. Several regional and statewide projects have developed their own framework and procedures, which can be used as references. Table 4 shows the summary of data collection, analyses and prioritization methods by state [15].

Commonly, these states examine WVC data, collect WVC carcass data, map carcass data and crash data to identify problem areas, perform analysis using AADT data for all roads; and perform analysis using wildlife habitat maps and wildlife linkage maps in their project prioritization process. Some states have developed guidelines for wildlife crossings to standardize the processes of data collection, data analysis, planning, project prioritization, design, effectiveness measurement and maintenance. As examples, the guidelines and reports in Florida, California, South Dakota, and Texas are summarized in following subsections.

## Florida

Wildlife crossing guidelines have been developed for use by the Florida Department of Transportation (FDOT) to evaluate proposed projects or retrofit projects on the State Highway System. Key recommendations and guidelines include:

| State | Carcass Collection Method | Carcass or Crash Mapping | Wildlife Linkage Mapping | Project Prioritization Processes |
|---|---|---|---|---|
| Arizona | No standardized protocol for road kill carcass documentation. Collection methods vary by district. | No statewide effort to map carcasses. Crash data are used instead. | A GIS least cost path analyses of whole state. | A wildlife connectivity prioritization process predominantly based on GIS maps (wildlife linkage maps, wildlife habitat diversity map, etc.). |
| California | Data collection approaches include 1) “eyeballing” the locations of carcasses in a digital map, 2) spatial analysis using spatial autocorrelation based methods. However, there is no formal process of data collection to support mitigation planning. | The Road Ecology Center annually maps road kill hotspots. Ecology Center website has a mapping tool for the public to use for recently collected data. | Regional and statewide linkage and corridor mapping projects available. A disturbance map based upon habitat isolation, urbanization, agricultural development, and/or road system impacts. | No standard process. Primary analyses are based on crash and carcass data, camera trap data, AADT, and mapping of adjacent habitat. |
| Colorado | Colorado DOT Maintenance workers collect carcass data to nearest 1/10 mile. Reporting effort for each unit is unknown and data are not comparable across a region or the state. | Wildlife carcass data are not mapped and used for planning due to inconsistent reporting. Crash data are analyzed to identify crash hotspots, including WVC. | The 2005 Linking Colorado’s Landscapes resulted in the identification and prioritization of nearly 200 coarse-scale, species-based linkages across the state. | No statewide process. A national example, which prioritized 17 linkages and proposed mitigation recommendations based on camera trap data, habitat data, wildlife collision data, citizen reported wildlife observations, field surveys of bridges and culverts. |
| Idaho | Idaho DOT Maintenance workers collect carcasses and enter data on: the time, GPS locations or mileposts and species into electronic database. Public can both upload data on carcasses found along the road, and download data from website. | Both the public and state agencies can use the carcass reporting website. The website brings up maps of carcass locations, but does not cluster them, so there are multiple pin points, rather than a display of hotspots. | A series of workshop conducted to identify wildlife linkage areas across roads in each district-region. Maps of all linkages are available and used in a 2014 study. Shape files and other GIS files are available to public. | In 2014, Idaho became the first state to create a systematic prioritization process for identifying WVC problem areas to target for wildlife mitigation. |
| Montana | Montana DOT maintenance workers collect data and fill out paperwork on carcass collection accurate to the 1/10 mile. MDT Maintenance is looking at how to start collecting all data with either tablets or smart phones. | There is no statewide mapping process. Carcass data are recorded in ranges for each one-tenth of a mile location. This information is reviewed by traffic safety engineer. | No statewide mapping within MDT, but many other efforts, including: Montana Natural Heritage Program, Non-profit organizations, and the Western Governors’ Association Crucial Habitats Assessment Tool. | MDT partners with Montana Fish Wildlife and Parks biologists on projects. In 2015, MDT selected a consulting company to create a standardized prioritization process for the state. |
| Nebraska | No systematic method to collect carcass data. The Nebraska State Highway Patrol records crash data with WVC information. | No mapping is done with the WVC crash data. A Deer-Vehicle Collision Information Kit was developed to show numbers of accidents. | No mapped wildlife linkages/corridors in Nebraska. | No statewide process. NDOT looks at projects that will be constructed on new alignments, adds capacity to an existing roadway, or involve new fencing as the primary factors when considering wildlife mitigation. |
| Nevada | Collection of WVC carcass is performed by Nevada DOT maintenance workers. Data on WVC are collected by Nevada Highway Patrol and are reported in their crash records. | No statewide effort to map WVC carcasses or crash data. Nevada DOT has used crash data to map occurrences across the state. | Nevada implemented the I-80 Corridor System Master Plan which included a working group that investigates potential problem areas. | No statewide process. For each project, few people are selected and assigned to communicate with biologists, planners and engineers. |
| New Mexico | A citizen monitoring program for collecting carcass data will be established. | A WVC priority road segments map available | Sky Island Linkages created an interactive map. | No statewide process. Several efforts have been made to reduce WVC in state. |
| Oregon | Oregon Department of Transportation Maintenance workers fill out paperwork on carcass collection and data are accurate to the 1/10 mile. | Trask used Kernel Density Analysis to map wildlife carcass data by ODOT region and for whole state, but there is no GIS site to update data. | Oregon Wildlife Linkages was an effort created and organized by Oregon Department of Fish and Wildlife (ODFW). | Current planning efforts rely on earlier reports, maps, and websites. The 2009 WVC Collision Hotspot Analysis report gives each ODOT District a list of priority areas to work with, as well as a statewide list. |

| | | | | |
|---|---|---|---|---|
| Utah | Outside contractors record GPS location and species, gender and age of every carcass on mobile phone application. | The GPS carcass data are immediately uploaded to map website and accessed by password protected users. | Utah conducted a 2004 Rapid Assessment mapping of wildlife linkages. | Prioritization process is heavily dependent on individuals in UDOT regions and UDWR districts. General processes: 1) crash and carcass data analysis; 2) identify problem area; 3) meet with stakeholders; 4) identify potential solutions; 5) estimate costs and benefits; 6) plan mitigation project |
| Washington | Washington DOT maintenance workers filled out paperwork on carcasses they collected, with data to the 1/10th of a mile. Software on I-Pads was developed to collect maintenance activities in May of 2015. | The WVC crash data from State Patrol is loaded into WSDOT GIS workbench. McAllister produced a static map for WSDOT. | The Statewide Wildlife Connectivity Analysis, which has maps that are used across the state for identifying wildlife linkages. | The Habitat Connectivity Investment Priorities Method uses: crash data, carcass data, roads, wildlife linkage maps, and federally and state listed 'species of concern' habitat maps. Two priorities are considered: the Ecological Stewardship Rank and the Safety Rank Priorities. |
| Wyoming | Wyoming DOT maintenance crews collect wildlife carcass data. They record the location's highway and milepost to the nearest one-tenth mile, species, sex, age class, etc. | The WYDOT HSP does produce maps of statewide crash hotspots. They can also produce carcass hotspot maps. | No linkage maps in the same sense that other states do such as Arizona and California. | Wyoming Game and Fish and the University of Wyoming have a lot of good data for wildlife migrations that, when combined with WYDOT WVC crash and carcass data, make it easier to identify locations for collision mitigation. |
| Ontario, Canada | Since 2006 provincial highway maintenance crews collect carcass data for large animals. Spatial accuracy varies, sometimes the personnel use GPS in trucks other times the data are reported with only a descriptive location. | The crash data was mapped using the linear highway referencing system (LHRS), and hotspots defined per 2-4 km highway segments around each LHRS station. | An analysis province-wide road of mortality hotspots for amphibians and reptiles, based on preferred habitat surrounding roads in a 200 m buffer. | A standardized prioritization process to identify where short- and long-term mitigation is required. Prioritization processes are based on WVC hotspots, crash rates, risk of WVC, motorist fatalities and injuries. |

**Table 4:** Summary of data collection, analyses and prioritization methods by state.

- Any state or federal highway safety criteria or FDOT design requirements cannot be compromised. If not approved, consider redesigning and coordination with agencies to select the feasible feature
- No restriction of legal access to or negatively impact on neighboring property owners without written approval
- Having no damaging impact on existing drainage system
- Cost efficient and biologically effective feature that meets the requirements of USFWS and FWC and regulatory agencies as well
- Avoiding and minimizing upland and wetland habitat as well as lighting at the sites accessible for maintenance
- Considering cost-benefit analysis while implementing different types of features
- Active review and monitoring of post-construction upon request

## California

The Califorrnia Department of Transportation (Caltrans) published a Wildlife Crossings Guidance Manual, which is a literature-based guide on how to identify and assess wildlife crossings and includes a review of best practices and effective strategies [27]. A Wildlife Crossing Process Decision Tree to identify wildlife crossings is proposed in this manual. This manual provides a series of methodologies (e.g. survey methods, data collection approaches) for baseline assessment and project impact assessment. Moreover, methodologies to identify wildlife crossings are documented in this report: 1) repeated observations of wildlife crossings, 2) a section of roadway with a high rate of vehicle-animal collisions, 3) professional judgments of biologists, 4) field surveys of obvious wildlife corridors, 5) suspected movement corridors with track plates, raked soil, remotely-triggered cameras to identify species present, 6) modeling of wildlife corridor based on occurrences, wildlife habitat, and habitat connectivity, 7) GIS models analyses, and 8) combined detection approaches.

## South Dakota

South Dakota Department of Transportation (SDDOT) reported that the most common WVC data source is law enforcement and safety departments. However, carcass data collection is loosely enforced and there are very limited resources for data management. South Dakota adopted three steps to identify high priority areas for WVC problems: 1) crash and carcass data collection through South Dakota Accident Reporting System database, 2) mapping of crash data using ArcGIS, and 3) agency collaboration and cooperation. SDDOT also proposes the process and framework for agencies to identify mitigation measures with decision support tools.

## Texas

Table 5 summarized the impacts of transportation on endangered and threatened animals in Texas. There is no statewide process to report WVC carcass data at TxDOT and TxDOT environmental staffs in headquarters are unaware of the magnitude of WVC in state [15]. There are 25 semi-autonomous districts in TxDOT, which makes difficult to track actions, raise awareness and support for wildlife mitigation actions. Besides, planning for wildlife in transportation is locally driven and also driven by the U.S. Fish and Wildlife Service.

The Programmatic Agreement of the 2013 Memorandum of understanding between TxDOT and Texas Parks and Wildlife Department (TPWD) defined Best Management Practices (BMPs). In that agreement, a list of Rare, Threatened, and Endangered species of Texas and some standard recommendations were provided to avoid killing or harming any wildlife species during the implementation of TxDOT projects. These recommendations include a) Vegetation BMPs; b) Water quality BMPs; c) Aquatic mitigation; d) Invasive species BMPs;

| Animals | Habitat in Texas | Reasons for Decline | Impact of Transportation |
|---|---|---|---|
| Black-footed Ferret* | Once inhabited extensive areas of the Great Plains ranging from the foothills of the Rocky Mountains east to Nebraska and from southern Canada south to Texas. | The Black-footed Ferret, including conversion of rangeland to cropland, elimination of prairie dog towns, urban development, and introduced diseases such as sylvatic plague. | Some ferrets are killed crossing roads, particularly during the fall dispersal period. |
| Jaguarundi* | Little is known about the habitat of Jaguarundis in Texas. | The extensive shrub lands of the Lower Rio Grande Valley have been converted to agriculture and urban development over the past 60 years. | Roads, narrow water bodies, and rights-of-way are not considered barriers to movement. |
| Ocelot* | In Texas, Ocelots occur in the dense thorny shrub lands of the Lower Rio Grande Valley and Rio Grande Plains. | The extensive sive shrub lands of the Lower Rio Grande Valley have been converted to agriculture and urban development over the past 60 years. | As Ocelot habitat in South Texas becomes fragmented by bigger highways with faster traffic, about half of the Ocelot mortality in the past 20 years from roads. |
| Louisiana Black Bear+ | Once a common inhabitant of forested regions of eastern Texas, Louisiana and Mississippi. | Depletion of populations through over harvest by humans, and to loss and fragmentation of suitable forested habitats. | Remoteness is an important spatial feature of black bear habitat. In the southeast, remoteness is relative to forest tract size and the presence of roads. Black bears involve in road kill as well. |
| Golden-cheeked Warbler* | Typical nesting habitat is found in tall, dense, mature stands of Ashe juniper mixed with trees such as Texas oak, Lacey oak, shin oak, live oak, post oak, Texas ash, etc. | The most serious problems facing the Golden-cheeked Warbler today, as in the recent past, are habitat loss and fragmentation. | Habitat fragmentation, losses in nesting habitat |
| Attwater's Prairie Chicken* | Only in the coastal prairie of Texas. | Habitat loss and alteration are the primary reasons for the population decline of Attwater's Prairie Chicken. | Naturally occurring short grass flats or artificially maintained areas such as roads, runways, oil well pads and drainage ditches. Highway construction causes habitat loss. |
| Houston Toad* | The Houston Toad is a terrestrial amphibian associated with deep sandy soils within the Post Oak Savannah vegetation area of east central Texas. | Habitat loss and alteration are the most serious threats facing the Houston Toad. | High traffic roads are a barrier and poses higher risk of road kill. Other linear features such as pipelines and transmission lines can create barriers between foraging, hibernating, and breeding sites, especially if native vegetation has been removed. |

*Endangered status, + Threatened

**Table 5:** Endangered and threatened animals in Texas [33].

| Mitigation measure | Costs (US$/km/year) | WVC reduction (%) | Benefits (US$/km/year) | Balance (US$/km/year) |
|---|---|---|---|---|
| Reduce vehicle speed | ** | ** | ** | ** |
| Standard wildlife warning signs | $12 | 0% | $0 | -$12 |
| Non-standard wildlife warning signs | $249 | ** | ** | ** |
| Seasonal wildlife warning signs | $27 | 26% | $10,420 | $10,393 |
| Animal detection systems (ADS) | $31,300 | 82% | $32,862 | $1,562 |
| Vegetation removal | $500 | 38% | $15,229 | $14,729 |
| Nutritional value | ** | ** | ** | ** |
| Road Design Features | ** | ** | ** | ** |
| Reflectors or mirrors | $495 | 0% | $0 | -$495 |
| Fence (incl. dig barrier) | $3,760 | 87% | $34,865 | $31,105 |
| Boulders in right-of-way | $2,461 | ** | ** | ** |
| Fence with gap and warning signs | $4,303 | 0% | $0 | -$4,303 |
| Fence with gap and crosswalk | $5,041 | 40% | $16,030 | $10,989 |
| Fence with gap and ADS | $10,036 | 82% | $32,862 | $22,826 |
| Fence with underpasses | $5,754 | 87% | $34,865 | $29,111 |
| Fence with overpasses | $26,378 | 87% | $34,865 | $8,487 |
| Fence with underpasses and overpasses | $7,403 | 87% | $34,865 | $27,462 |

*Key: The table assumes one km with five DVCs per year; ** Unknown/uncertain

**Table 6:** Summary cost/benefit of mitigation measures* [22].

e) Reptile BMPs; f) Rookeries; g) Stream Crossings and h) Wildlife crossings.

Examples of efforts by TxDOT are presented in the cases of bobcats and bat colonies. In Texas, use of culverts by bobcats was positively related to the openness ratio of the culvert and the amount of vegetation adjacent to the culvert. Fences erected to funnel wildlife toward culverts did not increase overall use of culverts, but may have increased use of the high-quality culverts [28]. Modified culverts were tried on US-98 in Texas for ocelots and bobcats [29]. Existing culverts were modified with a 0.46 m wide × 0.30 m high (18 inch × 12 inch) elevated concrete walkway to allow animals to move through even when water was present. However, ocelots were not shown to use the culverts. This was largely attributed to the low population in the area. More recently, Tewes et al. [30] studied the ocelots along transportation corridors in southern Texas by looking at road kill and habitat features to help determine locations for future crossings and develop management strategies.

Another example is the bat colonies. Bats frequent some bridges and even box culverts on TxDOT right-of-way. Some TxDOT districts have built box culverts that contain recessed roofs with textured surfaces to provide roosts for bats. If bat colonies are found on existing structures, contact the Texas Parks and Wildlife Department to determine what steps should be taken that may affect the bats. Incorporate these wherever possible. TxDOT has posted information regarding bats and structures on its DOT website. Bat Conservation International is a non-

| Crossing Structure Type | Approximate Range of Cost(s) |
|---|---|
| Box culvert, Class 1 concrete | $565-$1,380/m$^3$ |
| Box culvert, Class 2 concrete | $620-$3,630/m$^3$ |
| 12" alternative pipe culvert | $113/linear foot |
| 18" alternative pipe culvert | $192/linear foot |
| 1,050 mm alternative pipe culvert | $1,250/m |

**Table 7:** Crossing structure materials costs of caltrans [27].

profit organization that has published a primer on bats and highway structures and alternative design details for accommodating bat roosts. Texas is one of states that are managing bridges for bats with greater success [31].

## Costs-Benefits of Mitigating Measures

The costs associated with mitigating wildlife/vehicle conflicts can be substantial and these costs increase through time. It was estimated the average costs for each deer, elk, and moose collision are US$8,015, US$17,475 and US$28,600 respectively [32], which include costs associated with vehicle repair, human injuries, human fatalities, towing, accident attendance and investigation, hunting and recreational value of the animal concerned and carcass removal and disposal. Other costs fobr maintenance, financing and impact of construction on traffic are excluded. Furthermore, costs and benefits can vary widely for different sites and situations (e.g. geographic locations, effectiveness, frequency of WVCs, surrounding terrain). Table 6 summarizes the costs of various mitigation measures and their effectiveness in reducing WVCs, specifically deer-vehicle collisions (DVCs).

The materials costs of several types of structures for enhancing wildlife passage for a variety of mammals are estimated in Table 7 and were derived from the 2003 Caltrans Contract Cost Data book. These costs are variable depending upon site and application-specific characteristics and include material costs alone; installation and maintenance costs are additional. It is suggested that collaboration with a design engineer and project manager are essential in understanding the design and costs associated with proposed structural improvements or installation.

## Conclusion and Recommendations

In this paper, the mitigation measures and cost-benefit analyses to reduce the environmental and ecological impacts of transportation infrastructure in the USA are reviewed and summarized. It is recommended that each local transportation agency proposes implementation steps to examine the current practices to reduce the negative impacts of transportation infrastructure on wildlife and make recommendations on how to systematically incorporate the successful design practices into their local transportation projects.

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