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Innovative Strategies to Reduce the Costs of Effective Wildlife Overpasses

Editors

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Cover photos: Finalist conceptual designs for the 2010 ARC International Wildlife Crossing Infrastructure Design Competition.

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Abstract

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Wildlife crossing structures have been shown to be one of the most effective means of reducing animal-vehicle collisions on highways, while facilitating essential animal movement across the landscape. Yet the widespread implementation of such structures, especially wildlife overpasses, has been hindered by their perceived and actual expense. For that reason, a facilitated workshop was convened on October 8–9, 2014, in Bozeman, Montana, at Montana State University, with prominent wildlife crossing experts from Canada and the United States to determine whether there are design parameters and construction techniques that could be added, changed, or adjusted to reduce or avoid costs, while maintaining or improving the overall efficacy of wildlife overpasses. This document compiles the resulting strategies and considerations—ranging from recognition that good design requirements (such as design life, structural loading, and clearance box dimensions) can significantly affect project costs, to acknowledgment that settlement restrictions used for vehicular bridges need not apply to wildlife crossing structures, to recognition that the use of materials such as geosynthetic reinforcing systems and expanded polystyrene blocks for fill can potentially reduce costs. Determining the type of procurement process to use, which can potentially drive down costs, was also explored. Potential cost savings considerations were consolidated into three categories: (1) planning; (2) design and construction; and (3) procurement, delivery method, and cost accounting considerations.

Keywords: Cost-benefit analysis, design, landscape design, motorist safety, planning, procurement, wildlife mortality, wildlife overpass.

Executive Summary

Wildlife crossing structures that allow animals to move over or under our nation's highways have been shown to be one of the most effective means of reducing animal-vehicle collisions, while facilitating essential animal movement across the landscape. Although well-designed and well-placed underpasses, such as bridges and culverts, accommodate many species, wildlife overpasses offer a unique opportunity to reweave large landscapes bisected by roads, creating a seamless habitat for wildlife to move across highways. Yet the widespread implementation of such structures has been hindered by their perceived and actual expense. Further, the design of these structures is still novel to transportation planners and design engineers and often requires broader collaborative partnerships as compared to other transportation projects because of the need to incorporate ecological principles.

For that reason, a facilitated workshop was convened on October 8–9, 2014, in Bozeman, Montana, at Montana State University. Prominent wildlife crossing experts from Canada and the United States gathered to determine whether design parameters and construction techniques could be added, changed, or adjusted to reduce or avoid costs, while maintaining the overall efficacy of wildlife crossings. This report, which compiles the results of that workshop, is intended primarily to serve as a list of ideas (see below) for engineers and their ecological partners to consider when constructing a wildlife overpass on a stand-alone basis or as part of a larger planned transportation project.

The workshop captured a number of ideas and strategies that have the greatest likelihood of reducing or avoiding costs, or, in some cases, adding value, as a result of employing one or more particular design parameters. The resulting list of considerations and best management practices is based on the experience and expertise of workshop participants, determined by general consensus.

Design parameters have been consolidated into three categories: (1) planning; (2) design and construction; and (3) procurement, delivery method, and other considerations. Collectively, the options or considerations in this report offer a range of strategies to reduce costs through choices in materials, processes, design, and construction strategies—innovations that should not only maintain, but also, in some cases, improve the ecological effectiveness of a wildlife crossing. Although not all design options will apply to all projects and locations, the compiled considerations should aid practitioners in deciding how to minimize costs or avoid additional expenditures during the design, construction, and procurement of future wildlife overpass structures without compromising their effectiveness.

The following are strategies and considerations discussed in this report:

- **Determine target species movement patterns:**
  Determine local movement pathways for all target wildlife species and locate the crossing structure as close to those pathways as the surrounding topography and design considerations will allow (sec. 2.1.1).
- **Provide local-scale connectivity:**
  Provide local-scale connectivity at wildlife overpasses by ensuring that lands on both sides of the structure are conserved and managed in the long term for wildlife movement and population connectivity (sec. 2.1.1).
- **Apply integrated design approach:**
  Consider an integrated design approach that allows for the development of regional mapping tools and inclusion of ecological data, such as wildlife movement or linkage maps, into the earliest stages of transportation planning (sec. 2.1.1).
- **Take advantage of economies of scale:**
  Consider a programmatic approach that pools groups of structures or activities into one contract to benefit from economies of scale, such as lower per-unit prices (sec. 2.1.2).
- **Incorporate wildlife mitigation early in the planning process:**
  Stay informed of planned local and regional highway projects and consider the need for wildlife structures early in the planning process for those projects (sec. 2.1.2).
- **Integrate mitigation into other highway projects:**
  Take advantage of opportunities to incorporate or "piggyback" wildlife-related mitigation measures into planned highway projects (sec. 2.1.2).
- **Allow creative design solutions:**
  Allow the designer flexibility to consider multiple solutions that meet required design standards (sec. 2.1.3).
- **Evaluate appropriate design lifespans:**
  Evaluate and select an appropriate design lifespan for an overpass crossing based on its contextual location and other assumptions/requirements (sec. 2.1.3).
- **Accommodate anticipated highway standards:**
  Identify anticipated highway standards early in the planning process and develop a wildlife crossing that accommodates necessary geometrics, structural loading, and ecological requirements based on anticipated use by wildlife (sec. 2.1.3).
- **Consider using buried bridges:**
  Consider using buried, rather than traditional, bridges where feasible and appropriate (sec. 2.1.3).

- **Consider single- versus multispan clearance boxes:**
  When developing requirements for crossings over multilane roads that cover longer distances, consider providing clearance boxes for two- or multispan structures. For shorter crossings, single-span clearance boxes can reduce foundation costs and simplify construction logistics (sec. 2.1.3).
- **Minimize structural fill:**
  Reduce the quantities of overburden and structural fill required for the overpass design through proper layout and siting. By selecting a location that takes advantage of grades adjacent to the road that are proximate to the height of the structure, graded transitions can be substantially reduced (sec. 2.1.3).
- **Reduce, reuse, recycle:**
  Identify and assess materials available to be reused for wildlife crossings, including both structural and fill materials (sec. 2.1.4).
- **Consider dual-use structures:**
  Consider co-locating an overpass with recreational, agricultural, or vehicular interests (sec. 2.1.5).
- **Minimize foundation costs:**
  Assess the possibility of minimizing foundation costs by allowing a higher tolerance for overall and differential settlement (sec. 2.2.1).
- **Consider bevel end treatments:**
  Consider using bevels as end treatments if geological, soil, meteorological, and other considerations permit (sec. 2.2.1).
- **Explore new materials and new methods:**
  Consider new designs, technologies, and products developed for other applications or alternative situations for potential applicability to wildlife crossing structures (sec. 2.2.1).
- **Avoid specialized equipment:**
  When considering the design and construction of an overpass, minimize the need for costly specialized equipment and labor (sec. 2.2.2).
- **Consider transport costs:**
  Consider size and weight of fabricated structural members or components in relation to posted maximum loading for highways while accessing the site (sec. 2.2.2).
- **Use onsite supplier expertise:**
  Take advantage of onsite supplier expertise, product knowledge, and experience (sec. 2.2.2).

- **Use modular, stackable components:**
  Explore opportunities to use modular (prefabricated) and stackable overpass construction materials (sec. 2.2.3).
- **Limit use of complex components:**
  Limit the number and complexity of structural components (sec. 2.2.3).
- **Use modularity to optimize adaptation:**
  Use modular elements that allow the structure to change depending on use (sec. 2.2.3).
- **Incorporate "soil pockets":**
  Consider "soil pockets" (areas of larger soil volume) to effectively use limited soil resources and reduce the load on the structure (sec. 2.2.4).
- **Consider local sources of topsoil:**
  Consider locally available materials suitable for topsoil (sec. 2.2.4).
- **Use locally adapted native vegetation:**
  Use locally adapted planting material and locally sourced vegetative cover (sec. 2.2.4).
- **Explore new technologies from related fields:**
  Consider using technologies from related fields and integrating functions to reduce costs, such as technology originally designed for green roofs (sec. 2.2.4).
- **Collect surface runoff:**
  Consider grading surface topography to create low areas that collect surface runoff and planting in those moister microsites (sec. 2.2.4).
- **Consider alternative procurement practices:**
  Identify alternative procurement practices such as design build, and the construction manager/general contractor that may facilitate cost reductions, reduce risk, and promote innovation (sec. 2.3.1).
- **Foster early design collaboration with suppliers:**
  Foster early and proactive design collaboration, and invite superstructure suppliers into the prebid solution development team, regardless of procurement process (sec. 2.3.1).
- **Explore public-private partnerships:**
  Explore public-private partnerships to help defray public costs (sec. 2.3.1).
- **Use full-cost and life cycle accounting:**
  Consider full-cost accounting and life cycle costing when evaluating project costs, alternatives, and potential savings to society (sec. 2.3.2).

Contents

1.0 Introduction

1.1 Do Wildlife Crossings Really Work?

People unfamiliar with wildlife crossing structures often ask if animals actually use them and whether they reduce the risk of vehicular collisions with animals. The answer to both questions is an unequivocal yes!

Scientists around the world have documented hundreds of thousands of animals using crossing structures, including overpasses and underpasses.

These species differ from the pronghorn antelope to small salamanders, from grizzly bears to crabs, and even duck-billed platypuses (figs. 1 and 2). In Banff National Park, Alberta, for example, scientists detected more than 150,000 crossings by 11 different species (some of which are listed below) of large mammals over a 17-year period, including crossings by the principal species identified below.

Species	Number of crossings	Species	Number of crossings
Ungulates:		Carnivores:	
Deer	72,857	Black bear	1,663
Elk	53,251	Grizzly bear	1,549
Moose	534	Cougar	1,627
Sheep	4,999	Wolf	6,826

Renee Callahan

Figure 1—Pronghorn antelope, native to western North America, must move long distances to meet their needs for food and water over the seasons. Roads and fences hinder their ability to move freely to meet these needs.

USDA Forest Service Betsy Howell

Figure 2—Unlike the wide-ranging pronghorn, this rough-skinned newt moves relatively short distances in its search for food and mates. However, it must have precise habitat conditions otherwise it will dry out and perish.

Wildlife use crossing structures to safely move across our nation's highways. Although well-designed and well-placed underpasses such as bridges and culverts accommodate many species, wildlife overpasses offer a unique opportunity to reweave large landscapes bisected by roads, creating a seamless habitat for wildlife to move across highways. This is due, in part, to the fact that soil and moisture-holding capacity can be designed into the top surface of an overpass, thereby promoting natural ecological functions, such as access to sunlight and precipitation. This allows native vegetation to grow similarly to the surrounding habitat in which wildlife live.

The primary objectives of any wildlife crossing are to maintain the ecological functionality of the landscape for the wildlife species for which it is designed. Ecological design parameters such as the height and species of vegetation, moisture regime, gradients, microhabitat structure (such as logs and boulders), and line of sight across or through the structure are important factors in meeting that objective. Generally, in the case of overpasses, the more the top, or deck, and its designed landscape surface appears continuous with the habitat on each side of the highway, the more likely the target species will use it. Thus, one challenge in implementing overpasses is to produce a structure that flows across and with the surrounding landscape and topography. A biologist or ecologist familiar with the habitat needs of the target species can best determine the necessary landscape surface characteristics.

Wildlife crossing structures traversing highways have been shown to be one of the most effective means of reducing animal-vehicle collisions, while also facilitating essential animal movement across the landscape. Yet the widespread construction of wildlife overpass structures has been hindered by the perceived and actual expenses associated with their implementation and maintenance.

ARC Solutions and the Western Transportation Institute co-convened a facilitated workshop on October 8-9, 2014, in Bozeman, Montana, where prominent wildlife crossing experts from Canada and the United States met (see app. 1 for a list of workshop participants). Although wildlife crossings may be over, under, or at the same grade as the highway, the workshop focused on discussions about overpasses, and specifically, identifying cost-saving measures to consider when designing and constructing wildlife overpasses. Organizers asked the assembled group of engineers, landscape architects, wildlife biologists, ecologists, and other experts to examine whether wildlife overpass design parameters and construction techniques could be added, changed, or adjusted to reduce or avoid costs, without compromising their overall efficacy.

Participants were asked to assess costs and opportunities based on the assumption that transportation officials had already chosen to build a wildlife overpass because it was the most suitable and appropriate solution given the highway project's mitigation objectives. The workshop captured a plethora of ideas from all participants who identified strategies that have the greatest likelihood of reducing costs and adding value, by employing one or more specific design parameters. Participants decided that no idea should be eliminated simply because it might be applicable only in certain limited circumstances. Ideas were further organized into three categories: (1) planning; (2) design and construction; and (3) procurement, delivery method, and other considerations. Workshop participants chronicled and refined their ideas. The result is the following compilation of strategies and best management practices for design considerations to reduce the overall costs associated with wildlife overpasses. These strategies are based on the experience of workshop participants and practitioners and arrived at by general consensus.

Although these suggested management practices inherently include some ecological considerations, this report is aimed primarily at engineers who design and construct actual wildlife crossing structures. This compilation further assumes that the process of designing and building a crossing is a collaborative process between engineers and ecological partners, because both disciplines are critical for a successful outcome. Note that, just as most experienced engineers have not encountered a wildlife crossing structure in their careers, the applied science of highway-related wildlife mitigation is relatively novel to many ecologists as well. Thus, finding experienced and knowledgeable assistance will remain a challenge for years to come.

To ensure long-term cost savings, a well-designed wildlife crossing structure must be developed on time, under budget, and with structural integrity. Additionally, designers must ensure that the resulting structure serves the targeted wildlife species.

2.0 Strategies and Considerations

2.1 Planning

2.1.1 Site location and land security—
Although construction of the superstructure is often the primary focus and most costly element of a wildlife overpass, a well-planned site strategy is critical to its ultimate success. In the past, transportation-related mitigation tended to be site-specific, with little consideration for how the project fits into the larger context of the surrounding ecosystem (Evink 2002). Because of the broader landscape effect of

an extensive road system, it is essential to incorporate large-landscape patterns and processes when planning and constructing wildlife crossing structures.

When planning how to mitigate the disruptive effects of a road on wildlife, decisions are often made with little consideration for larger temporal or spatial scale consequences. The project's vision and goals may be limited to current wildlife populations, or to fine-scale conditions in the immediate vicinity of the crossing structure. Wildlife overpasses designed to have a lifespan of 70-or-more years should consider the changing needs of targeted wildlife populations. Over the structure's lifespan, populations may grow, exhibit changing patterns of movement, appear for the first time, reappear after being absent from the local landscape, or change behavior owing to external stressors such as climate change. To be effective and hold conservation value, crossing structures must maintain or restore ecological connectivity for a wide variety of dynamic species populations over the long term (fig. 3). Context is critical when planning and designing wildlife crossing structures. Every mitigation plan will be different. For instance, mitigation needs and planning will be vastly different between mountain and coastal terrain and vary depending on

Figure 3—Pronghorn antelope using Trapper's Point wildlife overpass across U.S. Hwy 191, near Pinedale, Wyoming. This overpass was placed at a migration route for pronghorn, enabling it to be used by migrating pronghorn within days of its completion.

landscape, human development, and in some cases, political considerations. Additionally, selecting the right site and building an appropriate structure saves time and money by minimizing future modifications or retrofits, which can be costly.

With this in mind, workshop participants agreed it would be beneficial to use an integrated, cross-disciplinary approach involving the expertise of wildlife biologists, ecologists, landscape architects, and engineers during the planning, design, and construction phases to maximize opportunities to identify cost savings while maintaining and potentially improving effectiveness. Such an approach ensures that decisionmakers carefully consider various site elements, including, but not limited to, topography, road dimensions, vegetation, exposure, climatic conditions of the site, and the proper location of a planned crossing based on current and anticipated wildlife movement patterns and available road kill data. Using a cross-disciplinary approach provides an opportunity to identify cost efficiencies at the onset, as well as ensure that the wildlife crossing solution meets the requirements of the targeted wildlife species.

Another important consideration is adjacent land use planning. Wildlife overpasses are only effective when adjacent long-term landscape management strategies are considered. Local or project-scale impacts from human development, disturbance, and land use change may negatively affect wildlife movement on the approaches to overpasses, potentially diminishing or preventing animals from using them and thereby rendering them ineffective. Similarly, alteration of landscape elements at a broader, regional scale may impede or obstruct wildlife movements toward the structures. Thus, transportation planners and project managers must consider human activities and adjacent land management to ensure that the location, benefits, and investment in wildlife crossings are maximized.

2.1.2 Program integration and planning—
Planning transportation projects that fully consider wildlife concerns often requires collaboration across multiple agencies and, in some cases, jurisdictional boundaries, which are challenges that are not easily accomplished and are rarely routine (Beckmann et al. 2010). To further complicate matters, transportation agencies may employ funding schedules and systems that are not readily compatible with those of nontransportation agencies. Agency missions typically do not align, except when both agencies seek to promote environmental stewardship. Although a cross-disciplinary approach is desired for project development, finding shared values that support cross-agency and cross-jurisdiction collaboration is often difficult. Workshop participants thus agreed that involving natural resource personnel early and often in the design planning process would improve design and construction efficiency, create cost savings, and increase the effectiveness of the crossing structure.

Transportation agencies often bundle dissimilar or adjacent highway project components into a single project to reduce mobilization costs and decrease disruption to traffic and existing infrastructure. Linking prospective infrastructure projects with wildlife migratory routes and potential crossing locations may help reduce costs for wildlife crossing structures as well (Brown 2006). For example, planners may use large-scale wildlife linkage maps and wildlife-vehicle collision analyses to identify and group multiple wildlife mitigation projects identified during the highway corridor planning and project design phases into a single project, thereby potentially reducing costs.

Other programmatic approaches that combine groups of structures or wildlife-related mitigation activities into one contract may also benefit from economies of scale that result in lower per-unit prices. Many state transportation agencies offer an Agreement to Render Services program that allows local organizations or agencies to piggyback, or add, a special project to a larger scale highway project. This approach eliminates construction mobilization costs for the special project, while taking advantage of per-unit quantity discounts of the larger highway project.

Incorporating wildlife mitigation early in the planning process can also drastically reduce mitigation costs, compared to retrofits, which are often costly. It is thus critical to stay informed of planned local and regional highway projects and to consider early on the need for related wildlife mitigation. In the United States, for example, practitioners may review their state's schedule of planned transportation projects, contained within its Statewide Transportation Improvement Program, to identify projects for which mitigation may be appropriate.

2.1.3 Early structural design requirements—
To ensure that a finished wildlife crossing structure provides adequate strength and safety for targeted species, transportation agencies typically set structural and other design requirements during the initial planning stage. The design requirements selected during planning will affect all future stages of the project, from conceptual design through construction, operation, and final disposition. According to studies of manufactured products (Anderson 2001), only 8 percent of the total product budget is spent on the product design stage, which determines 80 percent of the product cost. It is not surprising, therefore, that developing a document outlining project requirements can significantly reduce costs by leaving room for flexibility and creativity in how the required standards are met.

For wildlife crossing projects, a variety of factors influence design requirement costs including, design lifespan, type of superstructure, highway geometric standards, structural loading (for primarily dead load given minimal heavy repetitive live loading), clearance box, and site layout.

Wildlife crossing structures in many cases are designed to have a specific design lifespan similar to that for highway bridge structures (typically, 75 years). Design lifespan, however, is a theoretical timespan that estimates when major reconstruction or replacement is likely required based on materials used and the nature of construction. Accordingly, it may be appropriate to designate a shorter lifespan based on material composition or selection (such as choosing nonepoxy rebar given the lack of exposure to corrosive salts rather than expensive epoxy coated or stainless steel rebar), contextual location, and other assumptions/requirements.

Regulatory standards typically govern geometric and structural loading requirements for highways that pass vehicular traffic. It is unclear, however, whether such standards apply to structures designed to pass wildlife. Thus, it may be beneficial to assess whether compliance with such standards is required or even necessary. For example, do geometric requirements apply when a lower volume or lower speed roadway is involved, and do they apply when planning crossing structures for migration routes that are expected to shift in the future owing to climate change? Evaluating which regulatory requirements are applicable to specific wildlife crossing projects can additionally reduce costs.

Use of different superstructure types, such as buried bridges, may also reduce costs. Currently, wildlife overpasses typically employ one of two generic superstructure types: (1) traditional or (2) buried bridges. As depicted in figure 4, traditional bridges rely exclusively on manufactured structural materials (steel, aluminum, or concrete) to resist or support loading. In contrast, buried bridges rely on both manufactured materials and soil to resist or support weight loads, as shown in figure 5.

Traditional and buried bridges are commonly selected based on conditions and characteristics of the location. Many wildlife overpass structures in North America and Europe use buried bridges, which are more economical and may be more effective at passing wildlife. The installation of buried bridges typically results in 33 to 67 percent lower costs, as compared to the cost of installing traditional bridges (Transportation Research Board Committees AFF70 and AFS40 2013). Buried bridges also have high load-carrying capability and low maintenance requirements (Transportation Research Board Committees AFF70 and AFS40 2013). Buried bridges also enable greater soil depths, which foster a wider variety of vegetative growth. Depending on the loading criteria and span of buried bridges, soil depths

Arizona Game and Fish Department

Figure 4—Traditional bridge-style wildlife overpass crossing on U.S. Highway 93 in Lake Mead National Recreation Area to protect desert bighorn sheep.

Contech Engineered Solutions

Figure 5—Buried wildlife overpass crossing over I-90 in eastern Washington state.

of 2 feet (0.6 meter) are minimum, and soil depths of 5 to 7 feet (1.5 to 2.0 meters) are typical. Many highway projects are faced with the disposal of surplus or unsuitable excavated soil. Buried bridges offer an excellent opportunity for the use of this material. Buried bridges also facilitate the use of earth berms in addition to fencing along bridge edges, thereby providing a natural acoustic and light barrier.

Another important design consideration is the dimension of the highway traffic "clearance box," or the height and span necessary to accommodate the anticipated vehicle sizes and loads traveling under the wildlife overpass. Required clearance box dimensions are set by the transportation agency. In many cases, it is more cost-effective to have separate clearance boxes for each lane or lanes of traffic, as shown in figure 6, instead of designing the crossing to clear the roadway in a single span, as depicted in figure 7. Allowing designers to use either single-span or multilane clearance boxes, as appropriate, may lower overpass costs.

AIL Group of Companies

Figure 6—Two-span wildlife crossing over Trans-Canada Highway in Banff National Park, Alberta, Canada (the yellow box depicts the clearance box).

Neil Hetherington / Western Transportation Institute

Figure 7—Single-span wildlife crossing known as the "Animals' Trail," a 197-feet wide vegetated arch overpass for wildlife that crosses over U.S. 93 on the Flathead Indian Reservation, home to the Confederated Salish and Kootenai Tribes.

Siting a structure to optimize use by the targeted wildlife species, while minimizing costs, is a challenging task even for highly experienced biologists. However, compromises can be sometimes made that would likely optimize wildlife usage while reducing costs. For example, building an overpass at a site where the highway is cut through adjacent foothills would likely reduce the amount of required backfill and cost, compared to an alternate site a half-mile away that is on level land and would require twice as much backfill. In such a case, it may be possible to select the first site, which reduces construction costs owing to favorable topography without compromising the structure's effectiveness. This is especially true where fencing can be used to guide animals toward a structure.

2.1.4 Recycled and reused materials—
The familiar mantra for waste management—reduce, reuse, recycle—can also reduce the costs of crossing construction. "Adaptive reuse," in particular, offers some new opportunities, including repurposing bridge decks, beams, posts, or other decommissioned bridge components.

Searching for such elements can be a worthwhile effort if materials are locally sourced, efficient to transport, and sufficiently sound for use in the design. An example involving the Oregon Department of Transportation illustrates the potential magnitude of savings that can be attained by such "common sense" principles. Oregon reused 70 percent of the 326 beams from the Willamette River Bridge project for other highway projects around the state (fig. 8). Reusing these beams, salvaged from a temporary interstate bridge built in 2004, was projected to save $3.25 million (Construction Equipment Guide 2015).


Oregon Department of Transportation

Figure 8—Crews place large concrete box beams for the new path viaduct near the Willamette River in Oregon.

Other examples include the use of alternative materials, such as recycled or reused asphalt pavement mixtures, as backfill where traditional materials are lacking or in short supply. Identifying backfill materials from adjacent construction early on during planning and design can result in cost savings where cut-and-fill materials are redistributed across several regional project locations nearby.

2.1.5 Co-locating shared-use structures—
Designing or co-locating an overpass for both wildlife and human use can distribute the cost of the wildlife crossing across different agencies, thereby lowering the transportation agency's out-of-pocket expenditures. Although some wildlife species will not use structures with regular human foot or vehicle traffic, many species will tolerate shared use, particularly if the most active use is low to moderate and temporally separated (fig. 9). An assessment of the impact on the wildlife species expected to co-use the overpass should be conducted beforehand. Areas of natural substrate and vegetation adjacent to the trail or road are essential for success of shared-use structures by wildlife. Funnel-fencing is also necessary for shared-use structures to achieve maximum effectiveness.

Oregon Department of Transportation

Figure 9—Wildlife camera image of mule deer walking through an underpass with an access road to Lava Lands Visitor Center on the Deschutes National Forest in Oregon. The twin underpasses under busy U.S. 97 serve animals at night and in the off seasons when the visitor center is closed.

Summary of planning considerations:

- **Determine target species movement patterns:**
  Determine local movement pathways for all target wildlife species and locate the crossing structure as close to those pathways as the surrounding topography and design considerations will allow (sec. 2.1.1).
- **Provide local-scale connectivity:**
  Provide local-scale connectivity at wildlife overpasses by ensuring that lands on both sides of the structure are conserved and managed in the long term for wildlife movement and population connectivity (sec. 2.1.1).
- **Apply an integrated design approach:**
  Consider an integrated design approach that allows for the development of regional mapping tools and inclusion of ecological data, such as wildlife movement or linkage maps, into the earliest stages of transportation planning (sec. 2.1.1).
- **Take advantage of economies of scale:**
  Consider a programmatic approach that pools groups of structures or activities into one contract to benefit from economies of scale such as lower per-unit prices (sec. 2.1.2).
- **Incorporate wildlife mitigation early in the planning process:**
  Stay informed of planned local and regional highway projects and consider the need for wildlife structures early in the planning process for those projects (sec. 2.1.2).
- **Integrate mitigation into other highway projects:**
  Take advantage of opportunities to incorporate or piggyback wildlife-related mitigation measures into planned highway projects (sec. 2.1.2).

- **Allow creative design solutions:**
  Allow the designer flexibility to consider multiple solutions that meet required design standards (sec. 2.1.3).
- **Evaluate appropriate design lifespans:**
  Evaluate and select an appropriate design lifespan for an overpass crossing based on its contextual location and other assumptions/requirements (sec. 2.1.3).
- **Accommodate anticipated highway standards:**
  Identify anticipated highway standards early in the planning process and develop a wildlife crossing that accommodates necessary geometrics, structural loading, and ecological requirements based on anticipated use by wildlife (sec. 2.1.3).
- **Consider using buried bridges:**
  Consider using buried, rather than traditional, bridges where feasible and appropriate (sec. 2.1.3).
- **Consider single-span versus multispan clearance boxes:**
  When developing requirements for crossings over multilane roads that cover longer distances, consider providing clearance boxes for two-span or multispan structures. For shorter crossings, single-span clearance boxes can reduce foundation costs and simplify construction logistics (sec. 2.1.3).
- **Minimize structural fill:**
  Reduce the quantities of overburden and structural fill required for the overpass design through proper layout and siting. By selecting a location that takes advantage of grades adjacent to the road that are proximate to the height of the structure, graded transitions can be substantially reduced (sec. 2.1.3).
- **Reduce, reuse, recycle:**
  Identify and assess materials available to be reused for wildlife crossings, including both structural and fill materials (sec. 2.1.4).
- **Consider dual-use structures:**
  Consider co-locating an overpass with recreational, agricultural, or vehicular interests (sec. 2.1.5).

2.2 Design and Construction

2.2.1 Structural design development—

Once early design parameters, such as location, superstructure type and span, have been established, consider exploring additional structural design opportunities to reduce the costs of wildlife overpasses.

One option is to assess the possibility of minimizing foundation costs by allowing a higher tolerance for overall and differential settlement (either along the length of the footing or from one footing to the other). Because a wildlife crossing structure does not generally need to carry the same loads as a vehicular bridge or have a smooth transition at the pavement/structure interface, the usual settlement restrictions for vehicular bridges may not apply to wildlife crossing structures.

Suppliers of proprietary structures, in collaboration with the geotechnical engineer, should measure and apply their product's tolerance for settlement onsite to take maximum advantage of this aspect in the design. No standard exists for each product; therefore, specifications about the responsibilities and requirements for each product's use must be clearly spelled out. Generally, flexible structures tolerate greater settlements than rigid structures. The specification that will most likely require resolution is the geotechnical data. Therefore, the transportation agency will need to provide complete and relevant geotechnical information for the selected site. Designing based on this information allows the agency, contractor, and supplier to reduce their liability during the bidding and construction processes, which can further reduce overall costs.

Using bevels as end treatments can be beneficial to project costs and design if geological, soil, meteorological, and other considerations permit. Buried bridges employ several end treatment options, some of which cost more than others. In North America, many existing crossings have a retaining headwall treatment, while in other parts of the world, bevel end treatments, which incorporate the natural angle of repose for the fill material, are common (see examples displayed in figs. 10 and 11). For example, a budgetary assessment suggests that if the Banff National Park wildlife overpass structure had used a bevel end treatment, a $400,000 cost reduction might have been attained, all other factors excluded (Williams 2014).

Nevada Department of Transportation

Figure 10—Mechanically stabilized earth end treatment used on wildlife overpasses across I-80, near Wendover, Nevada.

AIL Group of Companies

Figure 11—Bevel end treatment on Nambu Beltway Tunnel in Gyeonggi Province, South Korea.

New materials, technologies, products, and methods developed for other applications should be routinely assessed to determine whether they apply or can be adapted to wildlife crossing structures. Two promising options for wildlife overpasses include geosynthetic reinforced soil buried bridges (fig. 12) and high-density expanded polystyrene geofoam blocks (fig. 13). Other new and emerging materials include ultra-high-performance fiber-reinforced concrete, resins, and laminates.

AIL Group of Companies

Figure 12—Geosynthetic reinforced soil is used for a buried bridge during construction.

AIL Group of Companies

Figure 13—Expanded poly-styrene geofoam used in construction.

2.2.2 Implementation and logistics—

Many, if not most, wildlife crossing structures will be located in remote rural locations. As a result, specialized equipment and ready-mix concrete may not be readily available or may be expensive to transport and assemble onsite (fig. 14). Transportation of components that are overweight, too high, or too wide can require special permits and procedures that add time and costs to a project. For example, assembling specialized tracked crane and outriggers/counterweights can cost up to $500,000. In comparison, using a highway-certified, rubber-tired, mobile crane costs about $50,000 for a typical project.

Having a supplier representative on-site during construction is recommended in order to take advantage of supplier expertise, product knowledge, and experience in erecting/assembling their product. Additionally, having a supplier present at preconstruction meetings and construction initiation can offer contractors insight into efficient and proper construction practices, thereby increasing the likelihood of a successful installation and meeting expected product performance. For the long-term success of the crossing structure, maintenance personnel and construction engineers specialized in large bridge or concrete arch construction should be included in the project design process.

Terry McGuire

Figure 14—Cranes erecting concrete arches over the Trans-Canada Highway in Yoho National Park.

2.2.3 Modularization— The overpass structure does not have to be built onsite to be effective. Studies have shown that modular (prefabricated) construction increases quality and construction site safety, while reducing construction time, overall costs, traffic disruption, material waste, and impacts on the environment (FHWA 2012, Rogan et al. 2000). In addition to exploring opportunities to use modular overpass construction materials, use of stackable elements can also improve efficiency. Hinged structures or other design techniques may decrease element lengths, thereby reducing costs by minimizing “lift” weights and potentially allowing for the use of a smaller crane. Use of complex structural components are also likely to result in higher construction costs; limiting the number and complexity of such components will likely reduce costs.

Research has shown that the range of some species may shift owing to migratory route changes, adaptation to climate change, or natural occurrences such as forest fires (Chen et al. 2011, Heller and Zavaleta 2009, Mawdsley et al. 2009). Using modular designs in wildlife structures could provide an opportunity to assess the effectiveness of different crossing widths. Designs that facilitate moving, widening, or narrowing structures can be particularly useful when it is too expensive to build a larger structure (FHWA 2015). Flexibility in design widths would allow project managers to try a narrow, modular overpass as a "test" case, which could then be widened at a later point if monitoring determines it is not effective at passing the targeted wildlife species. Alternatively, monitoring may reveal that the narrow structure is equally effective as the wide one. In that case, future projects would benefit from cost savings associated with reduced structure width.

2.2.4 Landscape design—

Many wildlife species need appropriate habitat and vegetation to move securely and freely across the landscape (fig. 15). However, planting design for growing native vegetation on wildlife overpasses can be a challenge. Topsoil, which is important for plant establishment and resiliency, can be a limiting factor on projects facing load design issues and costs. Decisionmakers should therefore consider using lightweight organic fill or synthetic planting mixes. Additionally, transplanting local vegetation or using locally adapted plant stock will improve chances for a successful outcome (Steinfeld et al. 2007).

By coordinating with specialists in plant ecology, wildlife biology, and landscape design, site-appropriate vegetative species can be identified and linked to the optimal soil volume necessary for long-term growth and plant viability (Steinfeld et al. 2007). In doing so, areas requiring more soil volume can be identified, and portions of the superstructure that can accommodate the increased load by employing "soil pockets" can be planned. These "pockets," which are deeper and thus hold

HNTB Corporation and Michael Van Valkenburgh Associates, Inc

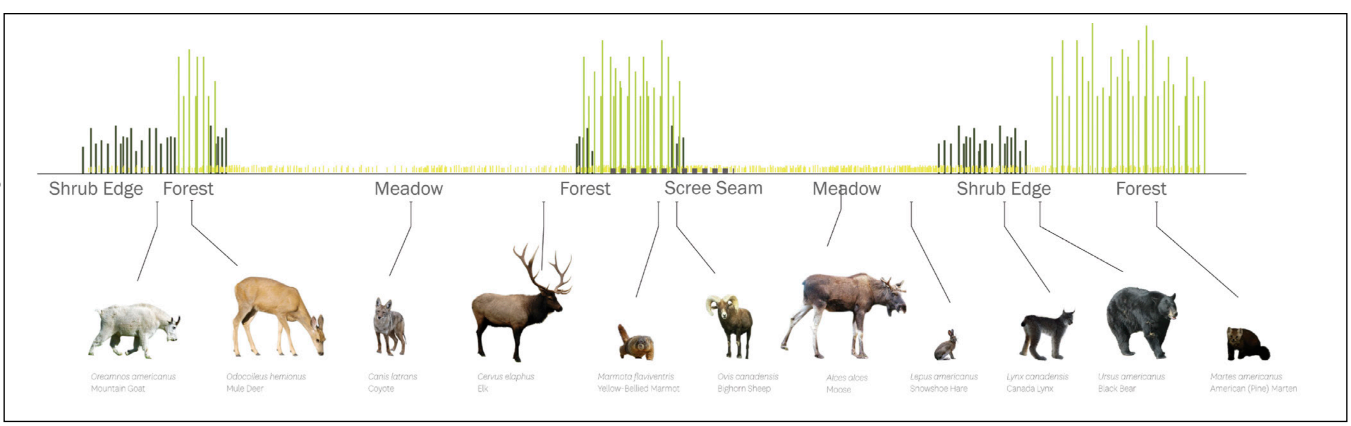

Figure 15—Sample cross section of multiple habitat types targeting species local to the Western Alpine region, planted across the width of the crossing structure. Part of the winning design for the ARC International Wildlife Crossing Infrastructure Design Competition.

a greater volume of soil, may be placed where vegetation cover is most critical for wildlife use. This can reduce load and cost, increase habitat design, and contribute to the success of plant establishment. Consistent with strategies that reduce costs by repurposing locally available backfill, using locally available materials suitable for topsoil can also reduce costs.

Integrated vegetative corridors are important to providing landscape continuity and foraging for the target species. Use of native plant material acclimated to the site may reduce maintenance costs and future losses, if planned for and installed properly (Steinfeld et al. 2007). Banff National Park, for example, used locally adapted plant stock to vegetate its overpass structures (fig. 16). Plant materials were grown from seeds taken from the affected site, cultivated in nearby greenhouses, and later planted onsite. Plant material can also be collected from adjacent project sites and containerized for later planting. As a cost-effective means of vegetating wildlife overpasses, 6- to 9-feet (2- to 3-meters) high trees were transplanted from the highway right-of-way to the overpass; this was done in the wetter spring months to improve root establishment and plant survival rates. Using native materials can provide the best opportunity for plant survival and is often cost-effective (Landis et al. 2005).

Incorporating technologies from related fields and integrating these functions into structures may also help reduce costs. For example, use of technology originally designed for green roofs may prove equally applicable to wildlife crossings. Lightweight soil media, drainage media, and protective membranes developed for these applications can be modified for wildlife crossings. Roofing membranes (such as EPDM, a type of synthetic rubber) may also improve safety as water is channeled off—rather than through the structure and onto the roadway, which can result in severe icing problems for motorists.

Terry McGuire

Figure 16—Vegetated wildlife overpass on Trans-Canada Highway in Banff National Park, Alberta, Canada.

Overpass surface grading techniques that create soil depressions and promote water retention at microsites can increase plant survival, which can further reduce overall revegetation costs.

Summary of design and construction considerations:

- **Minimize foundation costs:**
  Assess the possibility of minimizing foundation costs by allowing a higher tolerance for overall and differential settlement (sec. 2.2.1).
- **Consider bevel end treatments:**
  Consider using bevels as end treatments if geological, soil, meteorological, and other considerations permit (sec. 2.2.1).
- **Explore new materials and new methods:**
  Consider new designs, technologies, and products developed for other applications or alternative situations for potential applicability to wildlife crossing structures (sec. 2.2.1).
- **Avoid specialized equipment:**
  When considering the design and construction of an overpass, minimize the need for costly specialized equipment and labor (sec. 2.2.2).
- **Consider transport costs:**
  Consider size and weight of fabricated structural members or components in relation to posted maximum loading for highways accessing the site (sec. 2.2.2).
- **Use onsite supplier expertise:**
  Take advantage of onsite supplier expertise, product knowledge, and experience (sec. 2.2.2).
- **Use modular, stackable components:**
  Explore opportunities to use modular (prefabricated) and stackable overpass construction materials (sec. 2.2.3).
- **Limit use of complex components:**
  Limit the number and complexity of structural components (sec. 2.2.3).
- **Use modularity to optimize adaptation:**
  Use modular elements that allow for adaptations to the structure depending on use (sec. 2.2.3).
- **Incorporate soil pockets:**
  Consider soil pockets (areas of larger soil volume) to effectively use limited soil resources and reduce load on the structure (sec. 2.2.4).
- **Consider local sources of topsoil:**
  Consider locally available materials suitable for topsoil (sec. 2.2.4).

- **Use locally adapted native vegetation:**
  Use locally adapted planting material and locally sourced vegetative cover (sec. 2.2.4).
- **Explore new technologies from related fields:**
  Consider using technologies from related fields and integrating functions to reduce costs, such as technology originally designed for green roofs (sec. 2.2.4).
- **Collect surface runoff:**
  Consider grading surface topography to create low areas that collect surface runoff and planting in those moister microsites (sec. 2.2.4).

2.3 Procurement, Delivery Method, and Cost Accounting

Although not technically a design parameter, the procurement process offers significant potential for reducing the costs of wildlife crossing projects, by considering alternative procurement processes and fostering collaboration among transportation agencies and their contractors. Additionally, assessing the costs and benefits of wildlife structures may be more accurate if a life cycle accounting approach is used, which would evaluate the value of the wildlife crossing across the structure's lifespan and not simply based on construction costs.

2.3.1 Procurement and project delivery methods—

The project delivery method is the process by which a construction project is comprehensively designed, planned, and constructed. This method includes project scope definition, organization of designers, constructors, and various consultants, sequencing of design and construction operations, execution of design and construction, and closeout and startup. Different project delivery methods are distinguished by the manner in which contracts among the agency (or owner), designers, and builders are formed and the technical relationships that evolve among parties to those contracts.

Currently, there are several types of project delivery systems available for use with publicly funded transportation projects. As shown in figure 17, the most common systems are design-bid-build (DBB), design-build (DB), and construction manager/general contractor (CM/GC). A fourth structure, known as the public-private partnership (PPP), may be used in conjunction with one or more elements from each of the three most common project delivery systems. Note that no single project delivery method is appropriate or the "right one" for all wildlife crossing projects; rather, each project must be examined individually to determine how it best aligns with the attributes of each available delivery method.

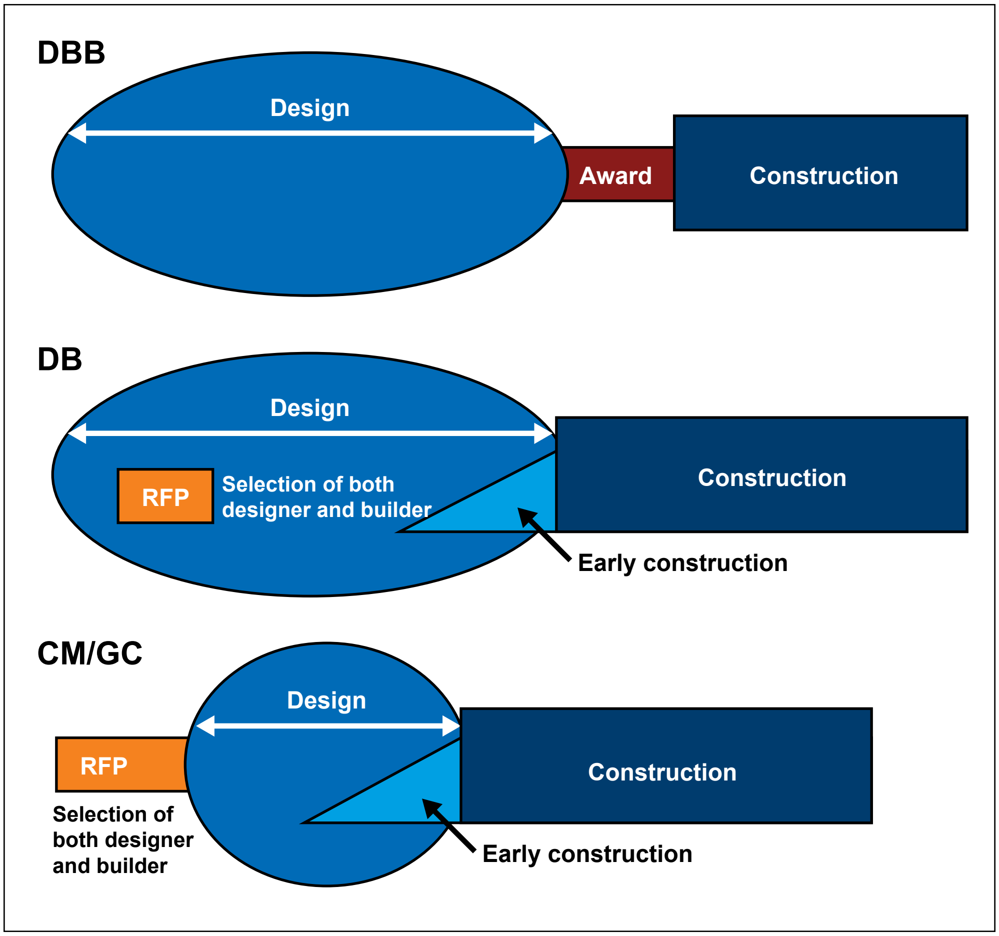

Figure 17—Three common procurement methods for highway construction projects: Design-bid-build (DBB), design-build (DB), and construction manager/general contractor (CM/GC). RFP = request for proposal.

Design-bid-build is the traditional project delivery method in which the transportation agency designs (or retains a designer to furnish) complete design services and advertises via an "Invitation for Bids" to award a separate construction contract based on the completed design/construction documents. In DBB, the agency "owns" the details of the design during construction and, as a result, is responsible for the cost of any errors or omissions encountered during construction. Additionally, the agency (or its agent) is responsible for developing cost-effective solutions, which means that the agency must manage accurate site design information and integrate thoroughly reviewed relevant products, materials, and related innovations into structure designs (Colorado Department of Transportation 2014, NASEM 2014).

Design-build is a project delivery method in which the agency procures both design and construction services in the same contract from a single, legal entity referred to as the design-builder. The method typically involves issuance of a "Request for Qualifications" or "Request for Proposals." In contrast to DBB, the design/builder controls the details of the design and is responsible for the cost of any errors or omissions encountered during construction. DB is thus used to minimize risks for the agency and to shorten the delivery schedule by overlapping the design and construction phases of a project.

However, the DB method may not be the most cost-efficient because it tends to pit the agency against the contractor, often leading to a lack of transparency and cooperation between the two groups. In addition to raising a potential barrier to the agency reaping any costs savings, this approach may result in the agency shouldering additional costs. For instance, if the contractor wins the work based on certain geotechnical assumptions and then realizes, during construction, that onsite geotechnical conditions are better than tendered, the contractor team can seize this cost reduction to increase its profit, which would mean leaving the agency with no benefits. Conversely, if the onsite geotechnical parameters are worse than tendered, the contractor team is likely to request a change order or actively seek an alternative way to pass on the additional cost to the agency. Another major factor potentially affecting use of a DB approach to design overpasses is that a wildlife crossing structure is still a relatively new technology, which may limit the contractor's ability to secure the most qualified designers (Colorado Department of Transportation 2014, NASEM 2014). Having explicit project criteria guidelines are critical for ensuring that designers are able to effectively consider, implement, and achieve all intended uses of the animal crossing.

The construction manager (CM)/general contractor (GC) method is procured through a two-part selection process: design and construction. The agency contracts separately with a designer and a CM. In contrast to DBB, where the builder is presented with a completed design, the CM is engaged early on to assist with evaluating, planning, and improving the project during the design phase. The CM then has an opportunity to bid on the completed design and, if all parties agree, the agency hires the CM to act as the GC. This method may lead to the most cost-efficient solutions, as a collaborative approach is more likely to successfully deliver cost-reduction opportunities to the agency.

Similar to DB, CM/GC also requires developing a contract between the agency and the construction manager, who will be accountable for the final cost and time of construction. Contractor input into design development and constructability under CM/GC, however, tends to foster a more collaborative relationship between the agency and the GC, an element often lacking in both the DBB and DB approach. Moreover, unlike DBB, CM/GC brings the builder into the design process at a stage where definitive input can have a positive impact on the project. CM/GC is particularly valuable for new nonstandard types of designs, where it is difficult for the owner to develop the technical requirements that would be necessary for DBB procurement without industry input (Colorado Department of Transportation 2014, NASEM 2014).[1]

Public-private partnership (PPP) is a form of project delivery resulting in a contractual agreement between public and private sector partners that allows for increased involvement of private sector partners. More project risk is transferred to the private partner, which assumes more of the funding, project management, and maintenance roles, than to the public partner. PPP examples can include elements of other delivery methods, including DB, DB-operate-maintain (DBOM), and DB-finance-operate-maintain (DBFOM).

In addition, PPP contracts such as DBFOM can be written to provide long-term maintenance via an endowment fund. Such funds may be provided solely by the private or public entity, or a combination of both.

Determining the best delivery method requires systematic analyses of project goals and constraints, including delivery schedule, cost, level of design, risk tolerance, and opportunities for partnerships. Such an analysis could include a determination of whether the designers have adequate skills and experience in designing wildlife structures. Secondary factors to consider include staff experience and availability, level of oversight and control, competition, and contractor experience.

It is important to recognize that focusing on limiting risk to the agency and emphasizing low project delivery costs may potentially hinder the ability to realize greater long-term cost savings by using more innovative and flexible procurement processes. Stated differently, risk and project control go hand in hand. If public agencies are to assume more or most of the construction risk, then it is best to select DBB as the delivery method. The tradeoff, however, is that DBBs may come at a cost premium, and they may limit innovation. In contrast, the CM/GC process, which is currently moving toward a more collaborative process, may spur innovation.

Regardless of the project procurement process selected, it is critical to foster early and proactive design collaboration between the transportation agency and the contractor. Superstructure suppliers are a key party for identifying and realizing cost-

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[1] In December 2016, the Federal Highway Administration (FHWA) issued a final rule authorizing use of the construction manager/general contractor contracting method for federal-aid highway projects, noting that it fostered consideration of innovative methods and industry best practices to accelerate project delivery and offer reduced costs and reduced schedule risks. FHWA Construction Manager/General Contractor Contracting Final Rule, 81 Fed. Reg. 86928 (Dec. 2, 2016) (to be codified at 23 C.F.R. pts. 630 & 635).

reduction opportunities; agencies are thus more likely to experience lowered costs if they invite superstructure suppliers into the pre-bid solution development team.

Agencies should also explore the use of PPPs to manage the project, as a way to optimize innovation while minimizing risk. For example, PPPs may aid in developing endowment funds to help defray or eliminate the costs of long-term maintenance. Although there is little opportunity for private partners to see a return on such an investment, there is a demonstrated interest on the part of the private sector—both corporate and philanthropic—in the development of wildlife crossings for furthering wildlife conservation and ecological connectivity. In particular, overpasses can promote environmental values for local communities, which have the capacity and desire to fund construction of wildlife crossing structures to reduce collisions and wildlife mortality on neighborhood roads.

2.3.2 Life cycle costing analysis—

As with procurement, life cycle costing analysis can potentially allow transportation agency decisionmakers to reconsider and reassess the cost of wildlife mitigation structures to better contextualize the agency's costs.

Often, cost savings are focused on, and limited to, reducing construction costs borne directly by the transportation agency. There are, however, other broad-scale economic and social benefits of wildlife mitigation projects that should be considered beyond immediate financial implications and costs. In addition to the added value of environmental education, wildlife monitoring, and research opportunities, society can benefit from a transportation agency's investment in wildlife mitigation strategies by:

- Reduced motorist injuries, fatalities, and suffering
- Lowered spending on vehicle damage and repair
- Increased wildlife hunting and viewing opportunities
- Fewer wildlife injuries and fatalities
- Decreased spending on recovery plans for threatened and endangered species (where vehicle-related mortalities are likely to affect a species' long-term survival)

Using a life cycle approach to assess the value of wildlife crossing projects would allow decisionmakers to determine costs and benefits accrued throughout the lifespan of the structure, rather than on the immediate costs of construction. As a result, decisionmakers should carefully consider all the costs and benefits of wildlife crossing structures, rather than only those costs borne by the agency itself.

Summary of procurement, delivery method, and cost accounting considerations:

- **Consider alternative procurement practices:**
  Identify alternative procurement practices such as DB and CM/GC that may facilitate cost reductions, reduce risk, and promote innovation (sec. 2.3.1).
- **Foster early design collaboration with suppliers:**
  Foster early and proactive design collaboration and invite superstructure suppliers into the pre-bid solution development team, regardless of procurement process (sec. 2.3.1).
- **Explore public-private partnerships:**
  Explore PPPs to help defray public costs (sec. 2.3.1).
- **Use full-cost and life cycle accounting:**
  Consider full-cost accounting and life cycle costing when evaluating project costs, alternatives, and potential savings to society (sec. 2.3.2).

Conclusions

The strategies and best management practices to reduce wildlife structure costs mentioned in this report include consideration and discussion of planning, design, procurement, delivery method, and cost accounting. These cost saving approaches are based on the experience of workshop participants, as arrived at by consensus. Although not all considerations or practices presented are applicable for all crossing projects and locations, the options provided are intended to aid practitioners in considering ways and means to minimize costs or avoid additional expenditures during the design, construction, and procurement of future wildlife overpass structures, without compromising their effectiveness. Taken together, the considerations in this report offer a range of strategies to reduce costs through careful selection in materials, processes, design, and construction—innovations that should not only maintain, but in some cases, improve the effectiveness of wildlife crossing projects.

Acknowledgments

We thank the International Conference on Ecology and Transportation (ICOET) for allowing the ARC Solutions Crossings and Culture Forum to be part of ICOET's biennial conference in Scottsdale, Arizona, in June 2013. During the forum, participants recommended assembling a group of experts in the field to develop strategies aimed at reducing the costs of wildlife overpasses, without compromising their effectiveness in reducing wildlife-vehicle collisions and improving habitat connectivity. In October 2014, ARC Solutions and the Western Transportation Institute at Montana State University (WTI) co-hosted a follow-up workshop in Bozeman, Montana. This publication is the product of that endeavor.

We greatly appreciate the guidance and financial support provided for this project by the ARC Solutions' Steering Committee, including the Federal Highway Administration, U.S. Fish and Wildlife Service, U.S. Forest Service, Western Transportation Institute, and the Woodcock Foundation. Their expertise and counsel have been invaluable to the execution of this project. We are also grateful to the Parks Canada Agency for its fiscal support of the October 2014 workshop. ARC Solutions is fiscally sponsored by the Center for Large Landscape Conservation in Bozeman, MT.

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Ryan Syme, Parks Canada

Robert Rock, Living Habitats

Roger Surdahl, Federal Highway Administration, Office of Federal Lands Highway

Kevin Williams, Atlantic Industries Limited

Theodore P. Zoli, HNTB Corporation

Appendix 2: Common and Scientific Names of Animals Mentioned in This Report

Common name	Scientific name
American marten	*Martes americana*
Bighorn sheep	*Ovis canadensis*
Black bear	*Ursus americanus*
Canada lynx	*Lynx canadensis*
Cougar	*Puma concolor*
Coyote	*Canis latrans*
Crab	*Brachyura*
Duck-billed platypus	*Ornithorhynchus anatinus*
Elk	*Cervus canadensis*
Grizzly bear	*Ursus arctos horribilis*
Moose	*Alces*
Mountain goat	*Oreamnos americanus*
Mule deer	*Odocoileus hemionus*
Pronghorn antelope	*Antilocapra americana*
Rough-skinned newt	*Taricha granulosa*
Salamander	*Caudata*
Snowshoe hare	*Lepus americanus*
Wolf	*Canis lupus*
Yellow-bellied marmot	*Marmota flaviventris*

Glossary

The definitions provided in this glossary have been compiled using a variety of sources including professional texts, publications, and other resources.

Agreement to Render Services (ARS)—A formal agreement to retain a contractor or other provider for one or more specified services.

Angle of repose—The steepest angle at which a sloping surface formed of a granular material is stable.

Backfill—Material used to replace soil removed during construction.

Buried bridge—An arch, three-sided, or box-shaped structure with an unsupported span that relies on surrounding backfill to support loads.

Clearance box—The height and width necessary to accommodate the anticipated vehicle sizes and loads traveling under an overpass.

Cut-and-fill—An approach to minimizing construction labor whereby material removed (cut) during the construction process in one location is used as fill material in a nearby location.

Differential settlement—A situation where the foundation of a structure settles unequally in different areas after construction, typically when the soil beneath all or a portion of the structure cannot bear the weight imposed.

End treatment, including bevel end and retaining headwall treatment— Elements of the overpass design deployed at either end of the structure.

Ethylene propylene diene monomer (EPDM)—EPDM is an extremely durable synthetic rubber roofing membrane widely used in low-slope buildings worldwide.

Expanded polystyrene (EPS) geofoam—A lightweight material used as void fill to reduce the load on the subsoil and minimize settlement.

Geosynthetic reinforced soil (GRS) (Adams et al. 2011)—Closely spaced layers of geosynthetic reinforcement and compacted granular fill material used in a variety of earthwork applications.

Green roof technology—A range of methods employed to vegetate rooftops, typically including growing medium, waterproofing membrane, drainage, and irrigation systems.

Habitat—The natural home or environment of an animal, plant, or other organism.

Life cycle costing analysis—A tool used to determine the cost to purchase, own, operate, maintain and dispose of an object or process, for an expected length of time.

Mechanically stabilized earth (MSE)—Soil stabilized with artificial reinforcement.

Microhabitat structure—Elements of a habitat that are of small or limited extent and differ in character from the surrounding extensive habitat.

Project requirements document—A document outlining the needs and expectations associated with a certain project. The document tends to avoid anticipating or defining precisely how those needs or expectations will be met, and instead allows designers, engineers, and other involved professionals to use their expertise to develop an optimal solution to meet the project requirements.

Soil pockets—Areas of larger soil volume placed where vegetation cover is most critical for wildlife use, thereby reducing load and cost and increasing habitat design and success of plant establishment.

Span (see also: width)—Length of a wildlife overpass from one side of the roadway over which it passes to the opposite side of the roadway.

Statewide transportation improvement program (STIP)—The STIP refers to "a statewide prioritized listing/program of transportation projects covering a period of 4 years that is consistent with the long-range statewide transportation plan, metropolitan transportation plans, and TIPs, and required for projects to be eligible for funding under title 23 U.S.C. and title 49 U.S.C. Chapter 53." 23 C.F.R. § 450.104.

Superstructure—The portion of a bridge that supports the deck and directly receives the live load.

Width (see also: span)—The distance from one side of the passable surface of a wildlife crossing to the opposite side.

Wildlife linkage map—A map that identifies key areas and connections for wildlife movement, usually framed as a corridor from one core habitat area to another.

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