

EVALUATING TRANSPORTATION ALTERNATIVES FOR HATTERAS ISLAND,  
NORTH CAROLINA OUTER BANKS

by

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## **Abstract**

The North Carolina coast includes a dynamic chain of barrier islands known as the Outer Banks. Transportation management on these islands has been the subject of debate over the past two decades because of the high cost of maintaining highway NC 12. The road is subject to frequent sand overwash and storm damage that causes interruptions in services and access and the bridge over a major inlet needs replacement. Interest groups disagree about the best solution, with some most concerned about environmental damage, some about economic impacts of service disruption, and some about emergency evacuation. We interviewed nine stakeholders from federal, state, and local government, citizen action groups, and environmental non-governmental organizations, asking them questions about their preferences pertaining to transportation in general and specific alternative transportation methods for the Outer Banks. The alternatives we researched were: (1) replacing the imperiled bridge with a new bridge across the same inlet (Short Bridge Plus), which would not alleviate the road maintenance difficulties on the islands; (2) building a long bridge through the sound behind the chain of barrier islands bypassing the troublesome road sections (Long Bridge) at very high initial cost; and (3) using ferries to provide transportation to the barrier islands (Ferry System), requiring extensive dredging of coastal habitat and high operational costs. Using data from archived reports and from our interviews, we compared these alternatives in terms of (1) access disruption from storm impacts (in days), (2) short-term cost (dollars), (3) long-term cost (dollars), and (4) environmental impacts (acres of habitat disturbed). We then interviewed three key stakeholders from state government, an environmental organization, and local government to determine how important each of the four factors was to each respondent in choosing a transportation alternative. By combining our evaluations of each alternative with the stakeholders' judgments of importance, we found that the state representative chose the Short Bridge Plus, the environmental organization representative chose the Long Bridge, and the local government representative chose the Ferry System. Because some of these calculated results contradicted what these three respondents told us they preferred, we examined the sensitivity of our calculated results to changes in short and long-term cost estimates, acres disturbed and relative importance of the four factors. A consistent result of our sensitivity analyses was that stakeholders would often switch their preferred alternative to the Long Bridge. Therefore, we believe the Long Bridge might be a point of compromise; however, the massive funding required to build this alternative diminishes the likelihood it will be implemented.

**Keywords:** transportation management, NC 12, Herbert C. Bonner Bridge, Outer Banks

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## Introduction

State Highway 12 runs for 130 miles along a strip of barrier islands off the North Carolina coast known as the Outer Banks (Smith et al., 2008) (Fig. 1). In many places, it is the only road linking several towns to the rest of the Outer Banks and to the North Carolina mainland. Along some stretches of roadway, the barrier islands are no more than about 357 yards wide, putting the road at high risk of flooding and sand overwash from the nearby ocean (Smith et al., 2008).



**Figure 1.** Highway NC 12 on the Outer Banks of North Carolina (Planet Outer Banks, 2013).

Due to the Outer Banks' unique geographical position on the Atlantic coast they have experienced damage from hurricanes as well as rapid erosion (Smith et al., 2008). While there is still uncertainty about whether or not the number of storms will increase with climate change, the intensity of hurricanes in the Atlantic is likely to increase (Pilkey, 2011). Given these factors and the natural tendency of barrier islands to move shoreward, maintaining a static highway has become increasingly difficult due to overwash sand removal and road repairs after storm events (Riggs, 2011).

Maintenance of the highway occurs on an almost daily basis through sand removal. Sand and water wash onto the highway during high winds and high tides, which create conditions that are hazardous to travel, including standing water on the highway (North Carolina Department of Transportation (NCDOT), 2013a). These conditions interrupt (1) residents' daily lives as they travel to work and school, (2) transportation of goods on and off the islands, and (3) the work of emergency response teams. The official social media site relaying NCDOT NC 12 updates, created in spring of 2013, shows that sand overwash and standing water conditions occur monthly. These disruptions have rendered parts of the roads closed or partially closed for multiple days (NCDOT, 2013a). In the spring of 2013, NC 12 experienced interrupted service from March 7-March 12 as a result of a late winter nor'easter (Figs. 2-3). In the fall of 2012, after Hurricane Sandy passed by the North Carolina coast, waves broke down the dunes protecting the highway and washed out the road, causing a 40-day disruption in vehicular access to Hatteras Island (Morris, 2012). In addition to daily disruptions there are concerns about the long-term stability of the Herbert C. Bonner Bridge and portions of the highway that regularly experience breaches after storm events (known as "hotspots") (Fig. 4).

NC 12 @ Mirlo Beach 2013-03-09 07:56:29



**Figure 2.** Sand and water on NC 12 north of Rodanthe, NC on March 9, 2013 (NCDOT, 2013a)

NC 12 @ Mirlo Beach 2013-03-11 10:33:48



**Figure 3.** NCDOT clearing sand from NC 12 north of Rodanthe, NC on March 11, 2013 (NCDOT, 2013a).





**Figure 4.** Map of NC 12 “hotspots” or areas that often experience damage after storms or other severe weather (NCDOT, 2013b).

The Herbert C. Bonner Bridge, which carries NC 12 over Oregon Inlet, is an area of particular concern (Fig. 5). Completed in 1962, the bridge connects northern Hatteras Island to Bodie Island, which then connects to the mainland via NC 64 across the Roanoke and Croatan Sounds (Fig. 1) (NCDOT, 2013c). Because Bonner Bridge exists in a dynamic environment subject to constant wave action and shifting sands, it has experienced rapid deterioration since its installation (Dean, 2012). The deterioration of the bridge along with the near-daily maintenance, including sand removal, makes transportation on the Outer Banks a complex and urgent issue. Furthermore, NC 12 runs through the Pea Island National Wildlife Refuge (NWR) between Oregon Inlet and

Rodanthe (Fig 1). This wildlife refuge is home to migratory birds and sensitive habitat. This section of the barrier island is the most rapidly eroding part of the Outer Banks, and it is where much of the debate about transportation alternatives is centered (Dean, 2012). Our analysis is focused on this study area.



**Figure 5.** Aerial photo of Bonner Bridge over Oregon Inlet, NC, facing south (Outer Banks Task Force, 2013).

Since the 1980s, nearly \$100 million has been spent maintaining and rebuilding sections of NC 12 (Kozak, 2012a). Hurricane Irene in 2011 caused at least \$10 million in damage and rebuilding does not present itself as a sustainable long-term plan (Kozak, 2012a). The rebuilding process is also complicated by the many stakeholders involved including: NCDOT, National Park Service, U.S. Fish and Wildlife Service, local governments such as Dare and Hyde Counties, NC Department of Environment and Natural Resources Division of Coastal Management, Environmental Non-Governmental Organizations (ENGOS), local businesses, homeowners, and North Carolina taxpayers.

With many stakeholders come different interests to protect, which further complicates the decision making and tradeoff evaluation process. Business owners and

local government rely on tourism and ease of access for visitors to boost the local economy. Any transportation alternative that might restrict access may therefore be less preferred than an alternative where access is easier for these stakeholders. On the other hand, agencies like the U.S. Fish and Wildlife Service and ENGOs are concerned with maintaining habitat for species and ecological integrity of the island, which could cause them to value alternatives differently than local businesses or government – perhaps focusing on environmental impacts rather than ensured access. The Division of Coastal Management and the NCDOT are primarily concerned with allowing access as safely as possible while adhering to state laws. These inherently differing values cause stakeholders to view the “best” solution differently; they support the alternatives that most closely meet their needs. For example, if ENGOs favor environment over access, they will likely support the solution that maintains the most ecological integrity and consider the amount of access a solution offers less.

Recently, environmental regulators in North Carolina signed off on a replacement plan proposed by the North Carolina Department of Transportation (NCDOT) to replace Bonner Bridge in approximately the area it currently occupies and address breaches in the Pea Island NWR using smaller bridges (NCDOT, 2012a). Many environmental groups, such as the Defenders of Wildlife and National Wildlife Refuge Association, oppose this plan and would prefer an alternative that would bypass the Pea Island NWR (Fig. 1) (Defenders of Wildlife and National Wildlife Refuge Association v. NCDOT and Federal Highway Administration (FHWA), 2012).

The objective of this project, for a client-based Masters Project for the Program for the Study of Developed Shorelines, is to analyze motivations for stakeholder

preferences and illuminate tradeoffs in the decision making process to maintain a viable and reliable transportation corridor between Oregon Inlet and Rodanthe along the North Carolina coast over the next 50 years. Given the varied stakeholder groups, with differing interests, we used multi-criteria analysis to assess the range of values stakeholders possess and their preferences amongst different management choices.

## **Materials and Methods**

### Multi-attribute utility theory

Multi-attribute utility theory is a method by which consultants may aid decision-makers in determining and ranking their values regarding alternatives and tradeoffs they face in a particular decision. Using this method, we developed a decision analysis framework based on a series of questions we asked of key stakeholders to determine what they want in terms of access from Oregon Inlet to Rodanthe. Our questions were based on the following properties related to access to the Outer Banks south of Oregon Inlet: (1) ecological integrity, (2) financial feasibility, (3) reliability, and (4) ability to accommodate evacuation. Through a series of questions we determined (1) what stakeholders believe are important features of a transportation system in the study area, (2) what criteria are most valued by which stakeholders, and (3) what tradeoffs are often made in the Outer Banks transportation decision-making process. The multi-attribute decision tool that we created from this information was used to evaluate the following transportation alternatives proposed by our client, Andrew Coburn, associate director for the Program for the Study of Developed Shorelines: (1) the Short Bridge Plus – a bridge across Oregon Inlet parallel to the current bridge and a plan to maintain Highway 12 within the Pea Island NWR, (2) the Long Bridge – an 17.1-mile bridge across the

Pamlico Sound, bypassing the Pea Island NWR, and (3) a Ferry System. Ultimately, the decision analysis framework illuminated the tradeoffs associated with each alternative using the input from decision makers and stakeholders.

### Interview Process

In order to acquire a wide range of opinions from multiple sectors we interviewed a variety of stakeholders from the following groups: (1) state government officials, (2) federal government officials, (3) local government officials, (4) local business interests, (5) scientists, (6) representatives from citizen action groups, and (7) environmental non-governmental organizations. We selected the initial round of respondents with input from our client, Andrew Coburn. Following each interview, we asked the respondents to provide additional expert contacts with opinions differing from their own. This “snowball sampling” allowed us to obtain a wide sample of opinions and interviews (Morgan, 2008). We then contacted the additional experts and asked if they would like to participate. We deemed the snowball sampling complete when respondents referred us to people who had already participated in the study. We contacted a total of thirty people, with a positive response from nine.. We informed the respondents that they would be identified by the organization they represented, but that they would not be identified by name in the study report. All of our respondents asked to remain anonymous and will only be identified in this paper by agency or organization type. The format for identification of direct citations from our interviews will be: (Interview subject #x, professional affiliation).

We based interview questions on criteria to provide access to the Outer Banks south of Oregon Inlet – whether this route can maintain ecological integrity, is financially feasible, is reliable, and can accommodate rapid storm evacuation. We administered two types of interviews to two categories of respondents. Respondents from the first category, general respondents, consisted of stakeholders from all aforementioned groups (local, state, federal government, citizen action, and environmental non-government organizations). We asked them opinion- and fact-based questions about whether they believe the current transportation method in the study area is sustainable for the foreseeable future, whether they believe there is a better alternative (either one discussed by NCDOT alternatives, or another that they can think of), and additional questions on social, political, fiscal, physical, and ecological viability of different alternatives. This category of interviews was used to capture the variety of opinions regarding transportation in the study area and to inform the development of the decision framework. See Appendix A for General Interview Script.

Respondents from the second category, in-depth respondents, consisting of individuals from state government, local government, and an environmental non-governmental organization, participated in a longer interview process consisting of two interviews. These interviews were used to evaluate the criteria for transportation in the study area and complete the decision analysis portion of our project as described in the decision framework section. Each interview was roughly forty-five minutes and we administered the follow-up interview within two weeks. During the first interview, respondents answered the same opinion- and fact-based questions as general respondents. During the first interview we asked respondents several additional questions to illuminate

which objectives they valued most. We then compiled all responses from the first interview administered to the in-depth respondents to help create the decision framework. During the second interview we administered questions to assess how much individuals valued certain aspects of each alternative relative to other aspects (e.g., environmental impacts compared to financial costs). See Appendix B for In-Depth Interview Script.

We interviewed nine respondents for general interviews and, of those nine, we chose three for in-depth interviews due to their particular importance in the decision-making process. The groups represented by the six general respondents included (1) federal government (U.S. Fish and Wildlife Service), (2) state government (North Carolina Department of Transportation and North Carolina Division of Coastal Management), (3) a citizen action group, (4) local business interests, and (5) a coastal scientist. The in-depth respondents represented (1) local government, (2) an environmental non-governmental organization, and (3) the North Carolina Department of Transportation. We administered informed consent for each respondent either orally (via phone interview) or in writing (email correspondence). If the respondent allowed, we recorded the interviews and later transcribed notes from the recordings. If we were unable to record the information, we took notes during the conversation. All interviews and informed consent forms will be archived at the Nicholas School of the Environment at Duke University for five years.

### Archival, Media, and Additional Sources

In addition to our primary data collection through interviews, we collected information about the alternatives, history of management decisions, and background on

stakeholder groups from archival sources, media, and published scientific journal articles. We primarily used archival sources for background and research on the alternative transportation methods. These sources included the Draft/Supplemental/Final Environmental Impact Statements and Environmental Assessments since 1993 for Bonner Bridge replacement, formal government studies (two ferry studies (The Institute for Transportation Research and Education at North Carolina State University, 2009; FHWA and NCDOT, 2013), and environmental surveys for sand supply and erosion (Outer Banks Task Force & NC Geological Survey, 1994)), and other government documents (e.g., meeting minutes from the Outer Banks Task Force from 1998-2008 and public hearings for the environmental impact statements for Bonner Bridge replacement) as cited throughout the body of the report. These sources were obtained through government websites, such as NCDOT and the Outer Banks Task Force (obtf.org). Additional government documents not available on these websites were obtained from the Program for the Study of Developed Shorelines archived public documents.

We used newspaper articles to gather information on alternatives and gauge general outlooks on management and decisions in the study area for our characterization of the interest groups. Newspaper articles were gathered from the following sources: The Outer Banks Voice, New York Times, Raleigh News and Observer, The Virginian Pilot, and The Charlotte Observer. We also gathered online news articles from WRAL Raleigh, NC News. We searched archived materials from 2009 to March 2013 using these keywords: NC 12, Bonner Bridge replacement, storm damage, and the names of stakeholder groups (NCDOT, NC Division of Coastal Management, U.S. Fish and Wildlife Service, National Parks Service, U.S. Army Corps of Engineers, Replace the



Bridge Now, North Carolina Coastal Federation, Southern Environmental Law Center). We analyzed 55 articles, 25 of which provided content useful to our analysis. We used these sources during our qualitative analysis of stakeholder groups to better characterize their preferences. Public comments from these relevant agencies made during the planning process were also used as a way to gauge each agency's general opinion on transportation management. We also used sources from the aforementioned stakeholder groups' websites, including news and updates from the Coastal Review Online (North Carolina Coastal Federation), Southern Environmental Law Center updates, and information from the "Replace the Bridge Now" website, to broaden our understanding of their opinions on transportation management in the study area (North Carolina Coastal Federation, 2013; Southern Environmental Law Center, 2013; Replace the Bridge Now, 2013). A PDF file of each article collected will be available as part of our data archive online, which can be found through the Nicholas School of the Environment at Duke University for a period of five years after this study is complete.

We researched scientific journal articles as part of a literature review on the alternatives, general study area, and history of the Outer Banks. We used the Duke Library database search tools with keywords such as: Bonner Bridge, North Carolina Ferry System, Highway 12, and decision analysis in coastal areas. We used this information for our background information as well as for our description of the alternatives considered.

## **Background**

### Coastal infrastructure analyses outside the study area

To begin our study of transportation management on the Outer Banks we researched how managers in other places have approached decision analysis in ecologically sensitive areas. Coastal managers in Europe have demonstrated the effectiveness of multi-criteria analysis to manage socially diverse and ecologically fragile coastal ecosystems. On France's Mediterranean coast in Lido de Sete, eroded shorelines threatened coastal development in a lagoon and barrier island ecosystem. The area was traditionally managed through narrowly focused, engineering-based solutions that included shoreline hardening similar to the Oregon Inlet jetty. Roca et al. (2008) applied multi-criteria analysis to choose a new method for accommodating the changing coastal ecosystem. Wide stakeholder involvement was paramount to ensuring a balanced and informed evaluation of shoreline management alternatives. The respondents tended to choose adaptive shoreline management strategies that accommodated the region's natural morphology over the traditionally used hard engineering strategies that tried to fight physical processes. The critical result was that having input from a broad range of interested parties resulting in a less environmentally damaging outcome that addressed the varying needs of the parties (Roca et al. 2008).

Similarly, Garmendia and others used multi-criteria analysis in 2010 to identify new ways to manage an estuarine system in northern Spain. Dredging done by a local shipyard was interrupting sediment supply in the estuary, leading to conflicts between recreational users of the estuary, industry, agriculture, and the overall health of the ecosystem. The focus of their analysis was exploring an integrated participatory process

involving stakeholders. The researchers (1) completed an in-depth historical and institutional analysis, (2) conducted interviews, surveys, and workshops, (3) evaluated alternatives using social multi-criteria evaluation, and (4) conducted additional public participation meetings. To understand management they studied social-ecological systems, focusing on how groups compromise, not forcing a consensus. The analysis was useful to break the traditional top-down approach of management decisions and to map compromises between parties that led to a better understanding among user groups (Garmendia et al., 2010). The collaboration and free exchange of ideas focused the attention of users on the changing aspects of the issue at hand. The shift led users to see management as an experience from which to learn, accepting uncertainty and expecting surprises (Garmendia et al., 2010).

Roca and others in 2008 and Garmendia and others in 2010 both demonstrated that user input was valuable to the decision making process (Roca et al., 2008; Garmendia et al., 2010). We believe that multicriteria analysis, given the input of stakeholders for management of NC 12, could have similar positive impacts by illuminating tradeoffs in transportation decision making. To further our understanding of the decision making process and how multicriteria analysis will be useful, we researched the history of decision making in our study area: the corridor of the Outer Banks between Oregon Inlet and Rodanthe.

### Outer Banks Transportation History

The complicated history of decision-making on the Outer Banks is understandable given the dynamic environmental conditions and multiple stakeholder groups with

oftentimes competing objectives. These stakeholders shape management decisions during the long-term and short-term planning processes. The primary driver of conflict in decision-making lies in the different objectives of each of the agencies involved, as well as the interests of active citizen stakeholders and environmental non-governmental organizations (ENGOS).

At the time of its construction in 1962, Bonner Bridge had an estimated lifespan of about 30 years. In 1993 it was known that the bridge was at risk from physical threats and possibly in need of replacement (NCDOT, 2012a). From these concerns and with the desire to reach a long-term solution, the Outer Banks Task Force (OBTF) was created through the cooperation of the decision-making agencies. The mission of OBTF is to develop the long-range protection and maintenance plan for the transportation system on the Outer Banks. OBTF goals include preserving the natural barrier islands, minimizing impacts of development to Hatteras and Ocracoke Islands, maintaining safe and efficient access, and developing a formal process for partnership of agencies (OBTF, 2012).

OBTF is made up of nine representatives from the following agencies: (1) NCDOT, (2) National Park Service (Cape Hatteras National Seashore), (3) U.S. Fish and Wildlife Service (Pea Island National Wildlife Refuge, Raleigh field office), (4) U.S. Army Corps of Engineers, (5) National Marine Fisheries Service National Habitat Program, (6) NC Dept. of Environment and Natural Resources (Division of Coastal Management, Division of Marine Fisheries), and (7) Dare County government (OBTF, 1998). Although this partnership seeks to find compromises in the decision making process, the issues are complicated by the different goals of each agency.

NCDOT is responsible for maintaining state roads and providing safe transportation for the citizens of North Carolina (NCDOT, 2012b). The National Park Service is concerned with preserving natural and cultural resources and providing for their use, such as Cape Hatteras National Seashore (NPS, 2013). The U.S. Fish and Wildlife Service is concerned with conserving, protecting, and enhancing the fish, wildlife, and plants and their habitats for the continuing benefit of the American people. Their primary interest in the study area is the Pea Island National Wildlife Refuge (U.S. Fish and Wildlife Service, 2013). In terms of related issues, U.S. Army Corps of Engineers is responsible for ensuring that construction in U.S. navigable waters meets the proper requirements and that water resources and the environment are protected (U.S. Army Corps of Engineers, 2013). National Marine Fisheries Service and NC Division of Marine Fisheries are concerned with maintaining and protecting primary nursery areas and other important fisheries habitat (National Marine Fisheries Service, 2013, North Carolina Division of Marine Fisheries, 2013). NC Division of Coastal Management is the primary permitting authority for construction in the coastal zone. As such, the Division of Coastal Management is required to uphold policies set forth by the Coastal Area Management Act to protect the environment, public rights, recreation facilities, and natural resources of the coastal area (NC Coastal Area Management Act, 1974). Given these various missions, each agency has a specific interest to protect. However, as with many policy decisions, there are compromises and concessions to be made so that each can achieve their goals and complete their due diligence as public servants, which is to fulfill their missions to the best of their ability.

From about 1990 through 2010, the OBTF considered about 30 alternatives to Bonner Bridge (NCDOT, 2010). These ranged from different permutations of a replacement Oregon Inlet bridge in the same area with different management strategies for Highway 12 between Oregon Inlet and Rodanthe, to a Long Bridge circumventing Pea Island NWR, and an expansion of the existing North Carolina Ferry System, to more unconventional ideas like a tunnel under Oregon Inlet (NCDOT, 2010).

The process reached its apparent conclusion in December of 2010, when a Record of Decision gave formal approval to NCDOT to implement the selected alternative, which we will call the Short Bridge Plus alternative. (FHWA and NCDOT, 2010b). The formal title of the Short Bridge Plus alternative is the NC 12 Transportation Management Plan. The Short Bridge Plus alternative is a phased project in which a replacement bridge will be built over Oregon Inlet as Phase I as soon as possible but later phases of the plan are currently undecided (FHWA and NCDOT, 2010a). This plan will use comprehensive monitoring and delayed decision-making to better accommodate the ongoing threats to NC 12. Thus, there is no specified action for the later phases of the chosen alternative; rather, the plan will take necessary actions according to changing environmental conditions (FHWA and NCDOT, 2010b). Construction of the bridge parallel to the original Bonner Bridge is expected to occur in early 2013, pending the outcome of a lawsuit brought against NCDOT by Southern Environmental Law Center (SELC) (SELC, 2013; NCDOT, 2010). Here we describe the three alternatives analyzed in our study and present information about their environmental impacts and economic feasibility.

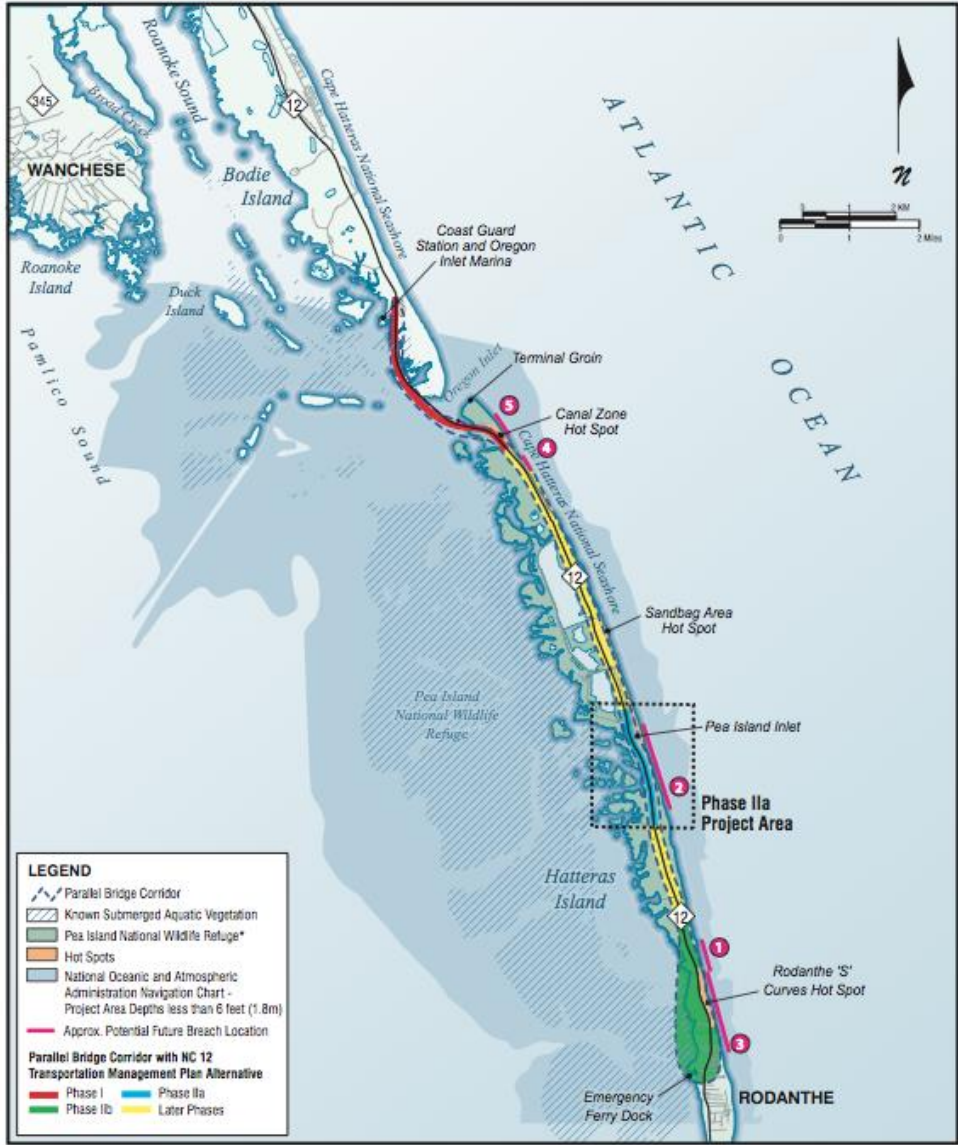
## **Review of Alternatives**

### Short Bridge Plus alternative

The Short Bridge Plus alternative will be completed in several phases, the first of which is the construction of a new bridge across Oregon Inlet, just west of the current bridge (FHWA and NCDOT, 2010b). The later phases are undecided at this time, and are to be determined as conditions change within the study area, as seen in the response to the new inlets formed by Hurricane Irene in 2011 (FHWA and NCDOT, 2012). Thus, for this alternative, it is helpful to break down the project into its phases and examine them separately.

### *Bonner Bridge Replacement (Phase I)*

According to the Final Environmental Impact Statement in 2008, the proposed replacement to Bonner Bridge will be a 2.8-mile long structure, leaving Bodie Island between the Oregon Inlet Fishing Center and the existing Bonner Bridge. The bridge will connect to Hatteras Island just west of the existing bridge terminus (Fig. 6). The forty foot wide bridge deck would include two travel lanes and shoulders safe for pedestrians and bikers. The width of the bridge deck would also allow for two northbound lanes and one southbound lane in the case of an evacuation. The new bridge would be built according to the latest research and guidance for bridges in high-energy environments. The new bridge will also have improved navigation channels for boat traffic in Oregon Inlet. Bonner Bridge has one navigation span that is 100 feet wide. It is located in a highly dynamic area that is prone to sediment scouring around the bridge pilings



**Figure 6.** Short Bridge Plus. NCDOT has selected this alternative to be implemented over the next 50 years (FHWA and NCDOT, 2010b).

(FHWA and NCDOT, 2008a, FHWA and NCDOT, 2008b). Tall oceangoing vessels are required to use this span due to high vertical clearance with the bridge. The shoaling occurring on the north end of the inlet has blocked access to this navigation span, often for weeks at a time. Large boats are forced to wait for the inlet to clear, or try going through one of the smaller spans not designed for navigation (Hampton, 2012). The new



bridge will have several 200-foot wide navigation spans with a high vertical clearance, giving boat captains plenty of options to choose from, depending on the changing shoaling patterns (FHWA and NCDOT, 2008a).

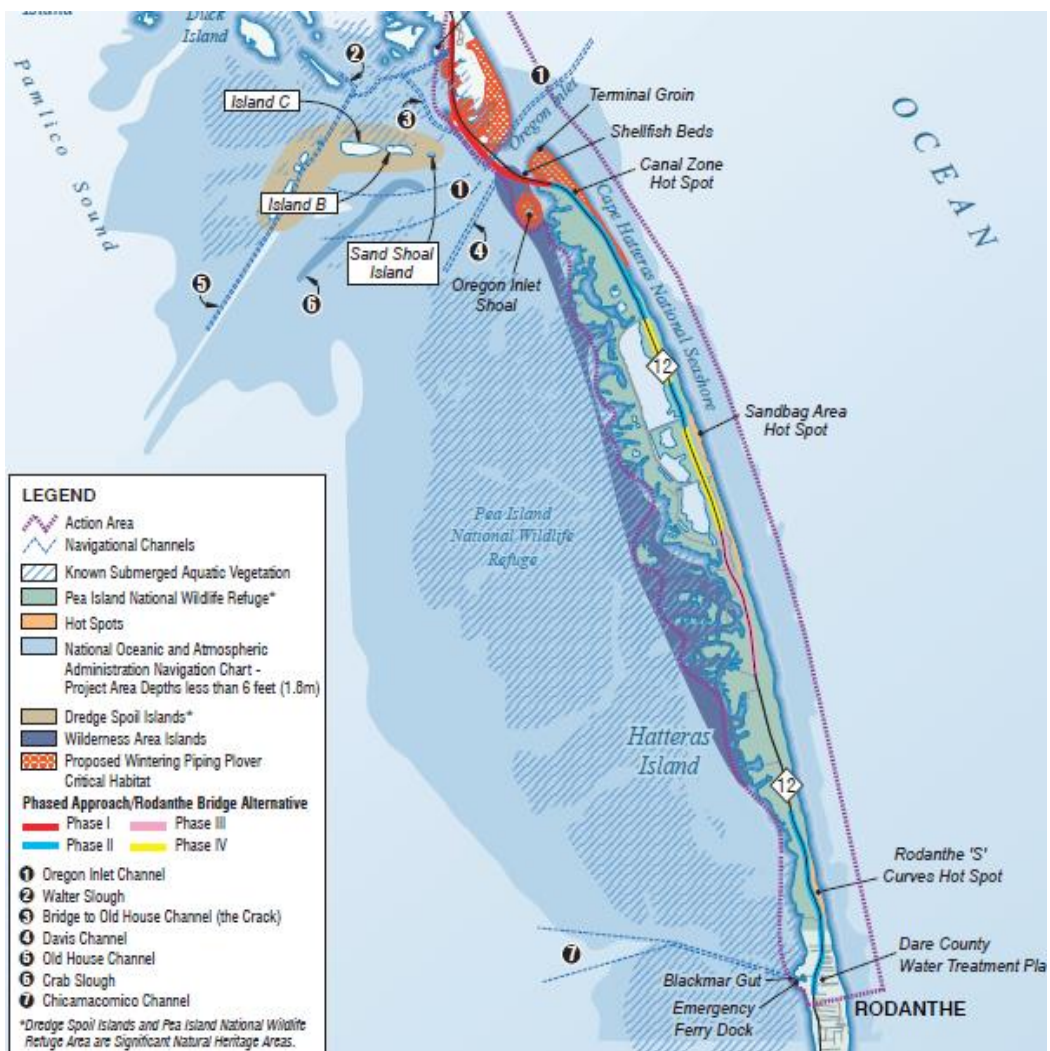
### Environmental Impacts

Environmental impacts of the bridge and its construction include short-term water quality impacts during demolition and removal of existing the Bonner Bridge and construction of the new bridge, resulting from actions such as construction barge traffic, fill and pile placement and channel dredging (FHWA and NCDOT, 2008a). After construction is completed, long-term impacts would include minimal submerged aquatic vegetation and wetland disturbance. There will also likely be adverse impacts to endangered species nesting on the beach nearby, including piping plovers and several species of sea turtles (Table 1) (Fig.7).

**Table 1.** Environmental impacts of the first phase of the Short Bridge Plus alternative (FHWA, NCDOT, 2010b).

<b>Short Bridge</b>	<b>Impact</b>
<hr/>	
<i>Biotic Communities</i>	<i>Fill and Pile Impacts, acres</i>
Submerged Aquatic Vegetation (SAV)	0.2
Wetlands	0.9
Upland-Natural and Man-Dominated	3.8
Impoundment	0.0
Aquatic Bottom	2.3
Total	7.3
Protected Species Impacts	Likely to disturb piping plovers, sea turtles nesting on beach. Not likely to adversely affect in ocean. Not likely to adversely affect <i>Seabeach amaranth</i> .

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**Figure 7.** Biological assessment and natural resources from Oregon Inlet to Rodanthe, NC (FHWA and NCDOT, 2010a).

### Economic Impacts

Having reached the final decision to pursue the Short Bridge Plus alternative in 2010, NCDOT awarded a \$215 million contract in 2011 to build the new 2.8-mile two-lane bridge that will replace the existing Bonner Bridge over the Oregon Inlet parallel to the existing bridge (Nolan, 2012). To support funding of this project, NCDOT will use transportation funds from the State Transportation Improvement Project and other federal

and state sources (FHWA and NCDOT, 2008a).

*NC 12 transportation maintenance plan (later phases)*

Environmental Impacts

Building a replacement for Bonner Bridge across Oregon Inlet commits NCDOT to maintaining a roadway between Oregon Inlet and Rodanthe. According to a study by Magliocca and others in 2011, an artificial dune system has protected the highway from ocean encroachment, overwash, and flooding. The artificial dune inhibits the normal geologic functioning of a sandy barrier island. In an unaltered system, ocean overwash from storms would erode sand from the front of the island and deposit it on the back of the island, allowing the island to naturally migrate landwards across the sound, and slowly build elevation in accordance with a rising sea level. What is eroded at the front of the island is replaced at the back, maintaining a consistent island width and elevation (Magliocca et al., 2011). However, the practice of removing overwash sand from the roadway and using it to rebuild the artificial frontal dune prohibits the natural nourishment of the island. Thus, the island is eroded from the ocean side, and no sand is allowed to remain on the interior of the island. The island subsequently narrows and loses elevation relative to a rising sea level (A. Brad Murray, Professor of Geomorphology and Coastal Processes, Duke University Nicholas School of the Environment, class lecture, October 3, 2012). This artificial dune is actually effective at protecting the highway from individual storms in the short run. However, in the long run, the cumulative impacts of the dune contribute to the highway's damage from large storms and from the increased rates of sea level rise rates predicted for the next 100 years. A narrower, lower island becomes easier to flood than a wider, higher island in a large

storm event (Magliocca et al., 2011). Research completed by Carolyn La Barbiera in April 2013 indicated that parts of Hatteras Island might be experiencing an increase in elevation, possibly due the dune blocking windblown sand erosion. Nevertheless, the research also confirmed the narrowing of Hatteras Island in association with the artificial dune (La Barbiera, 2013).

In several places, in particular the area just north of Rodanthe, Hatteras Island has narrowed so much that moving the road west, away from the ocean, is no longer an option (Fig. 8). Similarly, the allowed right-of-way for NC 12 within the Pea Island NWR limits NCDOT's ability to move the road further west, even where space allows for such a move. Thus, without significant expansion of the sound side of Hatteras Island, building a bridge out into Pamlico Sound, or a political move to allow NCDOT to move the highway further west into the Pea Island NWR, NC 12 must remain in its current location by necessity (Interview subject 1, NCDOT official).



**Figure 8.** Aerial photo of the north end of Rodanthe (S-curves “hot spot”) and facing the north to Pea Island National Wildlife Refuge (U.S. Fish and Wildlife Service, 2009).

According to a sediment stratigraphy study of Pea Island NWR by Culver and others in 2006, the artificial frontal dune also has ecological consequences for the rest of the barrier island. The short-term prevention of overwash disturbance allowed for significant vegetation planting, especially within the Pea Island NWR. This habitat, along with several maintained freshwater impoundments, supports a broad array of species and provides a resting place for migratory birds. Without a dune, the island would likely resemble its pre-1940s, pre-artificial dune state of mostly sand (Culver et al., 2006).

#### Economic Feasibility

Beyond the \$265-\$315 million predicted cost of building the Bonner Bridge replacement, there is uncertainty in pinpointing the probable cost of the later phases of this alternative because of many possible courses of action and the unpredictable nature of this highly dynamic ecosystem. However, NCDOT estimated that the 50-year cost could be anywhere between \$300 million and \$1.185 billion because of the variety of actions that may take place (FHWA and NCDOT, 2010a).

Less than a year after the 2010 Record of Decision, even before Phase I construction began, the NC 12 Transportation Maintenance Plan faced its first significant challenge, the formation of two inlets during Hurricane Irene in late August 2011 (Fig. 9). This event, and subsequent reactions, can be studied as a preview of the long-term implementation of the NC 12 Transportation Maintenance Plan. After making landfall near Cape Lookout, Irene continued northward up the Pamlico Sound, producing a significant westerly storm surge that flooded Hatteras Island from the sound side and cut two inlets, one through the town of Rodanthe and a second just south of the Pea Island

NWR impoundments. NCDOT filled in the former and rebuilt NC 12 within its existing right of way; NCDOT allowed the latter to persist and built a \$10 million temporary bridge to span the inlet until a permanent option could be pursued (FHWA and NCDOT, 2012; Davis, 2011). An NCDOT official indicated that a permanent replacement for the Pea Island inlet temporary bridge would cost approximately \$90 million (Interview subject 1, NCDOT official).



**Figure 9.** One of two breaches of NC 12 after Hurricane Irene in 2011 north of Rodanthe, NC (Associated Press, 2012).

In a Phase-II implementation meeting in October of 2011, a panel of coastal scientists agreed that low island elevations, man-made structures associated with refuge management, and higher sea level were all contributing to the formation of the inlets during Hurricane Irene. Due to the historical tendency for inlets to form in the vicinity of the Pea Island inlet, the panel recommended against filling the breach and repaving the

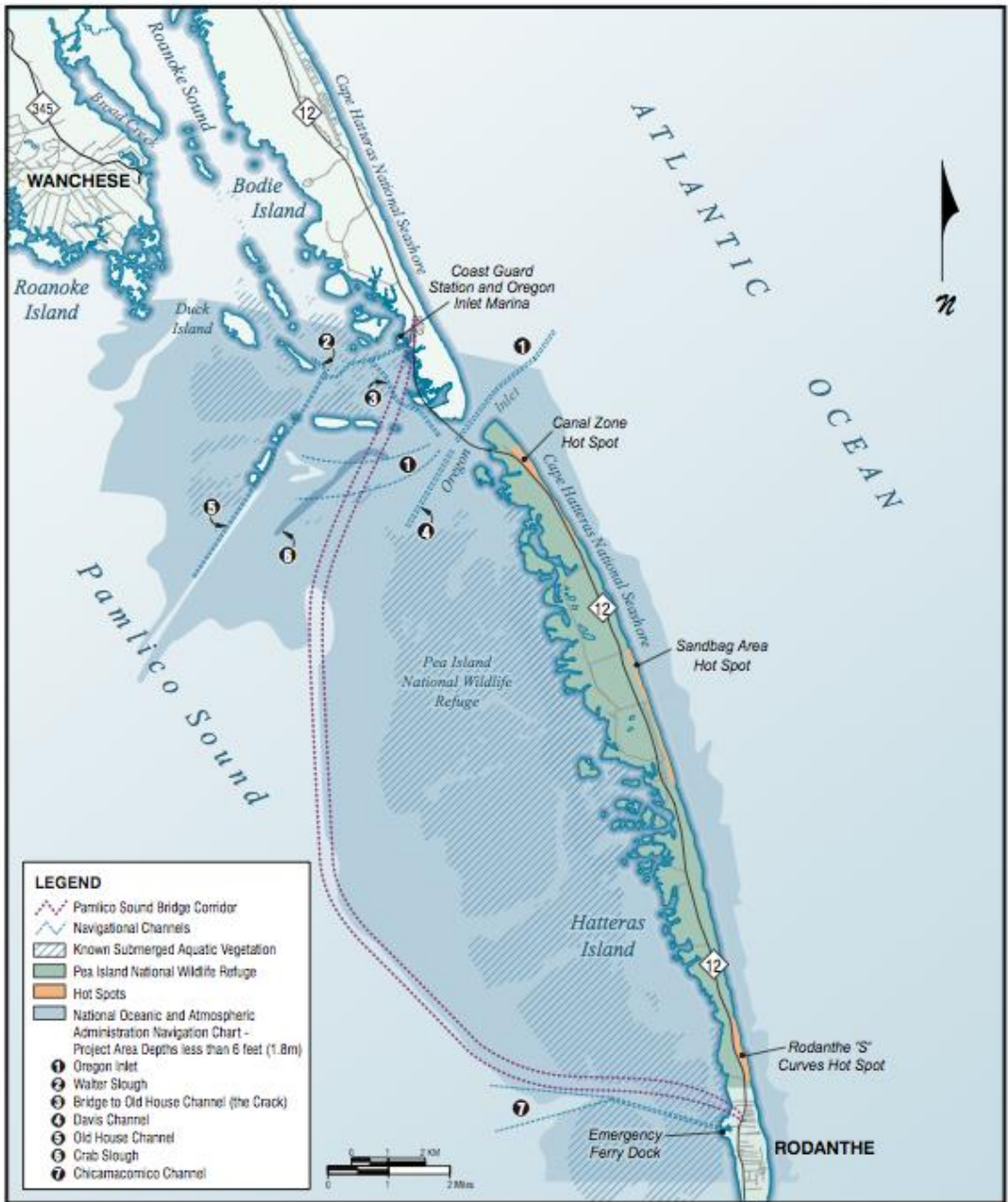
road, opting instead for a bridge spanning the active area. Also, recommendations were made to minimize inlet migration that could threaten several refuge buildings. Due to the high seaside shoreline erosion rates near the Rodanthe breach, the panel recommended that a permanent bridge bypassing the Rodanthe area through the sound would be the best action for the continued safety of NC 12 (FHWA and NCDOT, 2012).

Given this reactive methodology of implementing the NC 12 Transportation Management Plan, it will be hard to predict the actual structures that will be used to adapt to the changing shoreline over the next 50 years. Similarly, without knowing the specific methods and technology to be used, it is impossible to provide a narrowly defined cost estimate or accurate environmental impacts. An NCDOT employee indicated that a plan for a short bridge bypassing the Rodanthe hot spot would begin to receive public comments in the March of 2013. He estimated this project might be in the \$95-115 million range (Interview subject 1, NCDOT official). One might expect that the future pattern of action will resemble the pattern observed in the months following Hurricane Irene.

#### Long Bridge alternative

According to the Final Environmental Impact Statement (2008), the Long Bridge alternative across Pamlico Sound is not a phased project, unlike the selected alternative. By avoiding the troublesome stretch of Hatteras Island between Oregon Inlet and Rodanthe, it does not necessitate further highway maintenance within the Pea Island NWR such as the replacement of Bonner Bridge will require. Thus, the entire alternative can be evaluated as one complete product, which is to construct a 17.1-mile long

structure that would depart Bodie Island just west of the current Bonner Bridge (Fig. 10).



**Figure 10.** Long bridge alternative (FHWA and NCDOT, 2008a).

From there, it would travel southwest to a point about 5 miles west of the Pea Island NWR. It would roughly parallel Hatteras Island before turning eastward near the



southern end of the refuge and rejoining the existing Highway 12 corridor in the town of Rodanthe (FHWA and NCDOT, 2008a).

As stated in the 2008 Final Environmental Impact Statement, the structure would feature the same 40-foot wide deck as the Bonner Bridge replacement, with added vehicle pull-offs to clear the road in case of car accidents. Cars would be allowed to travel up to 60 miles per hour. Road grades would be no more than 5% to maintain cyclist access. A navigation zone would provide navigation spans 200 feet wide and 75 feet high, similar to the replacement of Bonner Bridge. Outside of the navigation zone, the bridge span width and height would decrease to 150 feet and 10 feet, respectively. Cable and telephone lines would also be placed on this bridge and routed away from the Pea Island NWR. Within the Pamlico Sound bridge alternative area, there were two options that differed on the basis of how the bridge approach road would intersect with the existing NC 12 in Rodanthe. The approach road from the bridge would rejoin the existing NC 12 footprint in either a T-intersection or a curved intersection. These options are minor choices in the larger implementation of the Long Bridge alternative and are most likely to affect only local traffic patterns (FHWA and NCDOT, 2008a).

### Environmental Impacts

The Long Bridge alternative across the Pamlico Sound was considered the least environmentally damaging alternative during the development and evaluation of alternatives in the early 2000's (FHWA and NCDOT, 2008a). The Final Environmental Impact Statement noted that the Long Bridge alternative would have no adverse impacts

on migratory birds and protected marine animals. Since the Long Bridge would abandon the existing NC 12 corridor within the refuge, dune maintenance, highway repairs, and beach nourishment would no longer be required within the refuge. This would alleviate pressure on migratory birds such as piping plovers, and sea turtles (FHWA and NCDOT, 2008a). The dynamic northern end of Hatteras Island would be allowed to function in its natural state, allowing overwash to let the island migrate and to maintain island elevation relative to rising sea level. This could change the biological and physical composition of Pea Island (Culver et al., 2006). This potential change could be viewed as positive or negative depending on management goals. The bridge route would avoid areas where submerged aquatic vegetation is present, and also would avoid shallow areas where dredging would be required to accommodate construction and maintenance barges (FHWA and NCDOT, 2008a).

### Economic Feasibility

Despite being the least environmentally damaging alternative, NCDOT identified this alternative as not practicable due to funding constraints and dropped the Long Bridge as a viable alternative. “The cost of either of the Pamlico Sound bridge alternatives would be of an extraordinary magnitude based on the funding currently available and reasonably expected to be available in the future to NCDOT to operate, improve, and maintain its state highway system” (FHWA and NCDOT, 2010a). According to the Final Environmental Impact Statement, the estimated cost of construction of the Long Bridge alternative was approximately \$1.5 billion in 2006 dollars (FHWA and NCDOT, 2008b).

The Final Environmental Impact Statement analyzed how the state might secure

funds to build the Pamlico Sound bridge alternative from federal funds, state bonds, toll revenue bonds, or a financial package with a combination of funding sources. However, there were no affordable funding sources to support a single construction project of that magnitude. The biggest obstacle was a budget limit of \$548 million for the seven-year period of 2007-2013 for NCDOT Division 1, the division that manages northeastern North Carolina. This amount was not enough to completely build the bridge within the allotted time frame, meaning construction would be prolonged to a later funding period. Unlike the other alternatives, which can be built in phases to spread out the costs over time, this alternative must be built all at once, as there is no way to only build part of the bridge and still provide access to Hatteras Island (FHWA and NCDOT 2008a). A NCDOT official indicated that building the Long Bridge would require putting all other construction projects on hold for 10 years for the 14-county Division 1 region. The entire state usually spends about \$1.6 billion in transportation projects annually, and there just is not enough funding in the budget to allocate nearly all of that money to one project (Interview subject 1, NCDOT official).

### Ferry Alternative

A system of ferries connecting barrier islands to the mainland has long been a part of the discussion as a solution to the Outer Banks transportation woes (FHWA and NCDOT, 2008a). Ferries have linked communities along the coastal sounds since the 1920's when a private operator offered transportation across Oregon Inlet. Gradually, the North Carolina Department of Transportation became involved, and ferry transportation in the state has evolved into a state-supported network of seven routes served by twenty-

one vessels and over 400 staff (NCDOT, 2013d) (Fig. 11). Over 1 million vehicles and close to 2.5 million people use the system annually (PB Consult, Inc., 2007).



**Figure 11.** Current ferry routes on the Outer Banks, NC (Hyde County, 2004).

However, only two of those seven routes connect the Outer Banks to the mainland across Pamlico Sound, while an additional route links Ocracoke and Hatteras Islands across Hatteras Inlet. Thus, current ferry system presence on the Outer Banks consists of five vessels across the two sound routes, and eight vessels across the inlet route (The Institute for Transportation Education and Research (ITRE), 2009).

#### Environmental Impacts and Economic Feasibility

A 1991 Feasibility Study examining alternatives to replacing Bonner Bridge considered expanding the Ferry System to make it the primary mode of transportation from Bodie Island to Hatteras Island (FHWA and NCDOT, 2013). The benefit of a ferry crossing at Oregon Inlet would be its adaptability to the changing shorelines and

migrating inlets that make fixed structures in the study area susceptible to erosion, scour, and overwash. The ferry terminals would be located in areas not historically prone to large amounts of erosion, thereby mitigating future endangerment of the terminals (FHWA and NCDOT, 2008a). Ferry service would also be able to provide transportation to and from Hatteras Island within days after a storm, as evidenced by the quick activation of the Stumpy Point to Rodanthe emergency ferry that was running only two days after Hurricane Sandy destroyed parts of NC 12 in late October of 2012 (Walker, 2012). By comparison, NC 12 between Oregon Inlet and Rodanthe did not open until six weeks after the destruction caused by Hurricane Sandy in the fall of 2012 (Morris, 2012).

As described in the Final Environmental Impact Statement, the alternative proposed by the 1991 Feasibility Study would have used twelve Hatteras Class ferry vessels, the same vessels used further south on the route between Hatteras Island and Ocracoke Island. These ferries have a 30-car capacity, and are specifically designed to operate in inlet environments. The proposed route was 3 miles long, operating between a terminal to be built on the southern end of Bodie Island and a terminal on the north end of Hatteras Island. The forty-year cost of the ferry option was estimated to be \$418 million in 1991 dollars (FHWA and NCDOT, 2008a).

However, the Ferry System alternative failed to appear in the list of alternatives evaluated in the 1993 Draft Environmental Impact Statement, on the grounds that the Ferry System alternative would decrease the level of traffic service to Hatteras Island and would require extensive dredging that was viewed as highly environmentally damaging. Additionally, an extensive system of salt marshes fringes the backside of the Outer Banks barrier islands. Constructing the necessary ferry terminals at both Bodie Island and

Hatteras Island would permanently destroy 60 acres of these wetlands (FHWA and NCDOT, 2008a). The diminished vehicle traffic on and off Hatteras Island would have other, less direct impacts. The limited capacity of the Ferry System would impede storm evacuation efforts. In extreme cases, the inclement weather prompting an evacuation may inhibit the ability of a ferry to safely transport people and vehicles to the mainland. Also, the increased cost of transportation would trigger an increase in the cost of goods available to island residents and visitors (FHWA and NCDOT, 2008a).

Despite being a politically dead option for close to twenty years, the Ferry System alternative received new life in 2011. In the months following Hurricane Irene in August 2011, the Merger Team in charge of implementing the selected Bonner Bridge replacement alternative received comments from the public and member agencies, suggesting that the OBTF rethink a Ferry System. Thus, FHWA, with input from NCDOT, re-evaluated the Ferry System option, and specifically examined high speed ferries in greater depth than the original 1991 study (FWHA and NCDOT, 2013).

As a result of the difficulty in maintaining NC 12 between Oregon Inlet and Rodanthe, the original 3-mile route across Oregon Inlet was extended to an 18-mile route all the way to Rodanthe, bypassing the Pea Island NWR (Fig. 12). This would make use of the existing emergency ferry terminal in Rodanthe, albeit with some expansions to handle increased vessel and car traffic. The Hatteras-Class vessels that operate across Hatteras Inlet with a 30-car capacity are no longer in production, meaning 38-car capacity River-Class ferries would be used. A fleet of 38 such vessels would be needed to meet the average traffic demand of 5,400 vehicles per day across Oregon Inlet (FHWA and NCDOT, 2013). There was no mention of peak demand, which would occur on the



**Figure 12.** Proposed map of Bodie Island to Rodanthe ferry route, with Stumpy Point-Rodanthe emergency ferry route (FHWA and NCDOT, 2013).

busiest summer holiday weekends. Thus, it is unclear if 38 River Class ferries could meet that demand, which can be as high as 11,000 vehicles per day (FHWA and NCDOT, 2008a). Federal Highway Administration (FHWA) again found several obstacles to implementing a Ferry System in place of a bridge and highway to provide transportation from Bodie Island to Rodanthe and points south. Adding the 38 vessels would double the existing fleet size of the entire North Carolina Ferry System, requiring an additional service facility and necessary crewmembers (FHWA and NCDOT, 2013). Also, the

longer route would require more extensive dredging than the original short 3-mile route, totaling 420 acres. Much of this acreage is submerged aquatic vegetation and shell benthos, providing valuable fish habitat and nursery areas as well as food for migratory waterfowl (FHWA and NCDOT, 2008a). The combination of vessel purchases, terminal expansion, dredging, a new maintenance facility, and necessary crewmembers resulted in an estimated 50-year cost of \$6.26 billion. A smaller fleet size that would effectively halve the annual vehicular travel capacity to Hatteras Island would have cost \$3.17 billion (FHWA and NCDOT, 2013).

The initial 1991 feasibility study briefly touched on the use of high-speed, high-capacity vessels in place of the small, slow-moving vessels currently in place. At the time of the evaluation, large capacity hovercrafts (greater than 3 vehicles) were not in production, and would have required custom manufacturing. NCDOT did reach out to manufacturers in the United Kingdom, who informed them that costs were unlikely to be competitive with the Hatteras-Class ferries. The landing pad necessary to load and unload vehicles and passengers was completely different from any other ferry terminal in North Carolina, making compatibility with other ferry terminals and maintenance sites impossible. NCDOT also addressed high-speed catamaran style vessels, but came to the same conclusions as for the hovercraft vessels (FHWA and NCDOT, 2008a).

The updated Ferry System alternative evaluation in 2013 included a more thorough discussion and assessment of high-speed hovercrafts and catamarans. The use of high capacity vessels would substantially decrease the required fleet size, and would also decrease the overhead costs associated with each vessel, such as crewmember salaries and maintenance costs. Most large-capacity, high-speed vessels have drafts at



least twice as large as the 4.5 ft. draft of the current vessels in the North Carolina ferry system. Because the vessels are also moving at higher speeds than the current vessels, channel depths would have to be much deeper than the current 10 to 12-foot deep channels to accommodate the larger vessels safely. Thus, the tradeoff with faster, high-capacity vessels is an increased need for dredging (FHWA and NCDOT, 2013).

The updated Ferry System assessment studied and measured a number of high-speed vessels, both in the U.S. and abroad, in terms of vessel cost, vehicle capacity, route characteristics, and draft. Of the studied vessels, the Austal Avemar Dos vessel, operating in the islands of Spain, comes closest to satisfying the low-draft, high-capacity conditions needed on the Outer Banks. With a draft of 7.8 feet, it is somewhat comparable to the existing vessels. Dredged channel depths would likely have to increase to about 20 feet. The vessel can travel 40 miles per hour and carry 150 vehicles, a large improvement over the current ferries traveling at 12 miles per hour carrying 38 vehicles. This vessel's current construction cost is \$9 million, \$3 million less than the cost of the existing ferry system vessel. Because the Austal Avemar Dos vessel can carry almost four times as many vehicles as the current River-Class vessel, a Ferry System using the former alternative would need far fewer vessels than the 38 estimated to be required if the latter vessel were to be used (FHWA and NCDOT, 2013). Considering the operational costs associated with each vessel, including crew, fuel, and maintenance, it would be considerably less expensive for the Ferry System to manage a smaller fleet of larger vessels (ITRE, 2009). Despite the competitive cost, roughly similar draft, smaller fleet size and increased speed and capacity of this vessel, FHWA concluded that none of the vessel options in the study were suitable for operation on the Outer Banks, mostly

because of the additional dredging required to accommodate the deeper draft (FHWA and NCDOT, 2013).

We feel that the Short Bridge Plus alternative, the Long Bridge alternative, and the Ferry System alternative encompass the most feasible transportation solutions for travel on the Outer Banks of North Carolina. We used these alternatives as the basis for our interview questions. The following section presents our results from the general interviews we conducted supplemented by information gained through our media review.

### **General interviews and Review of Media Sources: Results and Discussion**

This section is subdivided into categories including (1) current management, (2) viable alternatives, (3) ecological and physical limitations, (4) social and political limitations, (5) funding issues, and (6) future management perspectives. Each subheading first presents our results from our general interviews and media sources, and then our discussion and interpretation of those results.

#### **Current Management and Viable Alternatives: Results**

##### *Interviews*

Many interest groups, although not state government, expressed little confidence in current management strategies. In the cases of local business and citizen action groups, there is outright frustration with current management. These groups are primarily frustrated by the timeframe over which alternatives and environmental impacts have been studied. Respondents stated that the Bonner Bridge replacement process (initiated in 1991) began far too late, and asserted that a more proactive approach would have resulted

in a completed alternative by now.

While many groups expressed frustration with current management strategies, local business interests and citizen action groups supported the Short Bridge Plus. Citizen action groups, specifically, supported the Short Bridge Plus, including planning for long-term hotspot maintenance for those areas that experience breaches often. One representative of a local organization said “I agree with beach nourishment... You have to protect your infrastructure and your coast. A lot of the dunes in the areas down there were man-made dunes. They were man-built, for a reason, to protect the infrastructure and the area. And I believe we needed to have a long-term plan for keeping those dunes and the beach built up” (Interview subject 4, local activist).

Many Outer Banks residents supported the Short Bridge Plus rather than the Long Bridge due to safety concerns and potential economic loss from the extra time required to build the Long Bridge, which is projected to take at least a year longer than building the Short Bridge Plus, and from lost access to Pea Island NWR (Interview subject 4, local activist). Dare County government and the Outer Banks Chamber of Commerce also supported the decision to abandon the Long Bridge. Instead, they urged prompt construction of the Short Bridge Plus, which they believed to be a more practical way to provide access to Hatteras Island.

Coastal scientists and environmental groups shared misgivings about current management, but for different reasons. The main reason was the continued negative environmental impacts from maintaining a static structure on a dynamic barrier island, which includes a narrowing and flattening of the island. A coastal geologist was quoted as saying “the current practice of maintaining the frontal dune by removing all the

overwash, when overwash does happen in big enough storms to break down the artificial frontal dune, that sand is typically taken back off the island and put back into the dune. This is preventing the island from potentially widening on the backside once it gets narrow enough. I would expect the mode of operations as they currently are being done to lead to a narrower and narrower island” (Interview subject 6, coastal scientist). All groups expressed that management has focused on short-term solutions to a longer-term problem. Environmental interests and representatives of the scientific community were concerned that building a bridge and road back in the same general area is a short-term fix and that many of the same issues experienced today will remain in the future. They believed a high-speed ferry system should be the alternative to the Short Bridge Plus. One stakeholder from an environmental non-governmental organization (ENGO) explained, “I think that after the last three storms they’ve had major shutdowns of NC 12 north of Rodanthe and a ferry is the only thing that is immediately going the next day after a storm. It’s just reliable and good for all of the reasons that I said, so in my heart of hearts I feel like that’s the best solution” (Interview subject 8, ENGO respondent).

State government was the only group to have a different opinion of current management. This group contends that their methods have maintained access to private property and all the necessary precautions have been taken to ensure a feasible solution for transportation on the Outer Banks. Additionally, there was strong resistance to the Ferry System option from a state agency respondent. The North Carolina Ferry System has had trouble recently meeting Coast Guard minimum personnel requirements for their vessel fleet (ITRE, 2009); this person believed that doubling the size of the fleet to meet the projected travel demand was not a fiscally viable option. The North Carolina ferry

system is currently being pressured to downsize, streamline, and become more efficient, not expand (Interview subject 1, NCDOT official). In the winter and early spring of 2013, North Carolina struggled to maintain properly dredged channels at both Oregon Inlet and Hatteras Inlet. In the former inlet, ocean-bound traffic is having difficulty navigating shallow waters in the Bonner Bridge navigation span, and in the latter inlet, ferry traffic has been frequently running aground in the months since Hurricane Sandy, which happened in October 2012. Decreases in U.S. Army Corps of Engineers funding have prevented the purchase of additional dredging equipment to more effectively maintain open channels in the study area (“Army corps suspends,” 2012, Siceloff, 2013). A network of ferry routes across Pamlico Sound would require more dredging than the single route described in the NCDOT proposed Ferry System alternative. It is unlikely that funds could be found for newly dredged channels for an expanded Ferry System (Interview subject 1, NCDOT official).

### *Media Sources*

Frustration with current management was a common sentiment from ENGOS, including the Southern Environmental Law Center and the Defenders of Wildlife, as evidenced by their public comments (Southern Environmental Law Center, 2013; Waggoner, 2013). From their website, the Southern Environmental Law Center states that “the state's current plan to replace Bonner Bridge, the only bridge connecting the mainland to North Carolina’s Hatteras Island, at its same location ignores the obvious and persistent problems of NC 12” (Southern Environmental Law Center, 2013). Similarly, Jason Rylander of Defenders of Wildlife stated in a recent news article, “the solution

NCDOT is proposing would turn Pea Island NWR into a permanent construction zone, ultimately ruining the beauty of the refuge, destroying crucial wildlife habitat and failing to provide a safe, reliable long-term solution to the project” (Waggoner, 2013). Several coastal scientists have also voiced concerns through media sources over the current management plan. Dorothea Ames, a coastal geologist at East Carolina University, expressed in a news article that we should allow barrier islands to react to storms in their natural way (WRAL, 2012). David Mallinson, a colleague of Ames’ at East Carolina University, agreed that we “can’t just engineer our way out of this” (WRAL, 2012). Stan Riggs, a coastal geologist at East Carolina University, supported a ferry alternative in a 2012 news article, he believed, “the road needs to leave the island here (north of Rodanthe), and we need an alternative high-tech ferry system that can keep people in business down here” (Siceloff, 2012a). Riggs believed the Long Bridge alternative would delay storm damage to the road, but ultimately favors a high-tech Ferry System to transport people on and off Hatteras Island (WRAL, 2011a). The Long Bridge alternative is favored by Southern Environmental Law Center and Defenders of Wildlife. They jointly publicly commented that “the longer bridge option would be less exposed, more reliable and safer for people” (WRAL, 2011a). Southern Environmental Law Center believed a high-speed, shallow draft Ferry System is viable but that it has not been seriously studied, as evidenced from their news and updates on their website (Southern Environmental Law Center, 2013).

The U.S. Fish & Wildlife Service expressed concerns similar to those held by coastal scientists and ENGOS. The U.S. Fish & Wildlife Service vetoed plans to maintain NC 12 north of Rodanthe with renourishment, dune construction, or slight movement of

the road to the west during the decision making process (Siceloff, 2011). They also stated concerns about the elimination of the Pamlico Sound bridge and ferries as viable alternatives in public comments, saying that “the Federal Highway Administration and NCDOT have confined the analysis to a narrow range of options, all of which would result in large-scale and long-term adverse impacts to the Refuge and its resources” (NCDOT, 2010a).

While ENGOs and scientists have concerns with the current management plan, local citizens and government have voiced support. In a 2010 news article Ray Sturza, mayor of Kill Devil Hills, and Allen Burrus, a Dare County Commissioner expressed eagerness to see the Short Bridge Plus built right away (Morris, 2010). In response to the Environmental Assessment for the Short Bridge Plus, NCDOT received 3,856 form letters from local citizens and Replace the Bridge Now expressing support (NCDOT, 2010a). Additionally, Governor Beverly Perdue, State Senator Marc Basnight, State Representative Timothy Spear, the Outer Banks Association of Realtors, the Outer Banks Home Builders Association, and the Outer Banks Chamber of Commerce sent letters of support for the Short Bridge Plus alternative during the public comment process (NCDOT, 2010a). Other local government supporters included Dare County Sherriff Rodney Midgett and Dare County Commissioners Warren Judge, Jack Shea, and Allen Burrus (NCDOT, 2010a).

The Outer Banks Chamber of Commerce’s chief concern regarding the Long Bridge is time of construction; they asserted that immediate construction of the Short Bridge Plus is critical to maintain the island’s strong tourist-based economy and quality of life of residents (Outer Banks Chamber, 2010). In public comments the Outer Banks

Chamber of Commerce believes the Short Bridge Plus “is the only physical, responsible, and viable option available” (NCDOT, 2010b). Dare County Commissioners, Replace the Bridge Now, and the Dare County Democratic Party also favored the Short Bridge Plus alternative in public comments (NCDOT, 2010c). Bobby Outten, Dare County Manager, contends in a 2011 news article that a Ferry System would not meet the peak demand in summer of 10,000 vehicles per day (Siceloff, 2011).

#### Current management and viable alternatives: Discussion

The view the state government respondent holds that the multiple studies completed by various state agencies over the past 20 years have been reasonable and environmentally responsible is contrary to the view held by coastal scientists. The state government respondent’s view is reflected in the preparation of the long series of Environmental Impact Statements since the 1990s (FHWA and NCDOT, 2010b). The environmental focus of these documents has typically been on the various species and biological communities affected. These documents have specifically avoided what we believe is the largest environmental impact: the long-term alteration of the barrier island morphology. By avoiding this fact, the planning process automatically favors the Short Bridge Plus. The marginal impacts on wildlife and biotic communities in the Short Bridge Plus alternative are less than that of the Ferry System and Long Bridge alternatives, which both require extensive disturbance of sound bottom habitat in Pamlico Sound. However, the latter two alternatives will not interrupt the morphological processes on Hatteras Island that naturally maintain island elevation in response to rising sea levels.



The general frustration with timeframe of management decisions and implementation generates a disconnection between state agency managers and other stakeholders. If the state believes it is operating at a reasonable pace given the complex nature of the issue, but other stakeholders do not believe they are operating reasonably, there will be less overall cooperation. This frustration with the timeline could be because other stakeholders do not understand the environmental complexity or do not understand the legal requirements. Whatever the source of their frustration, it is probably contributing to a less cooperative atmosphere.

The fear held by the Chamber of Commerce that the time it takes to construct the Long Bridge could seriously impede tourism may be somewhat unfounded. According to the 2008 Final Environmental Impact Statement, construction would last four years and the bridge would have opened to traffic in 2013, had construction begun immediately (FHWA and NCDOT, 2008a). Comparatively, the Short Bridge Plus alternative would take about three and a half years (FHWA and NCDOT, 2010b).

The assertion by the Southern Environmental Law Center that a high-speed Ferry System has not been adequately studied can be confirmed in the ferry study released by the Federal Highway Administration (FHWA) in January 2013 (FHWA and NCDOT, 2013). In that study, FHWA's refused to consider the Austal Avemare Dos vessel. The Austal Avemare Dos offered increased speed, vehicle capacity, and value compared to the current vessels used in the ferry system, albeit with slightly deeper draft. Considering that crewmember expenses, vessel purchase, and vessel replacement made up nearly \$4.6 billion of the \$6.2 billion estimated 50-year cost for the Ferry System using current vessels, a system using a smaller fleet of large vessels would substantially decrease that

portion of the cost. FHWA's biggest objection to the larger vessels that have deeper drafts was dredging expenses; however, dredging expenses for a 50-year horizon only made up \$20 million of the \$6.2 billion (FHWA and NCDOT, 2013). Expenses incurred from additional dredging to accommodate the deeper draft of the Austal vessel would not change the overall cost by much. Thus, we believe that a more comprehensive study, including higher capacity, high-speed vessels, would more accurately reflect the tradeoffs associated with a Ferry System alternative.

### Ecological and physical limitations: Results

#### *Interviews*

All interest groups expressed concern for the environmental impacts of any transportation alternative; however, they also noted the need for a compromise between conservation and protecting investments. A federal agency, a state agency, environmental groups, and coastal scientists expressed concerns for sand supply if nourishment were to be used to protect the roadway from overwash. Barrier islands rely on overwash to replenish the back sides of the islands with sand. Coastal scientists were worried that eventually this will cause more flooding because of the change in elevation relative to sea level and future storm and climate impacts. Representatives of state government and local groups raised concerns about sensitive fisheries habitat, specifically submerged aquatic vegetation, on the sound side of the island and within Pamlico Sound itself. These concerns were mainly directed at dredging related to the implementation of a ferry or construction of the Long Bridge alternative. Federal interests

and environmental groups also raised concerns for habitat preservation in relation to road maintenance through the Pea Island NWR.

### *Media Sources*

Coastal scientists agree that maintaining static structures on barrier islands is not practical as evidenced by news articles from 2011 and 2012 (WRAL, 2011a; WRAL, 2012). Dorothea Ames, an East Carolina University geologist, said in a 2011 article, “it is a continuous battle, and I think the ocean is stronger than we are” (WRAL, 2011a).

However, NCDOT reports that physical limitations are not a problem. James H. Trogon III, Chief Operation Officer at NCDOT said in a different 2011 article “if we can design a bridge that can withstand the energy of the Oregon Inlet, we can design a bridge that can withstand the wave energy of the swash zone on the beach” (Siceloff, 2011). Other concerns about physical limitations were raised by Warren Judge, Dare County Commissioner, who stated in a news article that, “where boats are designed to go through is where it shoals the most (current Bonner Bridge)” (Hampton, 2012). This sentiment emphasized the challenge associated with construction and access in sandy, shifting inlets.

In response to the 2010 Record of Decision, several federal agencies commented on ecological concerns: (1) National Marine Fisheries Service expressed concerns about impacts to trust resources. (2) The Department of Interior expressed concerns about bridge impacts to migratory birds. (3) The Environmental Protection Agency expressed concerns about compliance with the Clean Water Act during bridge construction. (4) The

Army Corps of Engineers expressed concern about the effects of dredging on submerged aquatic vegetation (NCDOT, 2010a).

#### Ecological and physical limitations: Discussion

There was a lack of common understanding of barrier island geomorphology between the scientific community and representatives of local government, businesses, and citizen groups. Local representatives frequently mentioned stabilization and engineering of the shoreline to keep it from moving, apparently unaware of the dynamics of barrier island migration. The environmental tradeoffs for the Short Bridge Plus are not as clear as one might think. In addition to protecting the road, the dune protects a significant amount of biodiversity that would likely cease to exist if the dune were not there. However, the dune also inhibits the natural geophysical functioning of a sandy barrier island (A. Brad Murray, Professor of Geomorphology and Coastal Processes, Duke University Nicholas School of the Environment, class lecture, October 3, 2012). It is difficult to claim whether the presence or absence of the dune is more or less environmentally damaging. The debate becomes more about what type of environment humans value on Hatteras Island than about a traditional choice between development and nature.

#### Social and political limitations: Results

##### *Interviews*

The primary social and political concern amongst scientists, citizen action groups, federal government, state government, and local government was access. Representatives

of citizen action groups and a federal agency feared that a Long Bridge might limit visitor access to the Pea Island NWR. Another issue related to access was the speed and ease with which people can travel to and from Hatteras Island. Local business and citizen action groups expressed apprehension that ferries and a Long Bridge would be prohibitive to visitors and inconvenient for residents. State interests articulated that the Short Bridge Plus would provide the most direct, high volume of traffic to the island and was the most socially and politically acceptable alternative. Environmental groups did not really address the social concerns regarding an alternative. Nowhere in the interview with the representative of the environmental non-governmental organization (ENGO) did that person express how any alternative other than the Short Bridge Plus, particularly a Ferry System, might impact tourism or social dynamics in Dare County. However, the ENGO respondent was critical of the political process, criticizing the state for not being transparent in its cost estimate for the Long Bridge alternative. An ENGO respondent said “these local Dare County politicians sort of freaked out and wrote letters to politicians demanding NCDOT to stop the [Long Bridge] and review the numbers to do an alternative that routes people through the refuge. And DOT acquiesced to that, sort of inexplicably. I don’t know if part of that pressure was to inflate the cost of the Long Bridge to make [the Short Bridge Plus] more feasible; there is a letter from 2003 saying that [the Long Bridge] would cost \$300,000 and be done by 2010, now the estimates are \$1.5 billion, these are 2006 dollars” (Interview subject 8, Environmental NGO respondent).

### *Media Sources*

The Outer Banks Chamber of Commerce expressed fears of “drastic consequences to residents, small business owners, property owners and millions of yearly visitors” if there were no public access to Hatteras Island without the Bonner Bridge in a public comment letter (Outer Banks Chamber, 2010). Most residents depend on tourist-related business; tourism brought \$834 million into Dare County in 2010 (Kozak, 2012b). The area’s economy is highly seasonal. Dare County’s summer population in 2005 surpassed 220,000; this figure is about six and a half times the size of its year-round population (Kleckely, 2012). Residents and local business are concerned that any limitation to access would result in a direct negative impact to business as evidenced by many public comments (NCDOT, 2010c).

In addition to economic concerns, safety concerns are an issue when considering social and political limitations. At a public hearing, an elected public safety official stated that “emergency ferry service in the aftermath of a bridge failure would not be capable of handling a large amount of essential EMS, fire service, and law enforcement traffic that will be needed” (NCDOT, 2010c). That official went on to express concerns that ferries would not be able to operate during severe weather, which could hamper pre-hurricane evacuation (NCDOT, 2010c). However, ENGOs contend in media sources and public comments that a safer alternative would be to avoid the rapidly eroding areas altogether and construct the Long Bridge alternative (WRAL, 2011a; Southern Environmental Law Center, 2013; Waggoner, 2013).

### Social and political limitations: Discussion

ENGO's have sued NCDOT and FHWA for National Environmental Policy Act violations in the preparation of environmental documents (Defenders of Wildlife and National Wildlife Refuge Association v. NCDOT and FHWA, 2012). Legal action between stakeholder groups does not foster an environment of cooperation. Even though NCDOT and FHWA still seek public input from stakeholder groups in the form of town meetings, there seems to be a general lack of understanding amongst the groups. This may be because the ongoing studies have spanned 20 years and the various stakeholders have different interests to protect. To overcome lack of understanding, particularly on barrier island morphology and other scientific data, it would be helpful to foster open communication, not only between a particular interest group and the NCDOT and FHWA, but amongst all user groups.

### Funding: Results

#### *Interviews*

Local government, citizen action groups and local business interests felt that the funding should ideally come from state tax revenue. These groups cited Dare County as a net source of income for the state, and to continue that source of income, expedient and safe transportation is required. Some representatives of the local community even offered an increase in sales taxes or occupancy taxes in Dare County to help foot the bill for continued NC 12 maintenance. State government acknowledged that tolls could be used, but said that it would be difficult to implement because of political resistance. Federal government interests also cited tolls as a way to defray the cost of implementing

alternative transportation methods such as ferries. Environmental groups did not see a need for tolls or private involvement; rather, they believed NCDOT could reallocate some of its funds away from lower priority projects for a few years to pay for a more expensive alternative.

### *Media Sources*

In a 2012 news article local government, a state representative, and business and tourism officials felt that using state tax revenue to continue supporting NC 12 is reasonable and necessary (WRAL, 2012). Dare County Manager, Bobby Outten stated that the proportion of money spent on Dare County is “a drop in the bucket” compared to the economic impact of Dare County (WRAL, 2012). Former state Democratic Representative Stan White agreed in a different article that relatively little money is spent on NC 12 compared to other parts of the state and that most of the post-storm rebuilding is funded by the federal government (Lay, 2012).

However, coastal scientists, such as David Mallinson from East Carolina University, believed in a 2012 news article that the state is “throwing money into the ocean” (WRAL, 2012). Stan Riggs, a coastal geologist from East Carolina University, agreed that funding NC 12 through the state in the long-term is questionable, and even questioned the ability of the federal government to fund highway maintenance into the future in a 2011 news article (Siceloff, 2011).



## Funding: Discussion

Given that adding tolls to existing roads would be difficult and building toll roads is so unpopular, the idea provided by local government to increase sales or occupancy tax could improve the funding situation for NC 12. Additionally, an increase in sales tax to defray the cost could ease the concerns of critics who feel inland residents are footing the bill for NC 12 maintenance. Since state funds are limited, and there are many roads and bridges in the state that require maintenance, it may be politically and fiscally difficult to allocate more money to NC 12. Another source of funding is federal funds through the Federal Emergency Management Agency. However, these funds are only available after a disaster. That program is also suffering from budget cuts and may not be a viable long-term option (Khim, 2012).

## Future management perspectives: Results

### *Interviews*

Among local business interests, citizen action groups, and state government there is a general consensus that the implementation of the Short Bridge Plus is the best management for the future of the study area. Local representatives also described a sense of frustration with the slow pace of environmental assessments, studies, and lawsuits. Other state government interests expressed that there will likely be issues in the future with overwash and washouts. Federal government interests and coastal scientists noted that increasing storm impacts alert the public to the issues of NC 12 maintenance, but there is little sustained momentum for actual change to take place. All groups expressed concern for prioritizing long-term solutions over short-term fixes.

### *Media Sources*

Amongst coastal scientists who commented in news articles on the topic of NC-12 there is a general consensus that long-term management is difficult. Billy Edge, a coastal engineering professor from North Carolina State University, said, “I really don’t think there is a permanent solution in a situation like this. Building on a constantly shifting island is a huge challenge” (WRAL, 2011b). Stan Riggs, from East Carolina University, believes that maintaining NC 12 “is a totally lost cause” and “it will bankrupt the state” (Dean, 2012). However, local government official, Bobby Outten, remained confident that “the island isn’t going to wake up one morning and be gone. As things change, we’ll adapt and do what we have to do” (WRAL, 2012).

### Future management perspectives: Discussion

Although most stakeholder groups generally agree with the Short Bridge Plus alternative, they are prioritizing a short-term fix over a long-term solution. The Short Bridge Plus is constructing a bridge in the same general area and maintaining a portion of road that consistently experiences breaches and overwash. This approach prioritizes direct access and lower short-term construction cost over long-term maintenance. This is directly opposed to the sentiment that decision makers should focus on long-term solutions over short-term fixes.

### Limitations

Our goal with the general interviews and media review was to obtain a sense of what is most important to the various stakeholder groups. The primary limitation in our

general interview results was our small sample. To better understand stakeholder group interests in general would require a greater number of respondents. During our media review we reviewed many articles; however, only a fraction of media articles included direct opinions by stakeholder groups and, of those, some stakeholders were represented more often than others. Despite the limitations of the general interviews and media results, we did gain a better understanding of the motivations driving stakeholder interests and used those to develop our in-depth interview questions. In-depth interviews were used to develop the decision framework, the results of which can be seen below.

### **Decision framework: Results**

In an attempt to characterize advantages and disadvantages of proposed alternatives and stakeholder preferences for Outer Banks transportation management, we conducted individual in-depth interviews with three of our general respondents. We chose a respondent from NC Division of Coastal Management, one from an ENGO, and a one in a local government position, based on their active roles in the decision making process.

#### Initial interview responses

For these in-depth respondents, our initial interview questions allowed each respondent to articulate a number of objectives, or specific achievements, of a transportation system. We then organized the objectives into a hierarchy depicting a relationship between the objectives and a method of measuring its success, known as attributes (Clemen & Reilly, 2001). Respondents voiced concerns including impacts to local businesses, societal impacts, the adaptability and reliability of the chosen

alternative, the environmental impacts, success under emergency response conditions, and financing via toll charges. After we finished initial interviews with the in-depth respondents, we created a compiled objectives hierarchy that combined the individual hierarchies of each respondent (Table 2).

### Developing and finalizing the performance matrix

After considering the transportation objectives in Table 2, we reevaluated each attribute and attempted to remove any redundant criteria. We did this by evaluating what is driving the performance of the attribute and determining if there is a better indicator measurement (i.e., more cheaply or more easily assessed), which can be substituted as a proxy for a particular criterion.

For example, impacts to local businesses is likely directly correlated with number of days of access disruption, because people will not be able to access businesses if they cannot get onto Hatteras Island. Therefore, number of days of access disruption encompassed both of these values, and the impacts to local businesses attribute was no longer necessary. The results of our removal of criteria and justification for consolidation can be seen in Table 3. We believe that the measurable elements that respondents are concerned about can be condensed to four attributes: (1) environmental impacts, which can be measured by acres of biotic community permanently displaced by a transportation alternative, (2) short-term cost, the dollars required to construct or implement the first phase of an alternative, (3) long-term cost, the dollars required to build, maintain, or operate an alternative through 2060, discounted at 5%, and (4) minimizing access

disruption to the transportation system, which is measured in total number of days of access disruption per year.

**Table 2.** Transportation for Hatteras Island, North Carolina: transportation objectives identified by in-depth interview respondents, and measurable attributes of performance.

<b>Objectives</b>	<b>Subobjectives</b>	<b>Measures</b>
<b>Economic Stability</b>	<i>Continuity of commercial and sanitation services</i>	Number of days delay after storm
	<i>Maximize economic stability</i>	Percentage change in gross collection in retail sales between 2010-2012*
<b>Accessibility</b>	<i>Maximize access to local services</i>	Days of school missed due to road closures
<b>Adaptability</b>	<i>Increased pedestrian / tourist access</i>	Percentage bikeable
<b>Reliability</b>	<i>Minimize impacts from natural disasters</i>	Number of days road closed
<b>Ecological Integrity</b>	<i>Impacts to federally protected species</i>	Number affected
	<i>Impacts to biotic communities</i>	Number of acres affected
<b>Ability to Accommodate Evacuation</b>	<i>Medical response</i>	Minutes to response for local emergency services
	<i>Hurricane evacuation</i>	Evacuation of Hatteras Island residents (4300) and tourists prior to storm (hours before event)
<b>Financial Feasibility</b>	<i>Dollars of toll per project</i>	Dollars to travel to get to Hatteras Island

\*Including 2010 as a baseline year with no major disruptions. The years 2011 and 2012 were both storm years with significant disruptions to traffic service to Hatteras Island.

**Table 3.** Justification for eliminating overlapping criteria or measurements of transportation performance.

<b>Measure</b>	<b>Decision</b>	<b>Justification</b>
Number of days delay after storm for Sanitation and Commercial Services	Represented by access disruption	Access disruption directly affects number of days delay for services
Percentage change in gross collection in retail sale between 2010-2012	Represented by access disruption	Sales depend on visitor access
Days of school missed due to access disruptions	Represented by access disruption	Access disruption impedes student access to schools
Percentage bikeable	All alternatives offer the same amount of bike access	Can bike across bridges and take bike on ferry
Number of days road closed	<b>Kept</b>	
Number federally protected species affected	Represented by acres affected	The acres of biotic community measurement includes a variety of habitat types (submerged aquatic vegetation, wetlands, sandy beach, and dunes). All federally protected species depend upon at least one of these habitat types.
Number of acres affected	<b>Kept</b>	
Minutes to response for local emergency services	Represented by access disruption	Likelihood of having to take a slower (ferry) or very expensive (helicopter) emergency transportation option is dependent upon access disruption
Evacuation of Hatteras Island residents (4300) and tourists prior to storm (hours before event)	Represented by access disruption	Directly correlated to access disruption
Short-term Cost	<b>Kept</b>	
Long-term Cost	<b>Kept</b>	
Dollar to travel to get to Hatteras Island	Eliminated due to legal infeasibility	Due to NC Article 6H§ 136-89.187, cannot convert existing road into toll road

The resulting modified hierarchy can be seen in Table 4, a performance matrix. A performance matrix is a table with alternatives in columns and measurable attributes in rows. Within each cell is a natural value of the alternative's performance (dollars/# days/acres). We obtained numerical values for each attribute and corresponding alternative in the matrix (Table 4). Environmental impact values and construction costs were acquired from the 2008 Final EIS (FHWA and NCDOT 2008a). Number of days of road closure are estimates that come from (1) an average of the last two storm years for the selected alternative (Morris, 2012), (2) an assumption of what would be an adequate amount of time for NCDOT to check the structure of a 17-mile bridge prior to re-opening it, and (3) the assumption that emergency ferries would be able to run immediately after a storm (Walker, 2012). The immediate and long-term cost values were obtained from the ferry study for the ferry alternative, from the Final EIS for the preferred alternative, and from the 2010 Record of Decision for Pamlico Sound Bridge (FHWA and NCDOT, 2013)(FHWA and NCDOT, 2008a). By breaking down funding into long-term and short-term costs, we believe it is easier for respondents to think critically about the time horizon for management, and realistically about their preferences between alternatives. We defined short-term cost as the initial cost for constructing or implementing the alternatives (e.g., over a 4-year period for the Long Bridge). We defined long-term cost as the additional cost for operations, maintenance, and any other required construction over a 50-year time horizon.

**Table 4.** Performance ratings of Hatteras Island, North Carolina, transportation alternatives in natural values (acres/dollars/days).

<b>Impact</b>	<b>Measure</b>	<b>Alternatives</b>		
		<b>Short Bridge Plus</b>	<b>Long Bridge</b>	<b>Ferry System</b>
<b>Environmental Impacts</b>	<i>Acres Biotic Communities</i>	16.24 acres <sup>†</sup>	12.81 acres <sup>●</sup>	60 acres marsh + 420 acres dredging <sup>×</sup>
<b>Short-term Cost</b>	<i>Dollars</i>	\$315 million <sup>†</sup>	\$1.5 billion <sup>●</sup>	\$664 million <sup>×</sup>
<b>Long-term Cost</b>	<i>Dollars</i>	\$1.18 billion <sup>†</sup>	\$0.00 <sup>●</sup>	\$5.6 billion <sup>×</sup>
<b>Access Disruption</b>	<i># Days Access Disruption Post Storm</i>	50 days <sup>**</sup>	5 days <sup>♦</sup>	1 day <sup>^</sup>

<sup>†</sup>(FHWA and NCDOT, 2010b); <sup>●</sup>(FHWA and NCDOT, 2008a); <sup>×</sup>(FHWA and NCDOT, 2013); <sup>\*\*</sup>(Morris, 2012); <sup>♦</sup>We assumed 5 day closure due to storm winds and post-storm safety checks; <sup>^</sup> (Walker, 2012).

We assumed the 2013 ferry study used 2011 dollars, and we know that the Final Environmental Impact Statement and Record of Decision estimates were in 2006 dollars (FHWA and NCDOT, 2013; FHWA and NCDOT, 2010b; FHWA and NCDOT, 2008a). Using the Consumer Price Index inflation rate of 10.4% between 2006 and 2011, we converted 2011 dollars to 2006 dollars (Coin News, 2013). Consumer price index is useful in translating current dollar values to historical values because it accounts for changing prices across time. This ensured that all alternatives could be compared in similar dollar values. The Ferry System alternative was still by far the most expensive for long-term cost (\$6.2 billion in 2011 dollars and \$5.6 billion in 2006 dollars) and was still intermediate for the short-term cost attribute. Since the change in cost of the Ferry System did not change the rank of alternatives for either short-term or long-term cost we



felt it was a reasonable assumption to use the values given by NCDOT for the Ferry System alternative in 2011 dollars.

Because long-term costs are involved, it is necessary to discount costs to be borne in the future. Neither the 2008 Final Environmental Impact Statement, nor the 2010 Record of Decision, nor the 2013 Ferry Study indicated a specific discount rate that was used. A 5% discount rate was applied to costs in the 2007 Supplement to the Supplemental Draft Environmental Impact Statement. Thus, we will assume that FHWA and NCDOT are consistent in their use of a 5% discount rate, and that all long-term costs for the three alternatives in this analysis are discounted appropriately.

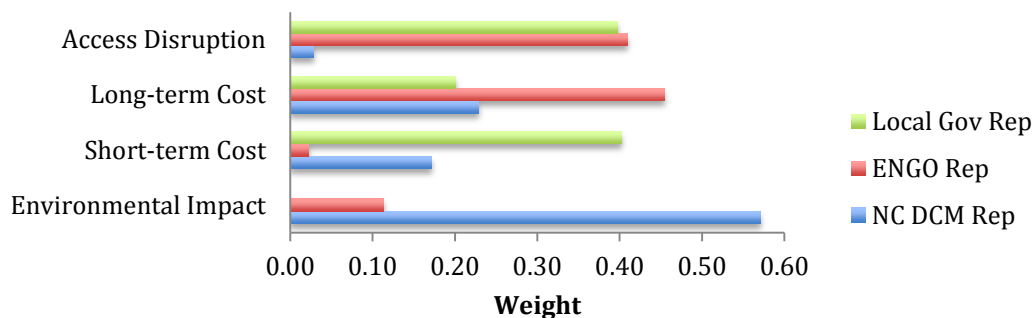
We then translated the performance values for each attribute from a natural scale (e.g., dollars, # days road closed, acres biotic community impacted) to a relative scale ranging from 0 to 1. We accomplished this by assuming a linear relationship between utility and the natural performance values (Clemen & Reilly, 2001). We then assigned the best performance value a relative value of 1 and the worst performance value a relative value of 0. Intermediate performance values are between zero and one, proportional to their positions on the natural performance scale. A linear relationship assumes a constant marginal decrease in satisfaction for every unit increase in performance, since all of our attributes represent disutilities, or “bads” (Clemen & Reilly, 2001). For example, if a respondent felt the same about access disruption increasing from 2 to 3 days as they did about the increase from 49 to 50 days, then the marginal change in satisfaction would behave linearly. In our in-depth interviews, we neglected to verify the assumption of a constant marginal increase or decrease in satisfaction at different performance levels. However, we completed three sensitivity analyses that varied

selected assumptions in the performance matrix, including the shape of our value functions, to see if there were changes in stakeholders’ ranking of alternatives. The results of that analysis are discussed and presented in our sensitivity analysis section.

### Follow Up Interview

We presented the results shown in Table 4 to our in-depth interview respondents during the second interview to determine each respondent’s priorities regarding individual attributes. Using a method known as “Swing Weighting,” we generated a chart with five fictional scenarios and asked respondents to rate and rank these scenarios (Clemen & Reilly, 2001).

A graphic depicting the relative weights of each respondent per attribute can be seen in Figure 13 below. This figure demonstrates each respondent’s personal priorities for the four attributes in composing overall value of an alternative as the weighted sum of performance (expressed on the relative scale described above) on each of the four attributes.



**Figure 13.** In-depth interview respondents’ comparative weights amongst attributes for evaluating transportation alternatives.

The final step of the decision framework was to multiply the performance values by weights taken from respondents, and then sum the four attribute values per respondent

in order to give each alternative an overall score. The matrix in Table 5 shows that each respondent prefers a different alternative. The respondent from the NC Division of Coastal Management preferred the Short Bridge Plus, the ENGO respondent preferred the Long Bridge, and the local government respondent preferred the Ferry System.

**Table 5.** Performance matrix showing attribute performance (upper panel), respondent’s weight (middle panel), and overall weighted score of each alternative for each respondent (lower panel). The overall scores describe which alternative a respondent preferred. In the lower panel, each respondent’s top scoring alternative is marked with an asterisk. In the upper panel, the numbers in the parenthesis are the performance measures of the alternatives on each measure converted to a zero to one scale using a proportional relationship.

<b>Impact</b>	<b>Measure</b>	<b>Alternatives</b>		
		<b>Short Bridge Plus</b>	<b>Long Bridge</b>	<b>Ferry System</b>
<b>Attribute Performance</b>				
Environmental Impacts	<i>Acres Biotic Communities</i>	16.24 acres <sup>†</sup> (0.99)	12.81 acres <sup>●</sup> (1)	60 acres marsh + 420 acres dredging <sup>×</sup> (0)
Short-term Cost	<i>Dollars</i>	\$315 million <sup>†</sup> (1)	\$1.5 billion <sup>●</sup> (0)	\$664 million <sup>×</sup> (0.71)
Long-term Cost	<i>Dollars</i>	\$1.18 billion <sup>†</sup> (0.79)	0 <sup>●</sup> (1)	\$5.6 billion <sup>×</sup> (0)
Access Disruption	<i># Days Access Disruption Post Storm</i>	50 days <sup>**</sup> (0)	5 days <sup>♦</sup> (0.92)	1 day <sup>▲</sup> (1)
<b>Individual Weight</b>	<b>Acres Biotic Communities</b>	<b>Short-term Dollars</b>	<b>Long-term Dollars</b>	<b># Days Access Disruption</b>
NC DCM rep.	0.57	0.17	0.23	0.03
ENGO rep.	0.11	0.02	0.45	0.41
Local gov. rep.	0.00	0.402	0.201	0.398
<b>Overall Score</b>		<b>Short Bridge Plus</b>	<b>Long Bridge</b>	<b>Ferry System</b>
NC DCM rep.		0.92*	0.83	0.15
ENGO rep.		0.48	0.94*	0.42
Local gov. rep.		0.56	0.57	0.68*

\*Top scoring alternative marked by asterisk per respondent <sup>†</sup>(FHWA and NCDOT, 2010b); <sup>●</sup>(FHWA and NCDOT, 2008a); <sup>×</sup>(FHWA and NCDOT, 2013); <sup>\*\*</sup>(Morris, 2012); <sup>♦</sup>Assumed 5 day closure due to storm winds and post-storm safety checks; <sup>▲</sup> (Walker, 2012).

## **Decision Framework: Discussion**

The results of the preceding section are useful in examining how stakeholders manage tradeoffs in making choices. We are not using their input to pick any one alternative, rather we are interested in distilling the reasons why stakeholders behave the way they do. Using Table 5, we dissected each respondent's preferences and compared them with results from their previous general interviews to see how well the decision analysis appears to represent the views each respondent stated verbally. There is no "clear winner" among the three alternatives chosen by the respondents. Beginning with the NC Division of Coastal Management respondent, we observe an expected choice of the Short Bridge Plus alternative, because that person indicated support for that alternative in the general interview. The ENGO respondent also has an observed preference consistent with our earlier expectations based upon general interview results. This individual ultimately chose the Long Bridge. This person's weight assignment was perplexing. As a member of an ENGO, we would expect the most weight to be given to the environmental impacts. However, this person assigned little weight to environmental impacts and much more weight to access disruptions, even though the respondent showed little interest in the social fabric of the region. We believe that having an interest in access disruption is more closely related to a concern for the social quality of life rather than the ecological integrity in the study area. We also had a surprising outcome from the local government respondent. The respondent was adamant about the need for the Short Bridge Plus in our general interview, but the results of Table 5 from the decision framework above indicate that the respondent preferred the Ferry System alternative. The local government respondent mentioned several times in our general interview that ferries would not work

in the study area, for reasons of diminished traffic capacity and disruption of the region's social cohesion. This respondent's high weight on access disruption leads to the selection of the Ferry System, which performs well on that attribute, even though this person was against a Ferry System in the interview session. The respondent predicts that access disruptions will be diminished with the implementation of the Short Bridge Plus alternative. However, this belief may reflect a limited understanding of barrier island morphology, because access disruptions continue to happen daily (NCDOT, 2013a). We did not present the results of our analysis to the respondents and ask for their comments or gauge their reactions.

All of the alternative scores for the local government respondent are quite close to one another, indicating weak preference among the alternatives. The ENGO respondent strongly favors the Long Bridge, as seen by the high score of the Long Bridge relative to the other two alternatives.

Because the inputs to our calculations of overall value are subject to error, we wanted to see how the preferred alternative for our three stakeholders might change in response to changes in inputs to the decision framework. We varied the following, one at a time: (1) alternative performance values for selected attributes, (2) respondents' allocations of weight among the four attributes, and (3) the relationship between relative satisfaction and performance on a particular attribute (i.e., alternatives to the linear functions we assumed earlier).

## **Sensitivity Analysis**

We conducted three sensitivity analyses: (1) sensitivity to performance value - varying the performance of an attribute to see the subsequent change in overall alternative score for each respondent, (2) sensitivity to weights - varying the weights assigned to the four attributes across their potential range (from 0 to 1), to see how the overall scores of the alternatives would change for each respondent, and (3) sensitivity to functional form - exploring the consequences of assuming linear value functions by substituting nonlinear value functions, to see whether a different function prompted a change in the respondents' top scoring alternatives.

### Sensitivity to Performance

The inputs for calculating the overall performance score for an alternative include the natural performance values for the alternative (acres, \$, days of access disruption) and the respondent's weight for the attributes. Many of the natural performance scores found in government documents were not precise values, but rather ranges of possible values, such as a predicted range of costs. Thus, we felt it would be useful to explore the change in respondents' overall choices at the low and high estimates for the performance values, specifically the long-term cost for the Short Bridge Plus alternative, and the option of using a small fleet of high-speed, high-capacity vessels in the Ferry System alternative.

The Short Bridge Plus alternative has a wide spread of possible long-term costs, ranging from \$300 million to \$1.185 billion (FHWA and NCDOT, 2008a). For our baseline analysis, seen in Table 5 we assumed the high end of that range. Replacing the \$1.185 billion performance value with \$300 million doesn't cause any of the respondents

to change their overall alternative preference. However, the Short Bridge Plus moves from the third choice to the second choice for the local government respondent, as seen in Table 6.

**Table 6.** Sensitivity of respondents’ overall scores of alternatives to changes in the estimated long-term cost of Short Bridge Plus. Changed value in red.

Impact	Measure	Alternatives		
		Short Bridge Plus	Long Bridge	Ferry System
<b>Environmental Impacts</b>	<i>Acres Biotic Communities</i>	16.24 acres <sup>†</sup> (0.99)	12.81 acres <sup>●</sup> (1)	60 acres marsh + 420 acres dredging <sup>×</sup> (0)
<b>Short-term Cost</b>	<i>Dollars</i>	\$315 million <sup>†</sup> (1)	\$1.5 billion <sup>●</sup> (0)	\$664 million <sup>×</sup> (0.71)
<b>Long-term Cost</b>	<i>Dollars</i>	\$1.185 billion (.79) <b>\$300 million (0.95)</b>	0 <sup>●</sup> (1)	\$5.6 billion <sup>×</sup> (0)
<b>Access Disruption</b>	<i># Days Access Disruption Post Storm</i>	50 days <sup>**</sup> (0)	5 days <sup>♦</sup> (0.92)	1 day <sup>▲</sup> (1)
NC DCM rep.		0.92 <b>(0.95)*</b>	0.83	0.15
ENGO rep.		0.48 <b>(0.56)</b>	0.94*	0.42
Local gov. rep.		0.56 <b>(0.59)</b>	0.57	0.68*

\*Top scoring alternative marked by asterisk per respondent  
<sup>†</sup>(FHWA and NCDOT, 2010b); <sup>●</sup>(FHWA and NCDOT, 2008a); <sup>×</sup>(FHWA and NCDOT, 2013); <sup>\*\*</sup>(Morris, 2012); <sup>♦</sup>Assumed 5 day closure due to storm winds and post-storm safety checks; <sup>▲</sup> (Walker, 2012).

The baseline cost values for the Ferry System assumed the use of 38 low-speed, low-capacity vessels crewed by six persons, according to the 2013 NCDOT Ferry Report (FHWA and NCDOT, 2013). As indicated earlier, we believe significant cost savings might be achieved with the use of larger, faster, less expensive vessels such as the Avemar Dos. Because of the vessel’s high capacity and high speed, fewer vessels would be needed to provide a similar amount of transportation across Oregon Inlet as the large fleet of smaller, slower vessels. Thus, we recalculated short and long-term costs

assuming the use of 9 Avemar Dos vessels, each crewed by 24 persons. Because of the vessel’s size, a larger crew is required, so cost savings were not achieved by reducing crew expenses. However, the use of nine vessels versus thirty-eight vessels offered significant savings, both for vessel purchase and vessel operations and maintenance. We replaced the \$664 million and \$5.6 billion estimates for short-term and long-term costs with \$273 million and \$4.2 billion figures, respectively. This reduction in cost merely strengthened the local government respondent’s choice of the Ferry System, due to the respondent allocating 60% of possible weight to both cost measures combined. Results can be seen in Table 7.

**Table 7.** Sensitivity of respondents’ overall scores of alternatives to changes in the short and long-term costs of Ferry System, assuming a smaller fleet of less expensive, high-speed vessels. Changed values are in red.

Impact	Measure	Alternatives		
		Short Bridge Plus	Long Bridge	Ferry System
<b>Environmental Impacts</b>	<i>Acres Biotic Communities</i>	16.24 acres <sup>†</sup> (0.99)	12.81 acres <sup>●</sup> (1)	60 acres marsh + 420 acres dredging <sup>×</sup> (0)
<b>Short-term Cost</b>	<i>Dollars</i>	\$315 million <sup>†</sup> (1) <b>(0.97)</b>	\$1.5 billion <sup>●</sup> (0)	\$665 million (0.70) <b>\$273 million</b> <b>(1)</b>
<b>Long-term Cost</b>	<i>Dollars</i>	\$1.18 billion <sup>†</sup> (0.79)	0 <sup>●</sup> (1)	\$5.6 billion (0) <b>\$4.2 billion</b> <b>(0)</b>
<b>Access Disruption</b>	<i># Days Access Disruption Post Storm</i>	50 days <sup>**</sup> (0)	5 days <sup>♦</sup> (0.92)	1 day <sup>^</sup> (1)
NC DCM rep.		0.92 <b>(0.90)*</b>	0.83	0.15 <b>(0.2)</b>
ENGO rep.		0.48 <b>(0.45)</b>	0.94*	0.42 <b>(0.43)</b>
Local gov. rep.		0.56 <b>(0.53)</b>	0.57	0.68 <b>(0.80)*</b>

\*Top scoring alternative marked by asterisk per respondent

<sup>†</sup>(FHWA and NCDOT, 2010b); <sup>●</sup>(FHWA and NCDOT, 2008a); <sup>×</sup>(FHWA and NCDOT, 2013); <sup>\*\*</sup>(Morris, 2012); <sup>♦</sup>Assumed 5 day closure due to storm winds and post-storm safety checks; <sup>^</sup> (Walker, 2012).



In other instances, definitive performance values were available in the literature; however, we have reason to believe that some of these may be questionable estimates. For example, the Ferry System alternative scored very well in our initial performance matrix for access disruption; however, we wanted to examine the possibility of a lengthy disruption in ferry service to Hatteras Island. The ferry route between Hatteras Island and Ocracoke Island experienced significant shoaling in the early winter months of 2013. This made ferry operation dangerous, which prompted NCDOT to close the route for nearly a month until dredging could reopen the route (NCDOT, 2013a). Because the proposed Ferry System alternative operates in a similar inlet environment, it may face similar difficulties with shoaling. Thus, evaluating the questionable performance value at a more plausible value can show how the alternative's score might change from the baseline per respondent. A respondent's preferred alternative may switch as a result of the changed performance value, especially if they assigned high weight to the attribute being varied.

Given the uncertainty, we did not choose a new value on which to test sensitivity. Rather, we calculated the break-even point, or the point at which the access disruptions of the Ferry System become large enough to change preferences. As seen in Table 8, once the Ferry System is unable to operate for more than 15 days in a given year, the local government respondent no longer prefers the Ferry System, but instead prefers the Long Bridge alternative.

**Table 8.** Sensitivity of respondents’ overall scores of alternatives to changes in the Ferry System’s level of access disruption. The value for days of disruption shown in red is the point at which the local government respondent’s choice switches from the ferry to the Short Bridge Plus.

<b>Impact</b>	<b>Measure</b>	<b>Alternatives</b>		
		<b>Short Bridge Plus</b>	<b>Long Bridge</b>	<b>Ferry System</b>
<b>Environmental Impacts</b>	<i>Acres Biotic Communities</i>	16.24 acres <sup>†</sup> (0.99)	12.81 acres <sup>•</sup> (1)	60 acres marsh + 420 acres dredging <sup>×</sup> (0)
<b>Short-term Cost</b>	<i>Dollars</i>	\$315 million <sup>†</sup> (1)	\$1.5 billion <sup>•</sup> (0)	\$664 million <sup>×</sup> (0.71)
<b>Long-term Cost</b>	<i>Dollars</i>	\$1.18 billion <sup>†</sup> (0.79)	0 <sup>•</sup> (1)	\$5.6 billion <sup>×</sup> (0)
<b>Access Disruption</b>	<i># Days Access Disruption Post Storm</i>	50 days <sup>*</sup> (0)	5 days <sup>•</sup> (0.92) <b>(1)</b>	1 day (1) <b>15 days</b> <b>(0.77)</b>
NC DCM rep.		0.92*	0.83 <b>(0.83)</b>	0.15 <b>(0.14)</b>
ENGO rep.		0.48	0.94 <b>(0.97)*</b>	0.42 <b>(0.33)</b>
Local gov. rep.		0.56	0.57 <b>(0.60)*</b> ←	0.68 <b>(0.59)</b>

\*Top scoring alternative marked by asterisk per respondent <sup>†</sup>(FHWA and NCDOT, 2010b); <sup>•</sup>(FHWA and NCDOT, 2008a); <sup>×</sup>(FHWA and NCDOT, 2013); <sup>\*</sup>(Morris, 2012); <sup>\*</sup>Assumed 5 day closure due to storm winds and post-storm safety checks; <sup>^</sup> (Walker, 2012).

We are skeptical of the small number of acres affected by construction for the Short Bridge Plus alternative. According to the Record of Decision, sixteen acres will be permanently disturbed as a result of construction (FHWA and NCDOT, 2010b). The small size of this value may reflect impacts only associated with the Phase I (new Oregon Inlet bridge) construction, and not the later phases (NC 12 Transportation Maintenance Plan). As indicated earlier, the combination of dune maintenance and potential bridge building that may occur with the later phases of Short Bridge Plus are likely to

substantially increase beyond the currently indicated sixteen acres. We calculated the break-even value for acres impacted for the Short Bridge Plus, similar to how we calculated the access disruption of the Ferry System alternative in Table 8. We were not interested in the overall value at a particular level of performance, but rather the threshold point at which the preferred alternative changes for a respondent. Table 9 shows that once acres impacted increases beyond 92 acres for the Short Bridge Plus alternative, the Long Bridge becomes the preferred alternative for the Division of Coastal Management Representative. This was the only observed change in preferred alternative amongst the respondents.

**Table 9.** Sensitivity of respondents’ overall scores of alternatives to changes in environmental impacts of the Short Bridge Plus. The value of acres impacted in red print is the point where the Division of Coastal Management respondent’s choice switches from the Short Bridge Plus to the Long Bridge.

Impact	Measure	Alternatives		
		Short Bridge Plus	Long Bridge	Ferry System
<b>Environmental Impacts</b>	<i>Acres Biotic Communities</i>	16.24 acres <sup>†</sup> (0.99) <b>92 acres</b> <b>(0.83)</b>	12.81 acres <sup>●</sup> (1)	60 acres marsh + 420 acres dredging <sup>×</sup> (0)
<b>Short-term Cost</b>	<i>Dollars</i>	\$315 million <sup>†</sup> (1)	\$1.5 billion <sup>●</sup> (0)	\$664 million <sup>×</sup> (0.71)
<b>Long-term Cost</b>	<i>Dollars</i>	\$1.18 billion <sup>†</sup> (0.79)	0 <sup>●</sup> (1)	\$5.6 billion <sup>×</sup> (0)
<b>Access Disruption</b>	<i># Days Access Disruption Post Storm</i>	50 days <sup>*</sup> (0)	5 days <sup>♦</sup> (0.92)	1 day <sup>^</sup> (1)
NC DCM rep.		0.92 <b>(0.82)</b> →	0.83*	0.15
ENGO rep.		0.48 <b>(0.47)</b>	0.94*	0.42
Local gov. rep.		0.56 <b>(0.56)</b>	0.57	0.68*

\*Top scoring alternative marked by asterisk per respondent

<sup>†</sup>(FHWA and NCDOT, 2010b); <sup>●</sup>(FHWA and NCDOT, 2008a); <sup>×</sup>(FHWA and NCDOT, 2013); <sup>\*</sup>(Morris, 2012); <sup>♦</sup>Assumed 5 day closure due to storm winds and post-storm safety checks; <sup>^</sup> (Walker, 2012).

A final observation is the performance value of \$0 for the long-term cost of the Long Bridge alternative. We assumed this value of \$0. According to the Final EIS, the Long Bridge project was predicted to have a 50-year cost of approximately \$1.5 billion; however, the bridge was to be built over four years. Thus, we assumed that most if not all of the \$1.5 billion would be spent in that four-year construction period, bringing the short-term cost to \$1.5 billion and the long-term cost to \$0. Unlike the other two alternatives, no additional construction or continued operational costs are explicitly defined in the Final EIS after the bridge is built (FHWA and NCDOT, 2008a). No new bridges, dune maintenance, or road relocations are necessary, unlike the Short Bridge Plus. Similarly, no crew salaries, fuel expenses, or dredging expenses are necessary, unlike the Ferry System. It is reasonable to expect there to be some sort of maintenance and upkeep for the Long Bridge; however, we did not find an explicit value to assume for this inconsistency. Therefore, a non-zero value for long-term cost is possible. To confirm that our results were robust against this possibility, a sensitivity analysis showed that even increasing the long-term cost for the Long Bridge to \$4.75 billion, an implausibly high cost of maintenance, did not change respondent preferences.

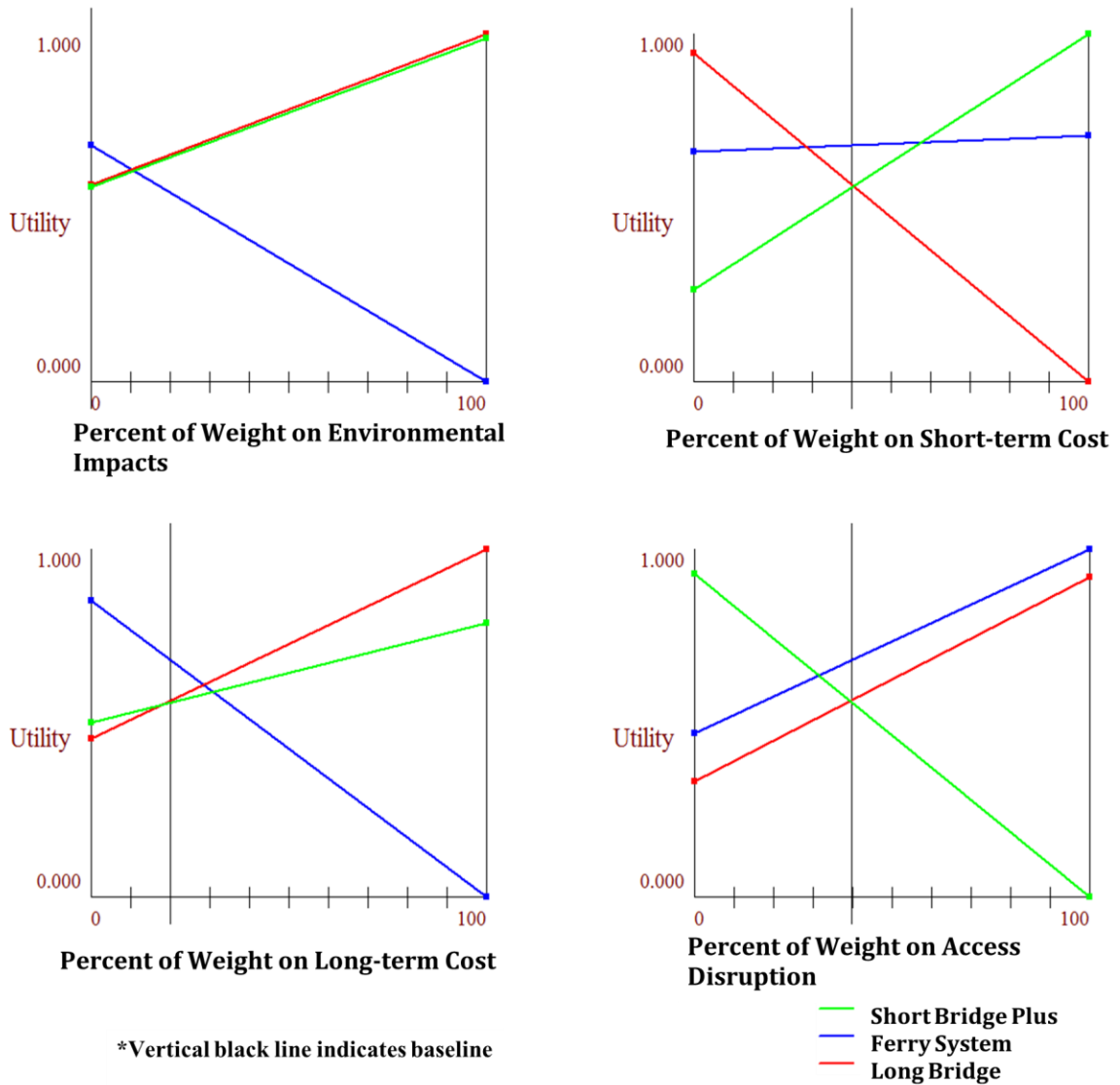
### Sensitivity to Weights

Due to our limited sample size, we may not have captured the true variation of weights for all stakeholders. To see how a reallocation of weight among the four attributes might result in a new preferred alternative, we investigated the sensitivity of overall value of an alternative to changes in each respondent's weights on the four attributes. For each of the three respondents we completed a graph for each attribute, resulting in twelve graphs (Fig. 14-16). We varied each weight over its possible range, 0

to 1, reallocating the other three weights in proportion to their originally assessed values to keep the sum of the weights equal to one (Clemen & Reilly, 2001). The only respondent whose preferences were very sensitive to weight allocation was the local government respondent, whose results can be seen in Figure 14 below. Results for the Division of Coastal Management and ENGO respondents can be seen in Figures 15 and 16, respectively.

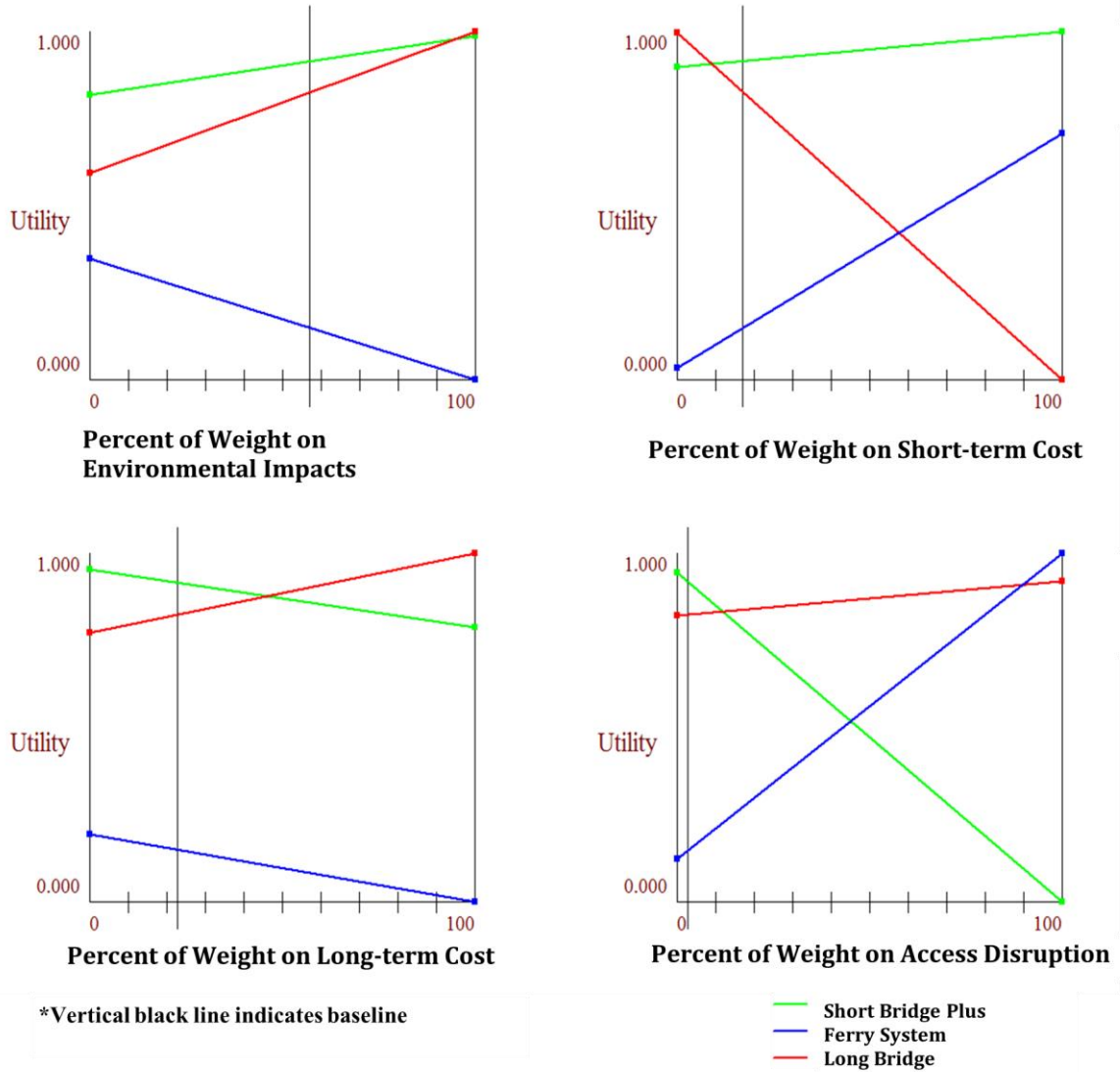
The vertical line on the graph denotes the respondents' original weight on that particular attribute. At that point, the topmost colored line indicates the preferred alternative. An increase or decrease weight on that attribute may result in a new preferred alternative if the topmost colored line changes. A respondent's choice is highly sensitive to weight if a small change in weight results in a change in preferred alternative. Conversely, a respondent's choice is not sensitive to weight if one colored line remains on top throughout the range of possible weights. When considering the local government respondent's sensitivity to weight, we found that this individual's preferences were sensitive to the weights on all attributes (Fig. 14). Originally, this person gave zero weight to environmental impacts. If a small amount of additional weight were placed on that attribute, the local government respondent's preferred alternative would switch from the Ferry System to the Long Bridge. Interestingly, if more weight is placed on short-term cost, the top choice for the local government respondent will change to the Short Bridge Plus alternative, which performs the best on short-term cost. If less weight were placed on short-term cost, the Long Bridge would be the ideal alternative for the local government respondent. This is because the Long Bridge performs poorly on long-term cost, relative to the other two alternatives. Lastly, on access disruption, a little less weight

makes the Short Bridge the best alternative. The important observation to make here is that the local government respondent's high sensitivity indicates a lack of strong preference for any one alternative. This individual quickly switches to another alternative in response to an approximately 10-20% change in weight.



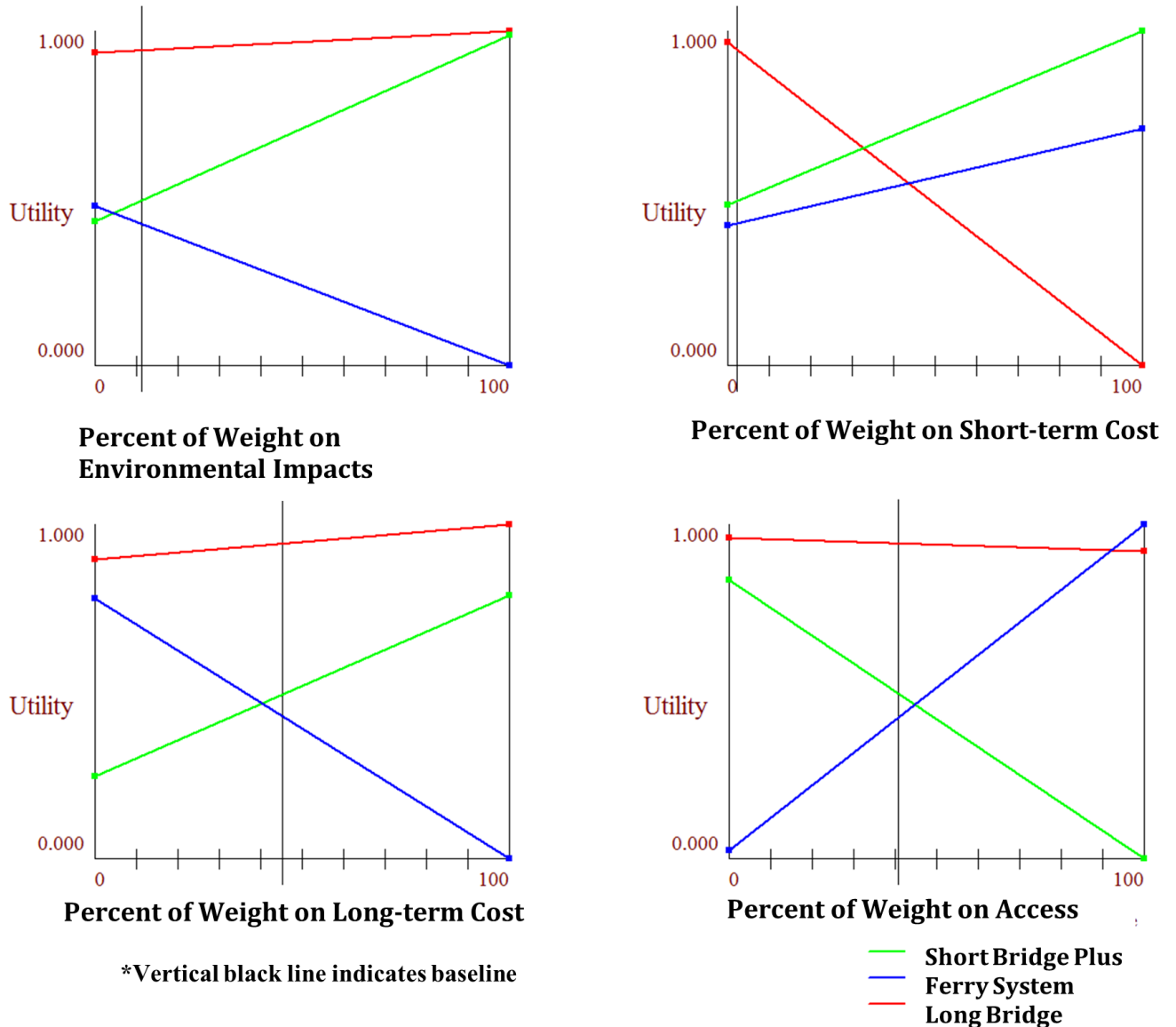
**Figure 14.** Sensitivity of respondents' overall score of alternatives to changing weights on attributes: Local government representative.

The DCM representative also exhibited sensitivity of alternative preference to weight assignment. In Figure 15, small shifts in weight on both cost attributes and the access disruption attribute lead to a different preferred alternative.



**Figure 15.** Sensitivity of respondents' overall score of alternatives to changing weights on attributes: North Carolina Division of Coastal Management representative.

The ENGO representative's preferred alternative is least sensitive to weight. Large changes in weights on short-term cost and access disruption are required to yield a change in preferred alternative. The environmental impacts and long-term cost attributes are completely insensitive to weight; the Long Bridge is the clear top choice across the range of possible weights (Figure 16).



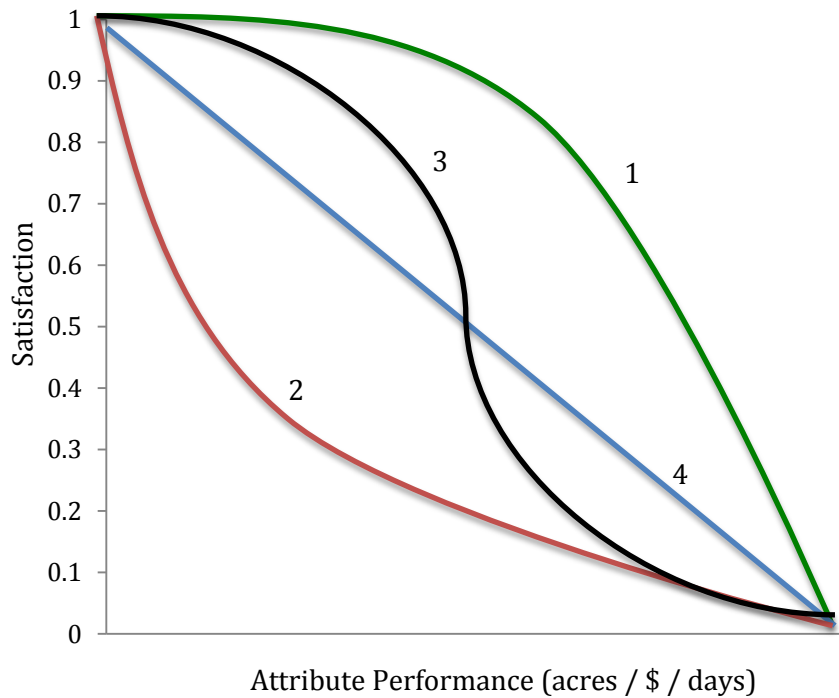
**Figure 16.** Sensitivity of respondents' overall score of alternatives to changing weights on attributes: ENGO representative.



The results of this sensitivity analysis show the change in a respondent's weight required to change that individual's preferred alternative. These weights often reflect closely held beliefs about the economic, social, and environmental norms of the study area, and are unlikely to change in a static setting. However, these attitudes may be subject to change as a result of increasing hurricanes and storms, or increased budget constraints at all levels of government. Thus, the changes in weights that we simulated have the possibility of occurring in the future.

#### Sensitivity to Value Functions Relating Relative Satisfaction to Performance

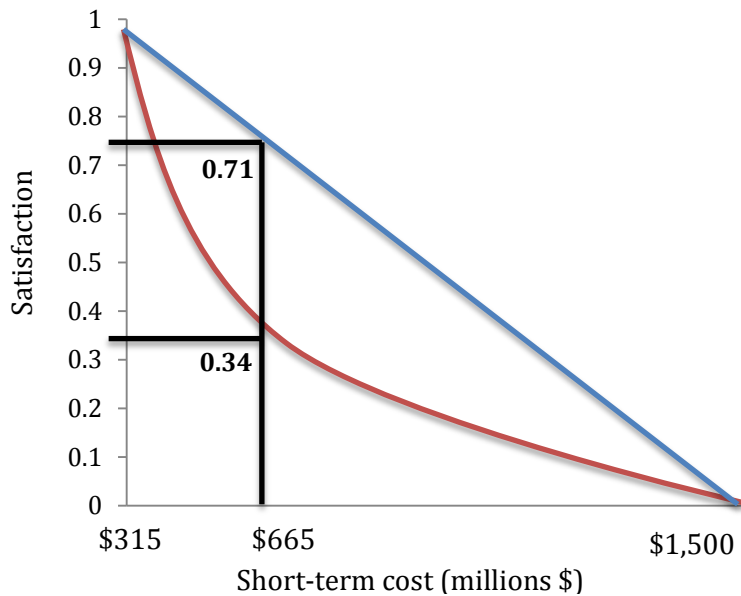
As stated earlier, we assumed a linear relationship between relative satisfaction and the performance value of each attribute. However, other relationships between satisfaction and performance may be more plausible. We analyzed sensitivity of the overall values of alternatives to some non-linear forms for these relationships. We estimated three nonlinear functions: (1) a value function where satisfaction declines greatly as the attribute performance level increases from its minimum value, but declines less sharply once attribute performance levels increase even more (Fig. 17, line 1); (2) a value function where satisfaction declines slowly as the attribute performance level increases from its minimum, but declines sharply once attribute performance levels increase even more (Fig. 17, line 2); and (3) a combination of functions (1) and (2), where satisfaction declines slowly at first, then rapidly, then slowly again with respect to increasing attribute performance value (Fig. 17, line 3). The original linear function is shown in Figure 17, line 4.



**Figure 17.** Alternative possibilities for shapes of value functions.

We used graphs of these three nonlinear functional forms to estimate new values in parentheses associated with the performance levels in Table 10 for all attributes (i.e., shape 1 for all four attributes, then shape 2 for all four attributes, and so on). Using the new values, we re-calculated overall value for each respondent. We only found one instance where changing the function form of the relationship between relative satisfaction and performance resulted in a change in a respondent’s preferred alternative. Where the local government respondent experiences a drastic drop in satisfaction as short-term costs begin to increase, but a less drastic drop as those costs get even higher (Fig. 17, line 2; Fig. 18), that person’s preferred alternative changes from the Ferry System to the Long Bridge. The individual’s perceived satisfaction decreases strongly as costs begin to rise. However, this person’s satisfaction declines less as those costs get exorbitantly high, as evidenced by the red line in Figure 18. The relative satisfaction


provided by a short-term cost of \$665 million (concave value function, red line) is much less (0.34) than the relative satisfaction of \$665 million from the linear function (0.71). The respondents' changes in preferred alternatives for the concave value function can be seen in Table 10 below.



**Figure 18.** Sensitivity: Change in value of short-term cost attribute when the value function decreases rapidly at first, then more slowly (red line), as opposed to linearly (blue line).

For the local government respondent, the diminished utility of the Ferry System's short-term cost (as seen in the red text in Table 10 below) is enough to decrease the overall value of the Ferry System below the overall value of the Long Bridge. This change in functional form is quite plausible; the local government respondent experiences great loss in relative satisfaction as costs begin to rise, but recognizes that once costs increase beyond some point, the loss in value from further increases is moot.

**Table 10.** Sensitivity of overall value of alternatives to the relationship between relative satisfaction and performance on short-term cost. The black entry is from the original linear function; the red entry is from the nonlinear function shown in Figure 18. The red arrow indicates the switch in preference for the local government respondent.

Impact	Measure	Alternatives		
		Short Bridge Plus	Long Bridge	Ferry System
<b>Environmental Impacts</b>	<i>Acres Biotic Communities</i>	16.24 acres <sup>†</sup>	12.81 acres <sup>•</sup>	60 acres marsh +
		(0.99)	(1)	420 dredging <sup>×</sup> (0)
<b>Short-term Cost</b>	<i>Dollars</i>	\$315 million <sup>†</sup>	\$1.5 billion <sup>•</sup>	\$664 million <sup>×</sup>
		(1)	(0)	(0.71) <b>(0.34)</b>
<b>Long-term Cost</b>	<i>Dollars</i>	\$1.18 billion <sup>†</sup>	0 <sup>•</sup>	\$5.6 billion <sup>×</sup>
		(0.79)	(1)	(0)
<b>Access Disruption</b>	<i># days Access Disruption Post Storm</i>	50 days <sup>*</sup>	5 days <sup>•</sup>	1 day <sup>^</sup>
		(0)	(0.92)	(1)
NC DCM rep.		0.92*	0.83	0.15 <b>(0.09)</b>
ENGO rep.		0.48	0.94*	0.42 <b>(0.42)</b>
Local gov. rep.		0.56	0.57* 	0.68 <b>(0.53)</b>

\*Top scoring alternative marked by asterisk per respondent<sup>†</sup>(FHWA and NCDOT, 2010b); <sup>•</sup>(FHWA and NCDOT, 2008a); <sup>×</sup>(FHWA and NCDOT, 2013); <sup>\*</sup>(Morris, 2012); <sup>•</sup>Assumed 5 day closure due to storm winds safety checks; <sup>^</sup> (Walker, 2012).

### Limitations

We addressed some of the limitations of our study with the above sensitivity analyses. We explored sensitivity to performance value by varying the performance of an attribute to see the subsequent change in overall alternative score for each respondent. We also examined sensitivity to weights by varying the weights assigned to the four attributes across their potential range (from 0 to 1) to see how the overall scores of the alternatives would change for each respondent. Lastly, we looked at sensitivity to functional form and explored the consequences of assuming linear value functions by substituting nonlinear value functions, to see whether a different function prompted a

change in the respondents' top scoring alternatives. These analyses allow for exploration of outcomes that may differ from the original outcomes as a result of a change in attribute performance, a respondent's weight, or a change in functional form.

However, other shortcomings include small respondent sample size, choice of attributes, and data availability. While we initially reached out to approximately thirty stakeholders for interviews, only nine respondents agreed to participate. Several of the stakeholders who declined interview requests voiced concerns of personal views conflicting with their respective agency or organization's views on this controversial topic. Also, only three of the nine respondents participated in the in-depth interview process. Had more time been available, we would have conducted a greater number of in-depth interviews. A larger sample size might have shown more diverse allocations of weight in the decision framework. We might have been able to better characterize similarities and differences among the various stakeholder groups.

In addition to a larger sample size, we also feel that we could have further subdivided some of our attributes. Our environmental impact measure represented a gross sum of all habitat types permanently disturbed by a transportation alternative, in acres. We might have further classified environmental impacts by subdividing this measure into acres of wetlands impacted, acres of submerged aquatic vegetation impacted, and acres of dune and beach habitat impacted. This would have allowed for a more precise comparison of environmental impacts among alternatives. Also, we measured total days of access disruption per year. That total may be distributed in different ways and stakeholder preferences regarding those scenarios may differ. For example, days of access disruption in a given year may range from several sporadic

events lasting only a few days each, to a single large storm event in which access is disrupted for weeks at a time. Respondents will likely have different preferences for those different scenarios.

We indicated our skepticism of several attribute performance values in our discussion of our sensitivity analysis to performance, specifically the environmental impact values for the three alternatives. For the Short Bridge Plus, the Record of Decision predicted 16 acres of biotic communities affected (FHWA and NCDOT, 2010b). We feel that this is a low estimate because the maintenance of a frontal dune between the highway and the ocean has morphological consequences for the elevation and width of the barrier island system, which would impact much more than 16 acres. Barrier island morphology has not been formally addressed in any Environmental Impact Statement, although it seems to be a major concern to many coastal scientists. Similarly, the Long Bridge and Ferry System would both abandon the maintenance of a frontal dune structure, thereby allowing more overwash and flooding on the barrier island. Again, this may also increase the acre measurement of biotic impacts. As noted by Culver and others in 2006, the biotic makeup of Pea Island National Wildlife Refuge would significantly change as a result of changing morphological patterns (Culver et al., 2006). This potential change in biotic makeup further supports the need for a formal discussion on barrier island integrity. The question is less about which type of ecosystem is more natural, but more about which type of ecosystem stakeholders would value more in the study area. For these reasons, we highlight the need for a more in-depth look at morphology of the island system, which should be reflected as an important environmental concern. Those numbers should be included in the preparation of any future environmental impact statements.

## **Conclusion and recommendation**

Although the Federal Highway Administration and NC Department of Transportation have chosen to implement the Short Bridge Plus alternative, it remains to be seen whether or not this alternative will satisfy the relevant criteria of minimizing environmental impacts, minimizing short and long-term costs, and minimizing days of access disruption. As recently as March of 2013, overwash from winter storms caused major disruptions in access to Hatteras Island just north of Rodanthe. The costs and environmental impacts of the Short Bridge Plus are quite uncertain due to the adaptive nature of later phases of this alternative, those concerning maintenance of NC 12 south of the bridge. Ferries are often heralded as an environmentally sound solution; however, the performance values and overall scores in our initial analysis and the sensitivity analysis show the ferry is rarely a preferred alternative. Vocal opposition from citizen action groups and state transportation officials further inhibits the likelihood of this alternative succeeding in the study area.

We see the Long Bridge as a possible point of compromise among our respondents. The results of our performance sensitivity analysis demonstrate that an increase in access disruption for the Ferry System could switch the local government representative's choice to the Long Bridge. Similarly, an increase in the environmental impact of the Short Bridge Plus could switch the DCM representative's preferred alternative switched to the Long Bridge as well. This indicates that stakeholder preferences may not be as different as they might seem from public comments to

environmental studies and media coverage (FHWA and NCDOT, 2008a; FHWA and NCDOT, 2010a; Kozak, 2012a).

The looming barrier to the implementation of the Long Bridge alternative is the large upfront cost of building the bridge, a cost that is almost three times as large as the maximum amount allocated to the Eastern North Carolina region for a seven-year funding period (FHWA and NCDOT, 2008a). The implementation of an alternative cannot wait for several more funding cycles given that hurricanes and winter storms have caused much havoc on NC 12 since Hurricane Irene in August 2011. As discussed in the general interview results, a stakeholder representing local businesses in the study area suggested increasing the share of local contribution to NC 12 maintenance through an increase in sales and/or occupancy taxes. We feel this may be a viable option for the state to explore to fund the Long Bridge. This type of funding strategy is exactly the type of foresight needed by small coastal communities to deal with transportation on dynamic coastlines.



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**Appendix A.** Interview script for general interviews. Our general interview questions were based on the following properties related to access to the Outer Banks south of Oregon Inlet – (1) ecological integrity, (2) financial feasibility, (3) reliability, and (4) ability to accommodate evacuation.

All interviewees will be asked questions from list 1. These are a mixture of fact-based and opinion-seeking questions, intended to seek expert advice and supplement the information obtained from the literature review. Questions from list 1 will require approximately half an hour, however the time will be open to the discretion of the interviewee.

**Q1** Do you agree with the current system for maintaining North Carolina’s Highway 12, in particular along the corridor from the Oregon Inlet through Rodanthe? Do you feel this is a long-term sustainable solution?

**Q2** What solutions do you feel are viable alternatives to the current methods used along the NC coast? (The current method being nourishment and retreat).

**Q3** In your expert opinion, what do you believe are the environmental (ecological) and physical limitations for any particular alternative to the current transportation method? I.e. things to keep in mind when considering alternatives, environmentally and structurally.

**Q4** In your expert opinion, what are the social and political limitations for any particular alternative to the current transportation method? I.e. things to keep in mind when considering alternatives, socially and politically.

**Q5** Are you familiar with high-speed ferry systems? Do you know of any successful systems, or any unsuccessful systems?

**Q6** (If these questions have not already been answered through conversation)

- a. **In your opinion**, will a high speed ferry system work here? Consider finances, ecological impacts and stability, timely evacuation, and general transportation needs.
- b. **In your opinion**, will a bridge or causeway that bi-passes the Pea Island National Wildlife Refuge work here? Consider finances, ecological impacts and stability, timely evacuation, and general transportation needs.

**Q7** If you were to imagine any method of transportation in the subject area (from the Oregon Inlet through Rodanthe), to be implemented immediately, what would you choose? Why?

**Q8** If you had a crystal ball, what would you see for this area in 20 years? 50? Imagine transportation, the physical landscape, etc. Have officials continued with the current transportation method, or with a different one? What are the results?

**Q9** If an alternative transportation method were chosen here, how would the program ideally be funded, in your opinion?

**Q10** Due to recent storm events with Hurricane Sandy, do you feel that the public and / or local government is more or less likely to support an alternative transportation plan in the area? Why or why not?

**Q11** Is there any additional information or advice you would like to give? Further research you would like to point us to?

**Appendix B.** Interview script for in-depth interviews. In-depth interview questions assessed how much individuals valued certain aspects of each alternative relative to other aspects (e.g., environmental impacts compared to short-term costs).

#### Meeting (1)

I'd like to get started by asking what are the components of a transportation system on the Outer Banks that you feel are the most critical or most important. Could you broadly define these components? For instance, what about impacts to local businesses? Or environmental impacts?

[Subject defines broad goals, I draw the top level of the objectives hierarchy]

Next, I'd like to discuss what aspects of these components are important to you. For instance, why are impacts to local businesses important? [Subject says for instance, it affects local economy, etc.]. Lets elaborate on each of these components.

- May have multiple aspects to each component of transportation
- Focus on tiers – lower-level and higher-level goals should be in order
- Ask “why is this feature important to you” in order to understand and connect ends to means.

[Subject creates objectives for each goal, then next step is measurable attributes]

Lastly, could you describe to me some ways of measuring these? For instance, with Reliability Over Time a measureable attribute could be the number of times a route would be refitted in the next 50 years (the lifespan of this report).

[Present chart to subject]

Could you please take a moment to look over this chart, and see whether it encompasses everything we've discussed here today? Is there anything you feel is missing either from our conversation, or perhaps that you've forgotten to mention? Does it look accurate?

Great! Before the next time we meet, I will compile your answers with the other subjects to create a compiled hierarchy. When we come together again we will discuss your preferences on the goals and attributes, and ultimately the differences between your views and the other interviewees should give our group a good understanding on what stakeholders are thinking when it comes to transportation along the Outer Banks.

#### Meeting (2)

In front of you is the compiled hierarchy we discussed in our last meeting. It may look smaller than you expected. We believe that this hierarchy includes the components of a

transportation system that were important to you and the other respondents – for instance you had mentioned (xxx) which can be tied back to the number of days the road is closed. Do you agree?

[shows performance matrix]

The performance matrix here includes how well each of the alternatives performed compared to each other. As you can see [discuss the chart]

Now let's get to the fun part! The following is called "Swing Weighting" – a way of figuring out how much more you prefer certain components of the transportation system. We're going to go through four *hypothetical* situations. The first will be made up of all worst-case scenarios (most environmental damage, most expensive, and longest access disruption). Every scenario after that (there are three), will have one of these components "swung" to its best situation. Do you understand the chart?

First off, I'd like you to rank these four scenarios between 1 to 4, 1 being the best, and 4 being the worst.

Next, I'd like you to assign points on a scale from 0 to 100 to the attributes, 0 being the worst and 100 being the best.

(Check to make sure 4 is assigned to hypothetical worst, and that points are assigned in same order as ranking)

That's it! I can do the rest of the calculations from here. Do you have any questions? Any other information? Thank you for your help in this project, we really appreciate it!