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Local Coastal Roads–Next Generation

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Garland P. Pennison, P.E.
HDR Engineering, Inc.
Lafayette, LA, 70508 USA

Robert J. Cloutier, Ph.D.
SE Department, University of South Alabama
Mobile, AL 36688 USA

Bret M. Webb, Ph.D., P.E.
CCEE Department, University of South Alabama
Mobile, AL 36688 USA

Abstract

Coastal road systems provide a vital transportation infrastructure asset within local coastal communities that are being challenged relative to resiliency and sustainability. Increasing demand on coastal infrastructure with increased development densities in coastal areas requires providing coastal road systems that meet changing needs. This study considers the growing disparity between uniformity in design standards with conflicting desirements of local communities. System engineers should approach this challenge from a divergent perspective. There is growing difference of opinion with "next generation" desirements. Next generations question whether development should continue in high risk coastal areas while choosing to live there. Physical and economic damages impacting coastal roads require reimagining fundamental system requirements for coastal infrastructure. Voices from a diverse group of stakeholders are considered in applying system models to local coastal roads. This analysis led to different desirements and priorities than provided in current unified technical guidance. Next generation priorities of framing systems analysis are changing system requirements. Providing systems analysis tools for local communities to reimagine connectivity and environments associated with local coastal road systems increases opportunity to meet desirements of the next generation. Changing conditions make systems analysis, planning, siting, and architecture design essential and beneficial for continued resiliency and sustainability.

Keywords
Sustainable development, functional requirements, coastal infrastructure, coastal roads

1. Introduction
Coastal road systems play a strategic role for continued development within the United States. According to the National Oceanic and Atmospheric Administration (NOAA) National Ocean Service (NOS), counties directly on shorelines account for 39 percent of total population occupying less than 10 percent of total land area (not including Alaska) [1]. Coastal counties and parishes population increased by almost 40% from 1970 to 2010. Population is projected to increase an additional 8% by 2020. Coastal population density is many times greater than corresponding inland counties and increasing in population at significantly faster rates.

Increased coastal development places greater numbers of engineered structures at risk for damage from coastal hazards. This includes coastal infrastructure associated with local roads, as well as state and federal highway systems. Coastal hazards (e.g., storm surge, hurricane force winds and waves, tidal and riverine flooding) place both population and coastal infrastructure at risk. Risk is greatest when measures are not taken to mitigate these natural hazard risks.

One significantly increasing hazard is the result of relative sea level rise (RSLR). Storm events are also increasing coastal hazards and frequency of coastal road flooding and damage. RSLR combines risk of local subsidence, glacial melt, gravitational redistribution, and sea level rise. When combined with increased atmospheric energy, the result has been increased levels of damage resulting from higher tides, greater intensity storms, natural wetland buffer loss, and beach erosion. Even in the absence of RSLR or other climate change impacts, risk in the coastal environment is exponentially increasing because of increased property development. The predictable response is to protect developed areas and coastal infrastructure at great expense without regard to robustness and sustainability.

Local communities and governmental transportation agencies struggle with policy decisions regarding changing requirements for planning, designing, constructing, maintaining, and operating coastal roads. Risk requirements vary locally, as do community desirements and levels of service provided by local coastal roads. Desirements is a term meant to convey stakeholders needs and desires, usually captured in client interviews, public hearings, and "voice of the customer" needs assessment, and often evolve to become system or functional requirements as the project matures.

Coastal roads and highways are an invaluable infrastructure asset for coastal communities in providing:

- Property access for private, business, commercial and governmental entities.
- Shoreline access for marine related industries and recreational activities.
- Critical egress for hurricane and nor'easter life-safety evacuation.
- Emergency response, property protection, and critical services restoration access post-event.
- Access corridor for utilities, pedestrians, cyclists, multi-modal transport.
- Connectivity to public spaces, shoreline features, aesthetic vistas and marinas.

Coastal communities and coastal road infrastructure are challenged relative to resiliency and sustainability with changing climate conditions and increased hazard risks. Increased demand on infrastructure due to increasing development in coastal areas requires providing coastal road systems that meet changing needs. Coastal system engineers, planners, environmental and social scientists are challenged to provide systems that meet changing desirements and functional requirements. Regulatory guidance is increasingly available with technical publications for planning, siting and designing coastal infrastructure and road systems. The United States Army Corps of Engineers (USACE) North Atlantic Coast Comprehensive Study (NACCS) Resilient Adaptation to Increasing Risk final report is one such example as shown in Figure 1 [2], which can be applied to transportation or other system types.

Figure 1. NACCS coastal storm risk management framework

2. Stakeholder Desirements

Private and community property developments, including required infrastructure support systems, are being more stringently assessed relative to potential impacts on community socioeconomics and natural environments relative to sustainability. There is a growing disparity between regulatory requirements for project development and local community perspectives relative to how road projects should integrate and evolve as coastal risks increase. The National Environmental Policy Act (NEPA), signed into law on January 1, 1970, requires federal agencies to evaluate environmental, social, and economic effects of proposed actions [3]. Because of inherent coastal risks, Federal Highway Administration (FHWA) developed Hydraulic Engineering Circular No. 25, Volumes 1 and 2, regarding planning and design of highways in the coastal environment [4, 5]. These manuals provide comprehensive design guidance from a coastal and transportation planning/engineering perspective.

System adaptability challenges from an analytical perspective include managing the following risks [6].

- Transportation system change occurs slowly (typically discontinuous and reactive) and coastal ecosystem change (typically continuous and responsive to some stressor). Transportation systems may not adapt at rates necessary to keep up with increased sea levels and storminess.
- Identifying infrastructure that is exposed (now or in the future) and vulnerable to both RSLR and increased storminess is complicated and a potentially expensive process for local and state transportation agencies.
- Physical structures are vulnerable to RSLR, which is likely to result in increased costs for maintenance, repair, replacement of facilities and materials, and eventual adaptation.
- Function of linked, regional transportation systems may be vulnerable to disruption if a RSLR-vulnerable link (e.g., a coastal highway) fails.
- Infrastructure and living system adaptations will need to occur to avoid a wholesale change in the marshes, estuarine systems, low-lying urban areas, and exposed highway infrastructure along the U.S. coast. (In many cases transportation infrastructure, because of its static nature, is an impediment to ecosystem resilience, e.g., barrier island rollover during overwash, marsh migration with SLR, etc.).

In August, 2014, the City of Boston and partners announced a “Designing with Water” juried competition to develop competing ideas for creative and innovative climate-change resilient design solutions for three at-risk waterfront sites in Boston [7, 8]. One of those at-risk sites is Morrissey Boulevard and Columbia Point in the Dorchester neighborhood of south Boston. The University of Massachusetts (UMass) is located on Columbia Point. Morrissey Boulevard completed in 1924 provides access to the UMass campus and is owned and maintained by the Massachusetts Department of Conservation and Recreation (DCR). It is increasingly flooded during storms and high tides.

Sea level in Boston has risen by a foot over the last century. It is projected to rise another two to six feet by the end of this century. As sea levels rise, and chronic flooding becomes the “new normal,” cities are moving to more flexible, resilient solutions. The competition represented Boston’s effort to explore innovative solutions, allowing defined areas to flood or contain water to prevent damage to other inland areas. These “next generation” ideas expand and potentially challenge concepts of how a coastal road should be designed in accordance with federal guidance.

These stakeholder desirements are not unique to Boston and vary based on local communities and cultures. While roads provide facilities for basic transport functions, desirements are changing from utilitarian functions determined by engineers, to include resiliency and sustainability components driven by local community aesthetic, cultural, and socioeconomic needs. The Living with Water competition teams reimagined requirements and needs for changing conditions in the Morrissey Boulevard area at Columbia Point in response to local stakeholder concerns, desirements and needs. Presentations included an extensive narrative with graphical depictions of concepts. These presentations represent a broad range of concepts for reimagining role and function of coastal roads in local communities.

DCR subsequently issued a Request for Proposals (RFP) for Morrissey Boulevard soliciting consultants to develop plans and complete engineering design for improvements necessary to improve road resiliency for the next 50 years. These requirements represent the voice of the stakeholder from the perspective of the owner and managing agency. While the RFP allows new ideas to be included in proposals, overall desirements are more utilitarian and practical than those generated in the competition. This disparity is increasing in coastal transportation system planning. Significant differences are apparent between what is feasible for implementing without much public resistance, and what is imagined for future needs, based on changing environmental conditions and diverse socioeconomic settings.

Because desirements varied, concepts were prioritized to assess which were most important for the competing teams in envisioning system requirements to satisfy stakeholder desirements. Using the top ten prioritized requirements, a Pugh decision matrix was used to evaluate concepts that generically represent different functional approaches as to “how” these objectives can be achieved. Providing flood risk reduction for coastal flooding is perceived as a mandatory requirement to be incorporated in the system architecture planning without being specified.

The priority desirement is for blue-green parkway corridors, referring to combined blue water and green open space features in a linear parkway corridor, whether natural or engineered. The second priority desirement is to regulate risky coastal land developments through limited access to local coastal roads. This creates potential conflicts with individual property rights; however, the right to own property does not implicitly or explicitly guarantee the right to infrastructure. Costs of maintaining access to at-risk properties is challenging budgets of many transportation agencies.

Dr. Derek Hitchins defines stakeholders as "those entities stand to gain, or particularly, to lose, from the successful implementation of a project or process [9]." Since local stakeholder desirements represented in the competition were filtered by the competing teams, a study recently completed for East Boston and Charleston in which 400 residents participated in the planning process was compared to the results from the design competition [10]. The concerns, desirements and strategies are shown in Figure 2 and compare well to priorities presented in the design competition.

Figure 2. Local coastal resilience priorities for East Boston and Charlestown

3. Functional Requirements

By providing efficient road networks, continued coastal development is encouraged, but at what risk? Both the perspectives of stakeholders presented in the Boston design competition and engineers represented in coastal highway design guidance are considered as a system to determine required components and functions. Quality function deployment (QFD) is a method to help transform customer needs (desirements) into engineering characteristics for a product or service. The priority functional needs for local coastal roads based on subjective valuation are shown in Figure 3. Priority weighted functional requirements based on QFD analysis are ranked in descending order in Figure 4 to address the question "How?" coastal roads can be better planned, sited, and designed.

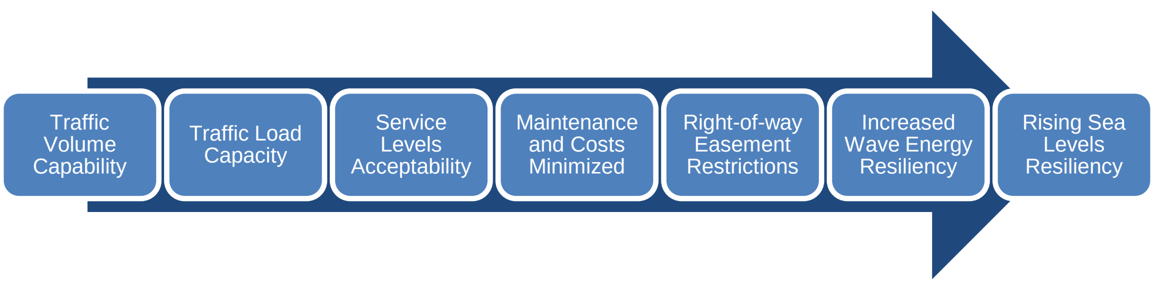

Figure 3. Priority functional needs for local coastal roads based on subjective valuation

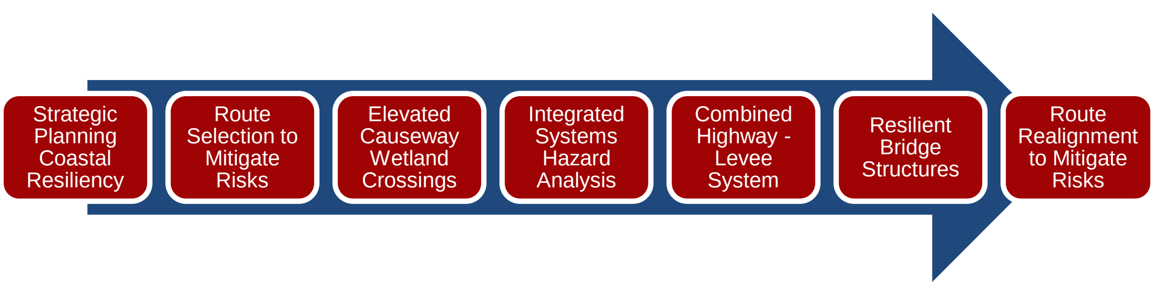

Figure 4. Priority weighted functional requirements for local coastal roads based on QFD analysis

These QFD functional requirements reflect what is expected and typical relative to current planning and engineering guidance. With the current concept of restoring to previous conditions after impact from major storms in coastal areas, sustainability of maintaining these restoration practices in providing coastal resiliency as prioritized above requires assessing whether this practice is functional or sustainable. System boundaries lack definition in coastal environments to delineate between complex infrastructure systems. Interactions between natural and manmade features increase these complexities in risk and reliability analysis. Improvements to increase resiliency often impact other systems and often resisted by a local community due to perceived negative impacts. For example, beach dune features to reduce wave energy and improve wildlife habitat are often rejected by property owners because of obstructed views [11].

To facilitate a systematic evaluation of local coastal road requirements, functions and components; a basic system model was initiated using CORE™ Spectrum UE 9.0 (SP 15) system analysis software provided by Vitech Corporation. An Integration Definition (IDEF0) function modeling diagram organizes decisions, actions, and activities for subsystems so these can be understood and improved. A systematic analysis and functional decomposition provides a next generation approach for planning, siting and designing local coastal roads. Based on stakeholder's functional requirements in an urban setting, seven system requirements are identified as priorities in Figure 5.

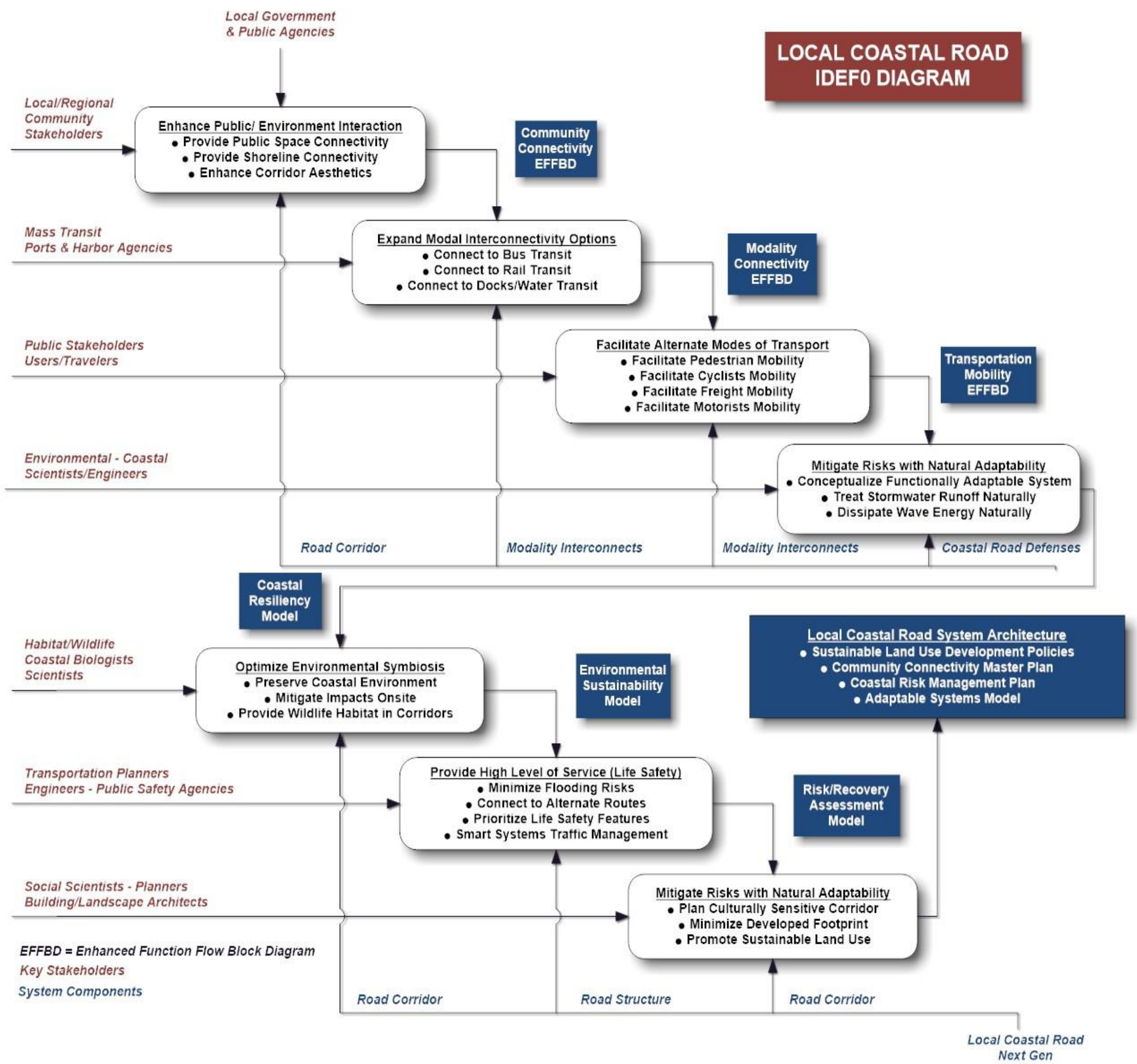

Figure 5. Local coastal road next generation IDEF0 diagram for stakeholders' priority desirements

These requirements effectively identify what the next generation perceives as its priorities for planning, siting, developing and utilizing local coastal road systems located in relatively high-risk environments. It recognizes that efficiencies of road systems designed for transportation and flood risk reduction should be balanced with quality-of-life experiences, modes of transportation other than automobiles, and environmental considerations. Since regulatory agencies, land use planners, landscape architects, engineers, environmental scientists, and others associated with infrastructure development work most efficiently in a structured approach, the outputs shown in Figure 5 provide a conceptual framework for systematic planning and design of next generation local coastal roads.

4. Conclusions

System engineers should approach coastal systems analysis from the perspective of integrating local desirements with the functional and practical system requirements for improving coastal infrastructure sustainability and resiliency. Increased physical and economic damages impacting coastal roads, require reimagining fundamental system requirements for coastal roads and associated infrastructure. Using the creative work of others from the Boston competition, voices from a diverse group of stakeholders were considered in applying systems analysis to local coastal roads. This analysis led to different desirements and priorities than provided in current technical guidance.

While technical requirements of applying engineering principles in design do not change, next generation priorities of framing systems analysis are consistently changing functional requirements. The IDEF0 function modeling diagram provides reasonable system requirements, inputs, outputs and components for a systems framework, which can be used in modeling local coastal road systems. Providing systems analysis tools for local communities to reimagine connectivity and environments associated with local coastal road systems, increases opportunity to meet desirements and needs of the next generation. Changing climates, socioeconomic, and environmental conditions will make local coastal roads systems analysis, planning, siting, and architecture design and modeling both essential and beneficial for resiliency and sustainability planning.

References

1. National Oceanic and Atmospheric Administration (NOAA), "What percentage of the American population lives near the coast?," 10 October 2017. [Online]. Available: https://oceanservice.noaa.gov/facts/population.html. [Accessed 15 November 2016].
2. United States Army Corps of Engineers, "North Atlantic Coast Comprehensive Study: Resilient Adaptation to Increasing Risk," USACE, Washington, DC, 2015.
3. Environmental Protection Agency (EPA), "What is the National Environmental Policy Act?," 24 January 2017. [Online]. Available: https://www.epa.gov/nepa/what-national-environmental-policy-act. [Accessed 11 November 2016].
4. S. L. K. J. Douglass, "Highways in the Coastal Environment, Hydraulic Engineering Circular 25, Second Edition, FHWA NHI-07-096," Federal Highway Administration, Washington, D.C., 2008.
5. S. L. Douglass, B. M. Webb and R. Kilgore, "Highways in the Coastal Environment: Assessing Extreme Events, Hydraulic Engineering Circular 25 (Volume 2), FHWA NHI-14-006," Federal Highway Administration, Washington, D.C., 2014.
6. F. M. Shilling, J. Vandever, K. May, I. Gerhard and R. Bregoff, "Adaptive Planning for Transportation Corridors Threatened by Sea Level Rise," *Journal of the Transportation Research Board,* vol. No. 2599, p. 9–16, 2016.
7. City of Boston, Massachusetts Mayor's Office, ""Designing with Water" In Boston and Around the World Press Release," 1 August 2014. [Online]. Available: https://www.cityofboston.gov/news/Default.aspx?id=14745. [Accessed 5 November 2016].
8. City of Boston, Massachusetts, "Boston Living with Water International Design Competition," 2 December 2014. [Online]. Available: http://www.bostonlivingwithwater.org/. [Accessed 5 November 2016].
9. D. K. Hitchins, Advanced Systems Thinking, Engineering and Management, Norwood, MA: Archtech House, Inc., 2003.
10. City of Boston et al, "Coastal Resilience Solutions for East Boston and Charleston Final Report," City of Boston, Boston, MA, October 2017.
11. J. R. Weggel, "Visibility over Shorefront Sand Dunes: An Ocean View," Drexel University Libraries , Philadelphia, PA, 1998.