NTC Program Progress Performance Report (PPPR) Information Form

For P.I.’s Use

On a semi-annual basis the NTC sponsored P.I. must report Program Progress Performance Report (PPPR) using the format specified in this PPPR Information Form. The form must be submitted electronically to the corresponding NTC Associate Director by 3/10/2015.


<table>
<thead>
<tr>
<th>NTC Funded Project Information (Round/Year 1, 2013-2016)</th>
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<tbody>
<tr>
<td><strong>University Name</strong></td>
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<tr>
<td><strong>Project Title</strong></td>
</tr>
<tr>
<td><strong>Principal Investigator</strong></td>
</tr>
</tbody>
</table>
| **PI Contact Information**                               | Dept. of Civil & Env. Engineering  
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The form includes the following six parts:

- Part I – Accomplishments: What was done? What was learned?
- Part II – Products: What has the program produced?
- Part III – Participants & Collaborating Organizations: Who has been involved?
- Part IV – Impact: What is the impact of the program? How has it contributed to transportation education, research and technology transfer?
- Part V – Changes/Problems

*Supplementary documents/materials can be attached to this form with the submission.*
## Part I – Accomplishments: What was done? What was learned?

The information provided in this section allows the OST-R grants official to assess whether satisfactory progress has been made during the reporting period.

### Reporting Period

<table>
<thead>
<tr>
<th>Reporting Period</th>
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### 1. What are the major goals of the program?

The National UTC aims to promote strategic transportation policies, investment, and decisions that bring lasting and equitable economic benefits to the U.S. and its citizens. The Center is concerned with the integrated operations and planning of all modes serving the nation’s passenger and freight transportation system, including the institutional issues associated with their management and investments. A balanced multi-modal approach will be used that considers freight and passenger travel mobility, reliability, and sustainability, as well as system operations during periods of both recurring and non-recurring incidents, including response to major emergencies. The modes in this theme include highway, transit, rail, and inter-modal interfaces including ports, terminals and airports. In particular, the center focuses on research, education, and technology transfer activities that can lead to (1) Freight efficiency for domestic shipping and for our international land, air, and sea ports; (2) Highway congestion mitigation with multi-modal strategies; and (3) Smart investments in intercity passenger travel facilities such as high speed rail. Major center activities are as following:

- **Advanced & Applied Research Promoting Economic Competitiveness:**
  Our research activities are multimodal/intermodal and multidisciplinary in scope, with the aims of addressing nationally and regionally significant transportation issues pertinent to economic competitiveness and providing practice-ready solutions.

- **Education, Workforce Development, Technology Transfer, & Diversity**
  The consortium is committed to providing high-quality transportation education and workforce development programs for a broad and diverse audience. Center’s efforts will support the development of a critical transportation knowledge base and a transportation workforce that is prepared to design, deploy, operate, and maintain the complex transportation systems of the future.

### 2. What was accomplished under these goals?

<table>
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<tr>
<th>Project: Objective Decision-Making Tools for Infrastructure Investments to Combat the Impacts of Sea Level Rise (PI: Miller-Hooks)</th>
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**Task 1:** Review works on climate change, sea level rise and their impacts on the transportation network (complete):

A comprehensive and wide-ranging review of this literature was conducted. The review focused on climate change effects, sea level rise (SLR), coastal flooding and
their impacts on the transportation network. Special emphasis was placed on understanding economic impacts, potential actions that can be taken to combat SLR effects, and tools for quantifying these impacts and such mitigative or recourse actions. Once identified, the works were categorized. The following themes arose: (1) justification of concerns about SLR and its impacts on the transportation network, (2) classification of impacts of SLR on the network, (3) establishment of a complete list of the adaptation (mitigative or recourse) strategies, and (4) introduction of methods to identify critical components of a system prone to SLR. The review is complete and documented.

Task 2: Review works on topics to support decision-support tool development (complete):
Despite that there are a large number of papers in the literature that consider SLR impacts on the transportation network, through task 1 efforts, we found only one work that presents a decision-making tool for optimizing investments to combat the impacts of SLR. This task is complete. Review of this work is complete and documented.

Task 3: Develop the mathematical model of the investment decision problem and method for its solution (complete):
Using the knowledge gathered in tasks 1 and 2, details to be addressed in the decision problem were identified and a mathematical modeling approach was formulated. A key element identified for incorporation in the model is the explicit recognition of uncertainty in future SLR values and frequency of flooding events of various magnitudes. Thus, a stochastic programming approach is used to capture and minimize long-term costs of a transportation network that is prone to probabilistic SLR futures and related flooding events. Costs included in the objective function are transportation costs (travel time of passengers) and monetary expenditures on the infrastructure (reinforcing components, constructing protective elements, recovering parts of network and rebuilding after destruction). The objective function can be written as follows:
\[
R = \text{Min} \ \text{invest0} + E[\xi_1 C_1 \xi_1, S_1]
\]
\[
Cm\xi_m, Sm=tt\xi_m, Sm+respm\xi_m, Sm+invstm\xi_m, Sm+E[\xi_m+1\xi_1, \xi_2, ... , \xi mCm+1\xi_m+1, Sm+1
\]
\[
\text{invstm}: \text{Major investments at the end of time period represented by point } m \text{ in time.}
\]
\[
\text{bm, awall}=\text{bm, awall}_m, \text{awall<HashMap}_m, m\in M
\]
\[
\text{bm, araise}=\text{bm, araise}_m, \text{araise.HashMap}_m, \forall a\in A, m\in M
\]
\[
\text{bm, adrain}=\text{bm, adrain}_m, \text{adrain.HashMap}_m, \forall a\in A, m\in M
\]
\[
\text{bm, arebuild}=\text{bm, arebuild}_m, \text{arebuild.HashMap}_m, \forall a\in A, m\in M
\]
where \text{bm, awall, bm,araise and bm,adrain} are m-th-stage costs of building one unit height of sea wall for link \( a \), lifting link \( a \) for one unit of height or one unit
improvement of drainage system, respectively. \( \gamma_m = [\gamma_{m\text{wall}}, \gamma_{m\text{raise}}, \gamma_{m\text{drain}}, \gamma_{m\text{rebuild}}, \gamma_{m\text{response}}]^T \) where \( \gamma_{m\text{wall}} = [..., \gamma_{m\text{wall}}, ...]^T \) is the vector of continuous-valued additional height of sea wall protection \( \forall \ a \in A \), \( \gamma_{m\text{raise}} = [..., \gamma_{m\text{raise}}, ...]^T \) is the vector of continuous-valued heights by which each element represented by a link \( a \in A \) is raised at the end of period represented by midpoint \( m \). \( \gamma_{m\text{drain}} = [..., \gamma_{m\text{drain}}, ...]^T \) is the vector of binary decisions representing whether a drainage system is implemented along link \( a \in A \) at the end of period represented by midpoint \( m \). \( \gamma_{m\text{rebuild}} = [..., \gamma_{m\text{rebuild}}, ...]^T \) where \( \gamma_m \), \( m \) are build \( = 1 \) if link \( a \) is rebuilt at the end of period \( m \) as needed to respond to significant damage due to cumulative impacts of flooding events prior and during period \( m \) and 0 otherwise. \( \gamma_{m\text{response}} = [..., \gamma_{m\text{f,arebuild}}, ...]^T \) where \( \gamma_{m\text{f,arebuild}} = 1 \) if recovery measures are taken for link \( a \) in time period \( m \) to combat impact of flooding event \( \xi_m, f(\xi_m) \) on link \( a \).

\[
\text{respm} \xi_m, Sm = \alpha \in \{(a \in A) \}, \xi_m, f(\xi_m) \omega \xi_m, f(\text{haresponse}\xi_m), f
\]

\[
\text{baresponse}\xi_m, f, Sm = \text{baresponse}\xi_m, f, Sm, \text{aresponse}, \forall a \in A, m \in M
\]

\( \xi_m \) is the realization for \( \xi_m \). \( Sm = \xi_1, \xi_2, \xi_3, \ldots, \xi_m, \gamma_m \) is the state variable. At stage \( m \), given the realization of random parameters in stage \( m \) and decisions made up until stage \( m \), but not that of random parameters in later time stages, decisions are taken. \( \xi_m, f \) is the realization of flooding event \( f \) of \( \xi_m \). \( \omega \xi f \) is the frequency of flooding event \( \xi_m, f \) which is part of realization \( \xi_m \) for period \( m \).

\[
t\xi_m, Sm = \alpha \forall a \in A, \forall f \neq \omega \xi_m, f; xar\xi_m, f; tar\xi_m, f; + \beta \forall a \in A, f = 0; xar\xi_m, f; tar\xi_m, f; xar\xi_m, f; tar\xi_m, f; \xi_m, f; xar\xi_m, f; tar\xi_m, f; \forall a \in A
\]

Coefficient \( \alpha \) is a multiplier that adds more weight to temporary effects of road closures on system performance than is captured in treating these events in terms of the portion of time over which they affect the network as a proportion of the study horizon. Coefficient \( \beta \) aggregates the travel time of all passengers for a time period. Both coefficient \( \alpha \) and \( \beta \) also convert the travel time to monetary values using the value of time of passengers.

If investment actions are taken, travel times under the scenarios will improve; and thus, the objective captures the tradeoffs between costs of increased delay to drivers and investment costs. To capture the spectrum of future SLR values that may arise, a range of predictions are considered and select trends with their probabilities over a study time horizon can be used to represent this range of values. Due to uncertainty in sea level prediction estimates and related capacity of the transportation network, the time horizon, perhaps on the order of 50 years, is broken down into several periods (of 5-10 years). The state of the system in each period will be represented by its state at a single point in time chosen randomly from within that period. Figure 1 shows the SLR prediction ranges and time periods with chosen...
representative points. For a given prediction of SLR at such a point in time, the frequency of storms of different magnitude and the related potential temporary or permanent damage to the civil infrastructure can be predicted stochastically. Related to this, flooding occurrences account for prior investment in flood prevention. For a given damage state, link travel times can be estimated under a User Equilibrium (UE) assumption. If investments are made to mitigate the occurrence of flooding and other SLR-related damage, then in a storm event the number of available (undamaged) options will be larger, overall system capacity will be greater, and the performance of the system will generally be better. If, however, such mitigative actions are not taken in advance, traffic links will be down, time for recovery will be needed and reconstruction may be required. In the former case, the burden of the cost is bared even if SLR estimates turn out to be erroneously high, and savings are incurred only if forecasted flooding events are prevented. In the latter case, damage is incurred and costs of repair are inevitable.

We conceptualize this investment decision problem as a multistage stochastic, bi-level program. At the upper level, the government agency charged with making public investment decisions (the leader) determines an optimal investment strategy. Optimal decisions are taken within a multi-stage stochastic program in which current preventative decisions are made at stage 0. Based on the realization of events and actions taken in previous time periods additional preventative decisions are made at
the end of each stage to benefit the network in coming periods. Recovery decisions are taken as recourse in every stage (post event) for each SLR-storm event scenario. Optimality of the infrastructure improvement decisions is determined, thus, over a range of potential flooding scenarios at a given point in time. At the lower level, system users (the followers) choose their routes given the infrastructure improvements gained through the upper level investment decisions. The optimal investment strategy is obtained when a Stackelberg equilibrium is reached between the upper level investment decisions and choices made by system users in response. Figure two shows this leader-follower structure.

\[
\begin{align*}
\text{Government} & : \min \quad 0 + 1, 1, 1 \\
& \quad \text{subject to} \quad m, + m, = m, \text{+} \quad 1, 2, \ldots, m+1, +m, +1 \\
\text{Users} & : \quad (x, y) \in X \\
\text{System performance} & \quad \text{is calculated for the whole time horizon given } x \text{ and } y(\cdot), \text{assuming UE achieved for each flooding scenario, } .
\end{align*}
\]

Figure 2- Bi-level Structure of the Developed Model

In the long-run, the tool provides the optimal investment strategies and recourse actions to minimize expected cost given predicted storm frequencies.

Exact solution of this bilevel, nonlinear, integer, stochastic program can be obtained for small problem instances. We developed an alternative, heuristic approach, a recursive Noisy Genetic Algorithm (NGA), that can be applied to larger, realistic problem instances. In the GA, each chromosome includes representation for the major investment decisions (building seawalls, raising elements, improving drainage systems or rebuilding) for all the links in the network for a given time period (stage). The chromosome values associated with first-stage decisions are first set with the objective of minimizing the objective over the entire time horizon given knowledge of all future scenarios with their associated occurrence probabilities. To this end, the
fitness of each generated chromosome in terms of first-stage decisions is evaluated. The fitness value is an expectation of the objective function taken over predicted SLR trends assuming that the best combination of future investments and response and rebuilding actions will be applied. Decisions set for the first stage within the chromosome supply input to second-stage decisions that must be considered for each future SLR trend. A search similar to that performed in setting the first-stage decisions of the chromosomes is then taken at the second and future stages based on input from prior stages. Thus, the algorithm has a recursive nature. The search for a good combination of actions continues until the final stage (time period) is reached. The results are then rolled back to give the fitness value of the chromosome in terms of decisions taken in the first time period.

To assess the fitness value, the lower level UE problem must also be solved for each realization of future conditions to obtain the required link travel times. For this purpose, a Disaggregate Simplicial Decomposition (DSD) algorithm was implemented. The DSD was chosen since it is known to be faster than the much simpler Frank-Wolfe algorithm commonly used for addressing similar traffic assignment problems. The recursive NGA and DSD algorithms were coded in MATLAB.

**Task 4: Prepare the case study and apply the tool** (complete): The proposed mathematical modeling and solution approach were applied on a case study of a portion of the Washington, D.C. Metropolitan Area as depicted below in the figure. This figure delineates the boundaries used for extracting roadway network and demand data. The study area includes critical roadways and national landmarks, which are positioned at low elevations in close proximity to the Potomac River, and thus, are vulnerable to climate effects. The study area also includes important national landmarks and heavily used roadways.
Roadway data was extracted from network files made available through the Metropolitan Washington Council of Governments (MWCOG). Elevation data associated with the network components were obtained using tools of ArcGIS to extract roadway elevations from the National Elevation Dataset (3-meter resolution). Elevations as extracted for the case study area are shown in the next figure. This figure also depicts the roadway network as extracted for the case study.
SLR predictions (chronic sea level values), shown in the next figure, were adapted from Climate Central website (Climate Central, 2014 - local sea level rise and coastal flood risk projections at Washington, DC; retrieved from Surging Seas Risk Finder). Values were calculated using global sea level projections developed by Vermeer and Rahmstorf in 2009, based on the historic relationship between global warming and the rate of sea level rise, combined with local factors, to make local projections which were obtained from the Potomac River station.

Episodic flooding events were replicated assuming an annual probability of flood exceeding 1 to 10 feet above high tides, plotted in the next figure, generated using the data from Climate Central.
Using data described above, three values of SLR predictions were obtained for each time period using the predictions for the midpoints of the respective periods. Three predictions in each point in time represent 5, 50 and 95 percentile values of SLR projections. Associated with each point in time and each SLR prediction for that point, a set of 8 flooding events (3 to 10 feet above high tides) were considered as episodic events with their associated probabilities of occurrence obtained from Climate Central data. This allowed for the probabilities of episodic events to be affected by SLR.

Four strategies were considered for combatting SLR and other deleterious effects of climate change: (1) building seawalls (most expensive), (2) raising the height of a roadway or other transportation infrastructure element, (3) improving drainage along chosen links (helping, but not completely mitigating effects of inundation, and (4) rebuilding after damage is incurred. These options are available over a long time horizon to address cumulative flooding event impacts from previous periods.

**Task 5: Assess the performance and results of the modeling and solution techniques on the case study** (complete):
Assessment of the performance of the rNGA is complete, and a number of modifications were made after testing it on the case study. A variety of insights were gleaned from this implementation and application.

For each realization, the impact on the network of either episodic precipitation events or higher sea level values requires solution of a traffic assignment problem. Solution of this problem provides link travel time estimates for the users of the network. This is the most time consuming part of the algorithm. Yet, it must be repeated as many as 10,000 to 100,000 times (depending on the number of periods, initial population of chromosomes and number of flooding events associated with different points in time and different SLR predictions) for a complete execution of the NGA. Thus, minimizing the computational effort needed to solve the traffic assignment problem is necessary.

The Frank-Wolfe algorithm designed to obtain O-D pair travel time estimates through traffic assignment relies on a subprocedure utilizing Dijkstra’s algorithm (a one-to-all shortest path algorithm) repeated for each demand origin. Dijkstra’s algorithm falls within the class of label setting algorithms (Ahuja, Magnanti, Orlin 1993 for background), and therefore can be terminated prematurely obtaining optimal solutions for those nodes whose labels have been permanently set. For greater efficiency, once the first minimum label with infinite value is identified, the algorithm is terminated. All destinations for which the label has not been permanently set upon such termination can be declared to be disconnected from the origin. Thus, disconnectivity created by inundation arising within the specific scenario under consideration in the current or a prior time period can be identified. This early termination was found to reduce run times for the Frank-Wolfe algorithm by
approximately 50% for this case study. Initially, a Disaggregate Simplicial Decomposition (DSD) algorithm with warm start was implemented, because of its reputation as a faster alternative to the Frank-Wolfe algorithm for traffic assignment. However, in practice we found that such speed up was not observed. The Frank-Wolfe algorithm was found to perform significantly faster.

A number of additional solution aspects were explored to reduce run times. A tolerance was exploited, the original 674 OD pairs were aggregated from the original 36,000 OD pairs in the study network, and travel time computations were sped up by saving solutions from prior runs with repeated realizations.

Assessment of the results of the algorithm is complete. Conclusions are being drawn and articulate for inclusion in the final report and resulting journal article.

**Task 6: Disseminate knowledge gained through the proposed research (complete):** A journal article is in preparation for submission and final report for the Center is near completion. The mathematical model and conceptual framework were presented in INFORMS 2014 conference in San Francisco.

4. **What do you plan to do during the next reporting period to accomplish the goals? (10/1/2015 – 11/1/2015)** None.

[Describe how the results have been disseminated. Include any outreach activities that have been undertaken to reach members of communities who are not usually aware of these program activities, for the purpose of enhancing public understanding and increasing interest in learning and transportation careers. ]
### Part II – Products: What has the program produced?

Publications are the characteristic product of research projects funded by the UTC Program. OST-R may evaluate what the publications demonstrate about the excellence and significance of the research and the efficacy with which the results are being communicated to colleagues, potential users, and the public, not the number of publications. Many research projects (though not all) develop significant products other than publications. OST-R may assess and report both publications and other products to Congress, communities of interest, and the public.

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<tr>
<th>Reporting Period</th>
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<tr>
<td>2. Books or other non-periodical, one-time publications</td>
<td>[Report any book, monograph, dissertation, abstract, or the like published as or in a separate publication, rather than a periodical or series. Include any significant publication in the proceedings of a one-time conference or in the report of a one-time study, commission, or the like.]</td>
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<tr>
<td></td>
<td>[Identify for each one-time publication: Author(s); title; editor; title of collection, if applicable; bibliographic information; year; type of publication (book, thesis or dissertation, other); status of publication (published; accepted, awaiting publication; submitted, under review; other); acknowledgement of federal support (yes/no).]</td>
</tr>
<tr>
<td>4. Website(s) or other Internet site(s)</td>
<td><a href="http://millerhooks.umd.edu/projects/proj45.html">http://millerhooks.umd.edu/projects/proj45.html</a></td>
</tr>
<tr>
<td>5. Technologies or techniques</td>
<td>Developed recursive noisy genetic algorithm with structure appropriate for general multi-stage stochastic programs.</td>
</tr>
</tbody>
</table>
| 6. Outreach activities | }
| 7. Courses and workshops |  |
| 8. Inventions, patent applications, and/or licenses | [Identify inventions, patent applications with date, and/or licenses that have resulted from the research. Submission of this information as part of an interim research performance progress report is not a substitute for any other invention reporting required under the terms and conditions of an award; as of the date of this document, UTC Program inventions may not be submitted to the Federal government’s Interagency Edison (iEdison) invention-reporting system, but OST-R is working to make that available and will notify UTCs. For additional requirements pertaining to Patents and Copyrights, refer to General Provisions of Grants for University Transportation Centers, Section III, 14.] |
| 9. Other products | [Identify any other significant products that were developed under this program. Describe the product and how it is being shared. Examples of other products are:  
  - Databases  
  - Physical collections  
  - Audio or video products  
  - Software or NetWare  
  - Models  
  - Educational aids or curricula  
  - Instruments or equipment  
  - Data & Research Material  
  - Other] |
**Part III – Participants & Collaborating Organizations: Who has been involved?**

 OST-R needs to know who has worked on the project to gauge and report performance in promoting partnerships and collaborations.

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1. **What organizations have been involved as partners?**

   [Describe partner organizations – academic institutions, other nonprofits, industrial or commercial firms, state or local governments, schools or school systems, or other organizations (foreign or domestic) – that have been involved with the program. Partner organizations may provide financial or in-kind support, supply facilities or equipment, collaborate in the research, exchange personnel, or otherwise contribute.]

   [Provide the following information for each partnership:
   Organization Name:
   Location of Organization: (if foreign location list country)
   Partner’s contribution to the project (identify one or more)
   • Financial support;
   • In-kind support (e.g., partner makes software, computers, equipment, etc., available
   • to project staff);
   • Facilities (e.g., project staff use the partner’s facilities for project activities);
   • Collaborative research (e.g., partner’s staff work with project staff on the project); and
   • Personnel exchanges (e.g., project staff and/or partner’s staff use each other’s
   • facilities, work at each other’s site).]

2. **Have other collaborators or contacts been involved?**

   [Some significant collaborators or contacts within the lead or partner universities may not be covered by “What people have worked on the project?” Likewise, some significant collaborators or contacts outside the UTC may not be covered under “What other
organizations have been involved as partners?” For example, describe any significant:

• Collaborations with others within the lead or partner universities; especially
• Interdepartmental or interdisciplinary collaborations;
• Collaborations or contact with others outside the UTC; and
• Collaborations or contacts with others outside the United States or with an international organization.
• Country(ies) of collaborations or contacts.]
**Part IV – Impact: What is the impact of the program? How has it contributed to transportation education, research and technology transfer?**

DOT uses this information to assess how the research and education programs:
- increase the body of knowledge and techniques;
- enlarge the pool of people trained to develop that knowledge and techniques or put it to use; and,
- improve the physical, institutional, and information resources that enable those people to get their training and perform their functions.

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1. **What is the impact on the development of the principal discipline(s) of the program?**

   Establishing an optimization framework for the selection of actions to combat the impacts of sea level rise on traffic networks can provide missing decision support tools and a conceptual, mathematical framework for considering the impact of SLR on transportation systems, as well as the impact of potential mitigative investment strategies.

2. **What is the impact on other disciplines?**

   [Describe how the findings, results, or techniques developed or improved, or other products from the program made an impact or are likely to make an impact on other disciplines.]

3. **What is the impact on the development of transportation workforce development?**

   [Describe how the program made an impact or is likely to make an impact on transportation workforce development. For example, how has the program:
   - Provided opportunities for research and teaching in transportation and related disciplines;
   - Improved the performance, skills, or attitudes of members of underrepresented groups that will improve their access to or retention in transportation research, teaching, or other related professions;
   - Developed and disseminated new educational materials or provided scholarships; or provided exposure to transportation,
| 4. What is the impact on physical, institutional, and information resources at the university or other partner institutions? | [Describe ways, if any, in which the program made an impact, or is likely to make an impact, on physical, institutional, and information resources that form infrastructure, including:

- Physical resources such as facilities, laboratories, or instruments;
- Institutional resources (such as establishment or sustenance of societies or organizations);
  or
- Information resources, electronic means for accessing such resources or for scientific communication, or the like.] |
|---|---|
| 5. What is the impact on technology transfer? | [Describe ways in which the program made an impact, or is likely to make an impact, on commercial technology or public use, including:

- Transfer of results to entities in government or industry;
- Instances where the research has led to the initiation of a start-up company; or
- Adoption of new practices.] |
| 6. What is the impact on society beyond science and technology? | Tools developed through this effort will aid governments and infrastructure owners and operators in effectively addressing the threats from potential sea level rise and significant, sustained flooding events that will arise more frequently with increased occurrence of extreme weather circumstances. |
Since the problem has as its objective the minimization of total costs, including both transportation costs (travel time of passengers) and money expended on the infrastructure of the network to combat sea level rise impacts (reinforcing components, constructing protective elements, recovering parts of network and rebuilding them after destruction), it can be used by decision makers to choose among possible projects to maximize societal benefits.

An additional feature of this effort is taking into consideration the occurrence of flooding events due to individual climatic events through a multi-temporal structure. Through optimal investment, the transportation network is made more resilient to future flooding events and thus safer and more reliable for the drivers who rely on it. By rebalancing terms in the objective function, more emphasis can be placed on investing to avoid flooding events with disastrous outcomes.

Solutions produced through this optimization-based modeling and solution approach (i.e. decision support tool) can help to answer a more general and much debated question: Is there a need for costly actions, such as building sea walls, raising roads, and relocating links, to combat sea level rise and prevent coastal flooding or would it be more prudent to wait until after such an event arises to address related damage? In fact, if the optimization tool suggests the application of such a preparedness action, then the cost of inaction exceeds the cost associated with preparedness, thus justifying the investment. In fact, the specific monetary benefits of preparedness can be quantified, aiding decision makers in determining when to make these large investments and to what elements of the network they should be applied and when it is best to apply them if it is not possible to make all identified changes immediately. Justification is made through the quantification of expected long term payback and less-than-obvious impacts that affect societal welfare.

Through minor modification, the formulation can consider a fixed budget for protective actions. The tool then can inform decision makers on the optimal investment of limited funds across subsystems, specific system components, regions or proposed projects.

| 7. Additional impacts | [NTC encourages to consider identifying program results by |
outcomes or impacts, as suggested by the examples below. Impacts should be linked to National goals expressed in the Secretary’s Strategic Goals.

[Outcomes are broader changes that are expected to result from the products, such as:
  • Increased understanding and awareness of transportation issues;
  • Improved body of knowledge;
  • Improved processes, techniques and skills in addressing transportation issues;
  • Enlarged pool of trained transportation professionals;
  • Greater adoption of new technology;
  • Other impacts.

Impacts are the longer-term, fundamental changes intended as a result of your activities, such as:
  • Safer driver behavior;
  • Increased travel time reliability;
  • Increased intermodal transportation operations;
  • Reduction in carbon and other harmful emissions from transportation sources;
  • Other impacts. ]
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<tr>
<th>Part V – Changes/Problems</th>
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<tbody>
<tr>
<td>If not previously reported in writing to OST-R through other mechanisms, provide the following additional information or state, “Nothing to Report, if applicable:</td>
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</tbody>
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1. Changes in approach and reasons for change

   [If there is nothing significant to report during this reporting period, state “Nothing to Report.”]

   [Describe any changes in approach during the reporting period and reasons for these changes. Remember that significant changes in objectives and scope require prior approval of the OST-R grant administrator.]

2. Actual or anticipated problems or delays and actions or plans to resolve them

   This project was delayed due to its difficulty. The problem turned out to have multi-temporal scales and to be mathematically intractable. Application to a realistic case study took significantly longer than expected.

3. Changes that have a significant impact on expenditures

   [If there is nothing significant to report during this reporting period, state “Nothing to Report.”]

   [Describe changes during the reporting period that may have a significant impact on expenditures, for example, delays in hiring staff or favorable developments that enable meeting objectives at less cost than anticipated.]

4. Significant changes in [If there is nothing significant to report during this reporting period,}
| use or care of human subjects, vertebrate animals, and/or biohazards | state “Nothing to Report.”]  
[Describe significant deviations, unexpected outcomes, or changes in approved protocols for the use or care of human subjects, vertebrate animals, and/or biohazards during the reporting period. If required, were these changes approved by the applicable institution committee and reported to the agency? Also specify the applicable Institutional Review Board/Institutional Animal Care and Use Committee approval dates.] |
|---|---|
| 5. Change of primary performance site location from that originally proposed | [If there is nothing significant to report during this reporting period, state “Nothing to Report.”]  
[Identify any change to the primary performance site location identified in the proposal, as originally submitted.] |