International Workshop on
Performance-based Infrastructure Asset Management
Istanbul, 6-9 July 2008

An international workshop that was organized and held in Istanbul during 6-9 July, 2008 focused on the paradigm of “performance-based infrastructure asset management (PBIAM)” for infrastructures such as transportation, water, power, etc. in general and the highway transportation in particular. The workshop served as a forum for discussing innovative paradigms and concepts that may be integrated and leveraged to advance the engineering and management of infrastructures. The presentations and panel discussions were designed to explore the inter-relations and synergies between systems identification, health and performance monitoring, lifecycle engineering, integrated asset management, performance-based engineering and multi-hazard risks, in addition to interdependence, resilience and sustainability of multi-domain systems.

The objectives of the workshop were:

(1) To bring an international, multi-disciplinary group of engineers and scientists from academe, government and industry together in Istanbul, offering a unique backdrop for this workshop. As a metropolis serving as a bridge between the West and the East, Istanbul exposed a multitude of infrastructure performance problems and served as a laboratory revealing the infrastructure concerns of future mega-cities.

(2) To initiate the construction of an Ontology of PBIAM. This was expected as a means for overcoming the fragmentation in civil engineering education, agencies and organizations, and, practice that is a barrier against effective integration and leveraging of concepts and paradigms with potential to innovate the engineering and management of infrastructures. Ontology is envisioned as a mechanism for creating a unified worldview and language in highly complex emerging fields of study that face integration challenges.

(3) To initiate the development of an “International Collaborative Research Agenda” on PBIAM. This Workshop provided sharing of recent experiences and advances towards PBIAM in Europe, the Middle and Far East, and North America. It permitted an understanding of how different social and cultural institutions and related human systems in different regions of the world impact PBIAM applications.
The Proposal prepared for NSF for funding the Workshop, additional sponsors and the Organization of the Workshop are appended to this Synopsis.

The Agenda of the workshop was:

July 6, 2008:
Registration, Opening Ceremony and Reception

July 7, 2008:
Opening Address: By Prof. Dr. Faruk Karadogan, President of ITU
Introduction to ITU Prof. Dr. Erkin Nasuh

Infrastructures and Sustainability: Where are we today?

1. Overview: Infrastructure Systems and Integrated Asset Management (F. Moon)
2. Policy, Planning, Financing and Revenue (M. Meyer)
3. Lifecycle Engineering (D. Frangopol)
4. Multi-hazards Considerations for Asset Management (P. Yen)
5. Societal Institutions, Organizational Systems and Individuals (L. Comfort)
6. Sustainability and Infrastructures (F. Montalto)
7. Is there really a need for asset management research? (P. Gurian)

Infrastructures and Sustainability: Vision for the Future

8. Resilience and Sustainability of Infrastructure Assets through Risk-Based Adaptive Incremental Revolution (Y. Haimes)
9. European Research on Sustainability and PBIM (H. Wenzel)
10. Japanese Research on Health Monitoring of Infrastructures (Fujino)
11. How to Ensure 100 Years Lifetime for Concrete in Marine Environment (S. Lykke)

July 8, 2008:
PBIAM: Current State of Applications and Research Needs

12. Asset Management Practice in the USA (Ghasemi)
13. Asset Management Practice in the Netherlands (Klatter)
14. Asset Management Practice in Japan (Kaneuji)
15. The Canadian perspective on Asset Management (Wade)
16. PBIAM Experience on Alpine Motorways in Italy (Mordini)
17. ITS applications in Istanbul (N. Ertas)
18. ITU’s Experiences and Lab Support for the Marmaray Project (Y. Akkaya and M. A. Tasdemir)
In addition to the above 30-minute presentations, there were panel discussions on:

1. Infrastructure Performance Measures:
   - System-Wide Performance Measures
   - Societal Domain Performance Measures
   - Natural Domain Performance Measures
   - Engineered Domain Performance Measures

2. PBIAM Ontology:
   - What is Ontology in general, and for infrastructures in particular?
   - How many ways are there for constructing Ontology?
   - How can we best leverage the construction and future applications of Ontology to integrate fragmented expertise areas and asset groups, and improve the engineering and management of infrastructures as multi-domain systems?

3. International Research Agenda on PBIAM:
   - Domain knowledge needs;
   - Corresponding data and information needs;
   - Tools and research infrastructure needs for data and information collection;
   - How to leverage existing data/information?
   - Research needs for data interpretation for knowledge;
   - Research needs for preserving and leveraging legacy heuristic knowledge and experience;
   - Country/Culture-specific issues in education and preserving wisdom/experience;
   - Future activities needed for completing a research agenda and launching international PBIAM research;

July 9, 2008:

An information Session on the Long Term Bridge Performance Program (LTBPP) that has been initiated by the FHWA was held. This was followed by a Panel meeting to discuss the opportunities for international collaborations. A brief synopsis of the LTBPP is Appended.

The Workshop included organized visits to the two major suspension bridges crossing the Bosphorus, together with their highways and viaducts. Presentations were arranged with the Municipal and State Highways Officials regarding their management practices of the system.
The participants of the Workshop, with their affiliations and expertise areas are listed in the following.

<table>
<thead>
<tr>
<th>US Delegation</th>
<th>Affiliation</th>
<th>Expertise Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Dr. Emin Aktan</td>
<td>Drexel University</td>
<td>Structural and Systems Engineering</td>
</tr>
<tr>
<td>2. Dr. Hamid Ghasemi</td>
<td>FHWA</td>
<td>LTBPP Research Manager</td>
</tr>
<tr>
<td>3. Dr. Phil Yen</td>
<td>FHWA</td>
<td>Seismic Performance Research Manager</td>
</tr>
<tr>
<td>4. Dr. Ali Maher</td>
<td>Rutgers University</td>
<td>Operations, Pavements and Geosystems</td>
</tr>
<tr>
<td>5. Dr. Nenad Gucunski</td>
<td>Rutgers University</td>
<td>NDE Technologies, Geosystems</td>
</tr>
<tr>
<td>6. Dr. Bala Balaguru</td>
<td>Rutgers University</td>
<td>Materials and Durability</td>
</tr>
<tr>
<td>7. Dr. Yacov Haimes</td>
<td>Univ of Virginia</td>
<td>Systems Engineer, Risk and Uncertainty</td>
</tr>
<tr>
<td>8. Dr. Michael Meyer</td>
<td>Georgia Tech</td>
<td>Transportation Planning and Policy</td>
</tr>
<tr>
<td>9. Louise Comfort</td>
<td>Univ of Pittsburgh</td>
<td>Social Scientist: Government Policy</td>
</tr>
<tr>
<td>10. Dan Frangopol</td>
<td>Lehigh</td>
<td>Reliability and Lifecycle Engineering</td>
</tr>
<tr>
<td>11. Kevin Womack</td>
<td>Utah State University</td>
<td>Politics and Engineering Management</td>
</tr>
<tr>
<td>12. Mehdi Saiidi</td>
<td>Univ of Nevada, Reno</td>
<td>Earthquake Structural Engineering</td>
</tr>
<tr>
<td>13. Haluk Aktan</td>
<td>Western Michigan U</td>
<td>Materials and Durability</td>
</tr>
<tr>
<td>14. David Lowdermilk</td>
<td>Pennoni</td>
<td>Transportation Consultant</td>
</tr>
<tr>
<td>15. M Mollaghasemi</td>
<td>Productivity Apex Int.</td>
<td>Industrial Engineer, Ontology</td>
</tr>
<tr>
<td>16. Sohila Bemanian</td>
<td>Parsons</td>
<td>Pavement and Geo-systems consultant</td>
</tr>
<tr>
<td>17. Celik Ozyildirim</td>
<td>VTRC</td>
<td>Concrete Materials</td>
</tr>
<tr>
<td>18. Marv Halling</td>
<td>USU</td>
<td>Structural Engineering</td>
</tr>
<tr>
<td>19. Franklin Moon</td>
<td>Drexel University</td>
<td>Structural Engineering</td>
</tr>
<tr>
<td>20. Patrick Gurian</td>
<td>Drexel University</td>
<td>Systems Engineering, Policy Analysis</td>
</tr>
<tr>
<td>21. Franco Montalto</td>
<td>Drexel University</td>
<td>Environmental Systems, Sustainability</td>
</tr>
<tr>
<td>22. Necati Catbas</td>
<td>Univ of Central Florida</td>
<td>Structural Engineering</td>
</tr>
<tr>
<td>23. Masoud Ghandehari</td>
<td>Brooklyn Poly</td>
<td>Materials and Sensing</td>
</tr>
<tr>
<td>24. Sam Fayez</td>
<td>Productivity Apex Int.</td>
<td>Industrial Engineer, Ontology</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Canadian Delegation</th>
<th>Affiliation</th>
<th>Expertise Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>25. Roger Chen</td>
<td>University of Alberta</td>
<td>Civil Engineering Department Head</td>
</tr>
<tr>
<td>26. Chris Wade</td>
<td>City of Calgary</td>
<td>Director, Infrastructure Services, City of Calgary</td>
</tr>
<tr>
<td>27. Gamil Tadros</td>
<td>SPECO and ISIS</td>
<td>Bridge Design Consultant</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>European Delegation</th>
<th>Affiliation</th>
<th>Expertise Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>28. Helmut Wenzel</td>
<td>Austria and EC</td>
<td>Consulting engineer, Vienna</td>
</tr>
<tr>
<td>29. Leo Klatter</td>
<td>The Netherlands</td>
<td>Asset Management Center for Public Works</td>
</tr>
<tr>
<td>30. Andrea Mordini</td>
<td>Italy</td>
<td>Transportation Consultant</td>
</tr>
<tr>
<td>31. Glauco Feltrin</td>
<td>Switzerland EMPA</td>
<td>Research Scientist</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Japanese Delegation</th>
<th>Affiliation</th>
<th>Expertise Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>32. Yozo Fujino</td>
<td>Tokyo University</td>
<td>Structural Engineering</td>
</tr>
<tr>
<td>33. M. Kaneuji</td>
<td>Kajima Corp.</td>
<td>Asset Management Consultant</td>
</tr>
</tbody>
</table>
### Turkish Participants

<table>
<thead>
<tr>
<th></th>
<th>Name</th>
<th>Organization</th>
<th>Position/Department</th>
</tr>
</thead>
<tbody>
<tr>
<td>34</td>
<td>Mehmet Ali Tasdemir</td>
<td>ITU, Dean of Engineering</td>
<td>Construction Materials</td>
</tr>
<tr>
<td>35</td>
<td>Ugur Ersoy</td>
<td>BU, Professor</td>
<td>Structures and Reinforced Concrete</td>
</tr>
<tr>
<td>36</td>
<td>Nadir Yayla</td>
<td>ITU, Professor</td>
<td>Transportation Engineering</td>
</tr>
<tr>
<td>37</td>
<td>Yilmaz Akkaya</td>
<td>ITU, Assoc Professor</td>
<td>Construction Materials</td>
</tr>
<tr>
<td>38</td>
<td>Tugrul Tankut</td>
<td>METU, Professor</td>
<td>Structures and Reinforced Concrete</td>
</tr>
<tr>
<td>39</td>
<td>Ozgur Yaman</td>
<td>METU, Assoc Professor</td>
<td>Construction Materials</td>
</tr>
<tr>
<td>40</td>
<td>Azmi Tiras</td>
<td>KGM, Assoc. Director</td>
<td>Highways Agency Administrator</td>
</tr>
<tr>
<td>41</td>
<td>David Arditi</td>
<td>IIT, Professor</td>
<td>Construction Engineering</td>
</tr>
<tr>
<td>42</td>
<td>Steen Lykke</td>
<td>MarmaRay Project</td>
<td>General Director of Construction</td>
</tr>
<tr>
<td>Many additional participants from</td>
<td>The Istanbul Municipality, Turkish Highways Agency</td>
<td>Various Specialties in Civil Engineering</td>
<td></td>
</tr>
</tbody>
</table>

---

**A Group of Participants Visiting the ITS Center at Istanbul’s FSM Suspension Bridge Operational Control Facility**

### Preliminary Conclusions and Recommendations:

1. Bringing an International and multi-disciplinary group together at the crossroads of Europe and the Middle East, and discussing cross-cutting topics related to infrastructures in general and highways and bridges in particular, proved to be a highly rewarding experience. The fact that the Workshop actually helped transform how they conceptualized various topics related to infrastructure management was articulated by many of the US researchers.

2. The presentations and discussions at the workshop revealed that infrastructures may be viewed in significantly different perspectives by researchers in various disciplines. There was agreement between participants from different fields that performance criteria for infrastructures may be articulated at the global, regional and local levels; and, in terms of
different asset groups such as roadways, bridges, operations; and, the human, natural and engineered systems that make up each of the asset groups. It was also possible to reach consensus on the broader global level performance of infrastructures such as safety, choice, efficiency, transparency, etc.

3. However, performance measures for individual asset groups, or, each of the human, natural and engineered domain making up various asset groups was difficult to identify. The intersections, interactions and interdependencies between asset groups and different infrastructures made it very difficult to identify performance measures at asset group levels. It was also recognized that there is no direct correlation between performance criteria at the local level and at the global level, since the make-up of the system is largely unknown, and that the system is highly dynamic and non-stationary.

4. Researchers from industrial, structural, environmental and organizational systems areas who had developed a preliminary Ontology on Infrastructure Asset Management for the workshop recognized the need to considerably change their approach following the experiences and input during the workshop. Ontology remains as a most valuable and promising mechanism for arriving at a common terminology and world-view by a diverse group of stakeholders on the challenges and opportunities we face today for prudently managing our existing infrastructures. However, the information and knowledge elicitation, and its hierarchical structuring as needed to construct the Ontology was discovered to be far more challenging than initially envisioned. The Ontology Committee will be continuing their efforts.

5. The Committee for developing an International Research Agenda made significant progress. Their draft will be ready by the end of August 2008. The most critical element of the research Agenda emerged as:

5.1 There are limits of theoretical research on “generic” infrastructures. Given that an important characteristic of infrastructures is their non-stationary and highly dynamic behavior, many intersections, interactions and interconnections may emerge during the time-window of a limit-event and then disappear. It follows that identifying infrastructures together with the interactions at their intersections of various domains, different asset groups and between different infrastructures is not possible unless research involves observations of actual operating infrastructures.

5.2 It is therefore highly desirable and in fact necessary to establish field laboratories where researchers may observe, measure and identify the behavior and performance of each of the human, natural and engineered
elements and systems that make up infrastructures. The dynamic interactions and interdependencies between different domains, asset groups and entire infrastructures should be identified and characterized based on concrete examples. Only after such an exercise that we may be able to formulate meaningful performance measures for each element, domain or asset group and understand how these local-level performances will in fact contribute to the regional and global performances of the entire system.

5.3 The research agenda will discuss how infrastructure systems such as highway transportation and water may be transformed into field laboratories with their human, natural and engineered domains, and the scientific standards of observation, measurement and modeling of all critical elements with their interrelationships for the characterization and identification of integrated systems.

5.4 Given that infrastructure performance is are highly culture-dependent concept, due to the human elements and systems making up the multi-domain system, it is desirable to have field laboratories at different areas of the world such as the European Union, the Middle East and the Far East.

6. The Workshop organizers envision that the Ontology and the Research Agenda will be drafted for presentation by September 2008. These products would be ready for discussion by various stakeholders, including NSF, FHWA, NIST, EPA and US Army Corps, in addition to academe and industry. The Organizers are interested in holding a smaller meeting at Washington DC during October or November 2008 to receive feedback before they finalize and submit their Final report to NSF and other interested Agencies.

Attachments:

1. Poster for the Workshop
2. Sponsors and Organization of the Workshop
3. Synopsis of FHWA’s Long Term Bridge Performance Program
4. The Proposal submitted to NSF for supporting the Workshop
International Workshop on Performance-based Infrastructure Asset Management

A 3-Day International Workshop in Istanbul, Turkey
July 7-9, 2008

Hosted by the Istanbul Technical University, with support from additional Turkish Universities and under the support of NSF, FHWA, NIST, US Army Corps and Turkish, European, Canadian and Japanese agencies. The PBIAM workshop intends to foster a discussion of PBIAM as a paradigm that may serve as a framework for effectively integrating and leveraging innovative concepts and technology tools to enhance infrastructure performance and preservation.

The PBIAM Workshop Objectives:

1.) To Initiate an Ontology of PBIAM.
2.) To Develop an International Collaborative Research Agenda on PBIAM.

For more information in the USA, contact Professor A. Emin Aktan (aaktan@drexel.edu)
For more information in Turkey, contact Dean Professor Dr. Mehmet Ali Tasdemir (tasdemir@itu.edu.tr)
Organization of PBIAM Workshop

Workshop sponsors:
US-NSF, USDOT-FHWA, Rutgers University CAIT
With the auspices of USDOC-NIST, USEPA, US Army Corps of Engineers
European, Canadian and Japanese institutions

Istanbul Technical University, Istanbul Municipality, TCK, TUBITAK
TCMB, SIK, IMO – ISTANBUL

Chairs:
Ugur Ersoy, Professor Emeritus, METU, Professor BU, Honorary Chair
Faruk Karadogan, President of ITU, Honorary Chair
Mehmet Ali Tasdemir, Dean of Engineering, ITU - Conference Host and Chair
Tugrul Tankut, Professor Emeritus, METU – Conference Co-Chair

International organizing committee:
Wenger, Sinaishin (NSF), Wlaschin (FHWA), Gaj (FHWA), Ghasemi (FHWA), Wu (NIST), Albee (USEPA), Mlakar (USArmy Corps), Aktan (Drexel), Tasdemir (ITU), Pala (ITU), Tankut (METU), Wenzel (Austria), Mufti (Canada), Fujino (Japan)

Local organizing committee:
Yayla (ITU), Yaman (METU), Tiras (KGM), Yigit (Depar International), Yilmaz (ArGenTours), Toklu (YT)

Technical committees:

- Committee for International Research Agenda:
  o Secretaries: Catbas (UCF), Ghandehari (Brooklyn Poly)
  o Review Board: Wenger (NSF), Gaj (FHWA), Casey (FHWA), Albee (EPA), Mlakar (USArmy), Kerley (VDOT/AASHTO), Chase (VTRC/UVa), Cullari (FHWA), Dunn (NJDOT), Fujino (Japan), Wenzel (EC), Balaguru (Rutgers), Meyer (GTech), Haimes (UVa), Comfort (UPitt), Frangopol (Lehigh), Yigit (Depar, Ankara), Klatter (the Netherlands), Kaneuji (Kajima, Japan), Tadros (ISIS), Wade (ISIS), Saiidi (UNReno), Mordini (Italy), Kuhn (NJDOT), Gomez (VTRC)

- Ontology Committee:
  Mollaghasemi, Fayez, Moon, Gurian, Montalto

- Committee on Performance Measures for the Highway Infrastructure System:
  Aktan, Maher, Yen, Ghasemi, Gucunski, Madanat, Womack, Lowdermilk, Celik, Aktan, H., Moon, Gurian, Montalto, Brown, Bemanian, Halling, Chen, Feltrin
FHWA’s Long Term Bridge Performance Program

In April 2008 FHWA’s Office of Infrastructure Research and Development launched a major new strategic initiative designated as a flagship research project entitled “The Long Term Bridge Performance (LTBP)” program. LTBP is intended to be a 20-year program, with the global objective of collecting scientific quality data from the Nation’s highway bridges, as representing critical node-points of the highway transportation network. The data and information to be collected is expected to advance our knowledge of how our highway transportation, together with its linkages to all other infrastructures, performs as a complex multi-domain system, governed by dynamic interactions between human, nature and engineering systems and elements. The LTBP program will therefore enable us with a holistic understanding of the true realities of highway transportation as a system, so that we may finance, plan, design, construct, operate, maintain, manage and renew this critical infrastructure safely, securely and effectively and in a sustainable manner within the frame of performance-based asset management, following lifecycle engineering principles. The program is expected to lead to a new generation of National Bridge Inspection Standards for Condition and Performance Evaluation of bridges and an integrated systems-level, performance-based asset management of the highway transportation network.

The highly ambitious goals of the LTBP program are driven by the necessity for a better understanding of the trade-offs we face as a Nation, given that we are at a time which demands prudence as a society in how we utilize our fiscal and natural resources within a new global reality. To reach its goal, the LTBP program has been designed with an awareness of the requirements for success in big-science projects such as space, arctic or deep-ocean explorations. The program is designed as a coordinated, collaborative, multi-institutional and multi-disciplinary manner with the researchers coming from government, academe and industry. The Prime Contractor of LTBPP is Rutgers University’s Center for Advanced Transportation and Infrastructure, in partnership with Utah and Virginia Transportation Research Centers, Parsons Brickenhorf and including technology providers Siemens and Advitam. An Advisory Board has been appointed to provide a rigorous oversight and quality control. Linkages with other long-term strategic research programs undertaken by the FHWA, AASHTO, TRB and ASCE, as well as agencies such as the NSF, EPA, NIST and the US Army Corps of Engineers have been established. Many state, bi-state and local transportation agencies are participating in the program which is also maintaining liaisons with leading foreign infrastructure agencies and organizations in Canada, Europe, Middle and the Far East, including Turkey, Japan, Korea, China, New Zealand and Australia.

The scope of the initial 2-Year pilot phase of the LTBPP has been designed to plan the research and establish the data and information that should be collected to provide answers to the following questions:

1. **How can we describe bridge performance** objectively, recognizing that bridges are critical elements of the multi-domain Highway Transportation System? Current measures such as “condition rating” and “sufficiency rating” are widely recognized as insufficient and may be often misleading for bridge and asset management. Bridge performance is affected by interactions between society, organizations and individuals, nature and the engineered systems that make up highway transportation, as well as their linkages and interdependencies with other infrastructures. The measures of condition and sufficiency rating, and even the more comprehensive “health index” that has been adopted by some states fall short of accounting for most of the interactions that we recognize as important for bridge and highway performance. Bridge performance should relate to the overall system performance, often expressed in terms of safety, efficiency, environmental impacts, cost and organizational effectiveness. The challenge is in formulating bridge performance in terms of rational, measurable indices that will strongly correlate with the desired global performances of the entire system, and especially, the risk associated with the reduction and loss of each and every one of the operational, safety, serviceability and durability performances of a given bridge.
2. What are the critical design, fabrication and construction parameters, loading and behavior mechanisms and operational as well as maintenance management decisions that have significant impacts on bridge lifecycle performance? What are the long term performances of various maintenance and repair measures that are commonly applied to bridges? How can we rationally estimate lifecycle, lifecycle cost and benefits given the complexity of multi-domain infrastructures?

3. What is the most meaningful way of re-classifying or clustering highway bridges as opposed to currently designated families of Reinforced Concrete (RC) slab, T-Beam and Arch; Pre-stressed Concrete I and Box Girder; RC Deck on Steel Girders (steel-stringer); Steel Truss, Arch and Cable-Supported types? There is evidence that such a grouping offers little correlation to the mechanisms and parameters that affect operational, structural and lifecycle cost performance of bridges, and especially, the risk associated with their lack of performance. For example, a more rational classification that would more definitively relate to operational and structural safety should incorporate any network-level strategic importance of a bridge, location-dependent multi-hazards, climate conditions, weather, traffic and accident information, organizational jurisdictions, soil-foundation, continuity, redundancy, bearings, joints and drainage, typical deterioration and damage mechanisms such as vibrations, any fatigue-sensitive details, and others.

4. Once we construct a new classification and grouping for highway bridges based on the considerations listed above, and that is more in-tune with the parameters and mechanisms that relate to network and bridge performance, we may then designate bridge populations for stratified statistical sampling. The advantage of such a new classification would be in being able to objectively test, measure, monitor, and construct field-calibrated simulation models for a sample to understand the behavior and performance of the larger bridge population. The related question is therefore how to sample bridges such that we may represent the behavior and performance characteristics of the broader population by the smallest number of samples?

5. What is the documentation, data and information that should be compiled on the sample bridges so that their lifecycle performance may be evaluated, and how should these bridges be monitored over time? What are the standards for quality assurance and management of data and information? It is clear that we need data on the organizational parameters, policy, planning, design, construction and operation including the operating and maintenance costs, how the capital cost of the bridge was financed, and various financing and revenue mechanisms through which inspection, evaluation, preventive maintenance and any repair or retrofit are funded. Additional data on operational demands and safety performance of the bridge and the demands from the regional highway system that it serves should be collected as discussed earlier.

The Scope of the initial pilot phase of the LTBP Program will include the following Tasks:

1. **Outreach:** Identifying and creating of a community of bridge and highway engineers that are the keepers of heuristic knowledge and are aware of the current state-of-best-practice. Government, industry and academic participants, especially expert participants from agencies and organizations such as FHWA, AASHTO, NCHRP, TRB, IABMAS, IABSE, ISHMII and ASCE would be identified and invited to join the program as advisers. Prominent bridge designers, contractors and researchers will be recruited. Experts from all of the pertinent areas of transportation such as planning, policy, financing, revenue generation, organizational management, pavement, safety, ITS, etc. are needed so that knowledge of the entire multi-domain system may be assembled through the selected community of experts. An international outreach program will solicit expertise from Europe, Canada and the Far-East.
2. Knowledge Engineering: The expert knowledge that has accumulated within the community identified above will be solicited through Workshops, questionnaires and interviews by a group of engineers, supported by knowledge-engineers including social scientists and psychologists, and, organized and synthesized. The knowledge will relate to the fundamental questions posed earlier. Especially, all the heuristic knowledge about which bridges perform better than others; why some bridges do not perform while apparently identical bridges do perform well; and, the maintenance and repair methods that work better than others, will be collected. In addition, experts on financing, planning and design, operations and safety, organizational performance, maintenance management, etc. will be interviewed to understand how investment decisions are made and how funds from various financing and revenue mechanisms are distributed and expended at different states and within different organizations.

3. State-of-Research: Literature on all aspects of Bridge Engineering, Bridge Management and Asset Management in the USA and in the world will be identified, reviewed and summarized. Special emphasis will be on the state-of-the-art in the world on bridge NDE, structural testing, system-identification, health monitoring, as well as bridge maintenance and repair techniques. Also, all available data and knowledge on bridge failures, destructive bridge tests and forensic studies will be obtained and synthesized.

4. Informatics: Current NBI data (and element-level inspection data that is being collected by some states) will be transferred to an innovative web-based data-base that will support queries, data visualization and statistical analysis. The data-base will be designed together with an interface that will enable organizing various types of data and information on a statistical sample of bridges, including interview results with design, construction and maintenance engineers, plans, documents, visual inspection details, digital imaging and video, material tests and NDE results, structural test results, operational and structural monitoring results, weather and accident data, etc.

5. Classification into Statistical Populations based on Performance: The expert community described in the “Outreach” above, will be interviewed to construct consensus definitions for bridge performance, and the objectively measurable and quantifiable indices that will provide metrics for performance. Based on these performance metrics, and the existing data and relevant fundamental and applied research results on bridges and the highway infrastructure system, a new bridge classification will be identified to organize the large majority of highway bridges into stratified statistical populations for sampling.

6. Sampling: Building on the foundation described above, the researchers will select samples from the statistical bridge populations by leveraging heuristic knowledge, past research results, and in conjunction with the principles of stratified statistical population analysis and the theory of design-of-experiments. The statistical populations will be visually inspected and available documentation, data and information will be evaluated to arrive at a final sample for rigorous study. Through such an intelligent stratified sampling process, the final sample bridges will represent the most common soil-foundation and structural types and materials with all the important variants in addition to jurisdictions, as-is conditions, exposures, loading environment, network locations and strategic importance.

7. Studies on Sampled Bridges: A comprehensive documentation of the entire past history of a sample of several hundred representative bridges, including information on their planning, financing, design, construction, operation, maintenance and retrofit, will be retrieved and assembled. A highly detailed, objective characterization of these bridges in terms of 3D finite-element models will be generated and documented by following the most rigorous material, element and structural testing, evaluation and system-identification standards. This will be followed by their long-term instrumented health-monitoring and re-testing at various points along their lifecycle when indicated by monitoring results. The collected data will help us to understand and quantify the most critical deterioration,
corrosion, and other types of degradation mechanisms such as intrinsic effects and overloading, as well as how these may be most effectively mitigated during design, construction, operation and maintenance.

8. **Pilot Phase:** The Program in its initial 2-Year Pilot Phase will accomplish Tasks 1-6, and establish the standards and specifications for carrying out Task 7. Pilot demonstration of Task 7 for 6 bridges will be accomplished. These include 2 bridges at NJ, 2 at Utah and Western US, and 2 at VA. Researchers will work on these demonstration projects collectively, as they develop and demonstrate the standards for:

(a) Documenting the anatomy of a bridge, from its conception to its current state, including an electronic database for all of the plans, documents, data, information, including information on the agency, designer, design checker, contractor, inspections, rating and permit history, safety and maintenance engineers, lifecycle cost information, etc;
(b) Detailed visual inspection and condition documentation by leveraging an information system designed after the currently available BIM systems. This will include digital imaging and close range photogrammetry, 3D CAD, 3D FE model, instrumentation and test program results, monitoring results and field-calibrated 3D FE model;
(c) NDE, Materials sampling and testing, structural testing (vibration testing, crawl testing, static testing and ambient monitoring under traffic), long-term intermittent monitoring of ambient conditions and critical structural responses;
(d) Data quality assurance, visualization, statistical multi-variate correlation analysis and interpretation protocols.
(e) Synthesis of the products from (a)-(e) for performance modeling for bridge and network-level asset management.

9. **Pilot Phase:** The Program in its initial 2-Year Pilot Phase will accomplish Tasks 1-6, and establish the standards and specifications for carrying out Task 7. Pilot demonstration of Task 7 for 6 bridges will be accomplished. These include 2 bridges at NJ, 2 at Utah and Western US, and 2 at VA. Researchers will work on these demonstration projects collectively, as they develop and demonstrate the standards for:

(a) Documenting the anatomy of a bridge, from its conception to its current state, including an electronic database for all of the plans, documents, data, information, including information on the agency, designer, design checker, contractor, inspections, rating and permit history, safety and maintenance engineers, lifecycle cost information, etc;
(b) Detailed visual inspection and condition documentation by leveraging an information system designed after the currently available BIM systems. This will include digital imaging and close range photogrammetry, 3D CAD, 3D FE model, instrumentation and test program results, monitoring results and field-calibrated 3D FE model;
(c) NDE, Materials sampling and testing, structural testing (vibration testing, crawl testing, static testing and ambient monitoring under traffic), long-term intermittent monitoring of ambient conditions and critical structural responses;
(d) Data quality assurance, visualization, statistical multi-variate correlation analysis and interpretation protocols.
(e) Synthesis of the products from (a)-(e) for performance modeling for bridge and network-level asset management.

9. **The LTBP program incorporates destructive testing** of a small but critical sample of decommissioned bridges so that their actual capacity, failure modes and mechanisms impacting the actual capacity and failure modes may be understood. Such information is critical for any post-hazard emergency decision, which should be included within a comprehensive asset-management program. In conclusion, the LTBP program database will provide scientific-quality, objective and quantitative performance data for highway bridges as elements within our highway transportation network, fostering highly needed improvements in all aspects of their cost-effective operational and structural performance and life-cycle preservation.

9. **By the very nature of its objectives, only completely proven, demonstrated reliable and warranted commercial hardware and software, loading and excitation systems, sensors, data acquisition, communication and computing technologies will be used in the LTBBP while there are many new, yet unproven products that may offer more practical, economical and in fact even more reliable manners of monitoring bridges and highways in the future.** Given the obvious synergy between the LTBBP and a sensor technology demonstration initiative, it is logical that any such an initiative be designed and implemented as an element or a layer within the LTBBP organization. It is envisioned that some of the sample bridges will serve as a field laboratory for “new product validation and demonstration”. The complete set of test bridges, including those that are documented and monitored by partners in foreign countries, will be networked to constitute a unique global field laboratory for civil engineering. This global field laboratory will not only serve the LTBP research, but it will also serve for innovating civil and environmental engineering education and training of bridge and highway transportation engineers worldwide.
Performance-based Infrastructure Asset Management (PBIAM)

Summary
This proposal solicits NSF’s support and auspices, through a partnership with FHWA, for holding a 3-Day international workshop in Istanbul, Turkey during July 7-9, 2008, on the topic of “performance-based infrastructure asset management”. The proposal is co-sponsored by the US Federal Highway Administration (FHWA). Partial support has been promised by Turkish, EC, Canadian and Japanese agencies.

Objectives of the Proposed Workshop
We propose an international workshop in Turkey to dissect the paradigm of Performance-Based Infrastructure Asset Management (PBIAM). The highway transportation infrastructure, its linkages and interdependencies to other modes of transportation and other infrastructures will be leveraged as a case. Turkey is at the cross-roads between Europe and Asia, and the highway infrastructure connecting Asia and Europe at Istanbul will serve as an excellent backdrop for the discussions. Specific objectives of the proposed workshops include:

(1) To bring a multi-disciplinary group of engineers and scientists from academe, government and industry together for discussing how innovative paradigms and concepts may be integrated and leveraged to advance the engineering and management of infrastructures in general, and highway transportation infrastructure in particular. The workshop will explore the inter-relations and synergies between the concepts and paradigms of asset management, performance-based engineering, multi-hazards risks, multi-domain systems identification, applied systems analysis, health monitoring and intelligent systems in addition to interdependence, resilience and sustainability.

(2) To construct Ontology of PBIAM of highway transportation infrastructure to help overcome the fragmentation that is obstructing effective integration and leveraging of concepts and paradigms with potential to innovate engineering and management of infrastructures. Ontology has been leveraged as a mechanism for creating a community sharing a similar worldview and speaking the same language in order to foster highly complex emerging fields of study that face integration challenges. Space, defense, AI, IT are examples.

(3) To develop an International Collaborative Research Agenda on PBIAM. This Agenda will incorporate an in-depth understanding and sharing of recent experiences and advances on PBIAM in Europe, the Far East and North America. It will also permit an understanding of how different social and cultural institutions and related human systems in different regions of the world impact PBIAM applications.

Intellectual Merit
While we broadly recognize that infrastructures are multi-domain and multi-disciplinary systems with human, natural and engineered elements, there is currently little awareness and no consensus regarding how innovative paradigms and concepts need to be integrated and leveraged to advance the engineering and management of infrastructures in general and transportation infrastructures in particular. The principal intellectual merit of the proposed workshops will be to bring experts and stakeholders that have so far remained apart, in order to start bridging this gap by leveraging highways and bridges for a realistic case-study.

Broader Impacts
No one country or region has yet discovered the best and most effective framework for efficient, safe, sustainable and secure operation and preservation of their infrastructures. The path to innovation has to go through global, coordinated, multi-domain, and multi-disciplinary research. The proposed workshop was conceived in this manner and the Ontology and PBIAM Research Agenda will be broadly disseminated through a web site linked to FHWA’s site to promote the adoption of PBIAM principles by transportation infrastructure stewards throughout the US.

To facilitate the participation of experts from traditionally underrepresented groups in these workshops, several strategies will be employed. First, leading civil engineering faculty and practitioners from traditionally underrepresented groups will be directly contacted by the workshop organizing committee and invited to participate in the proposed workshops. To aid in the identification of qualified faculty and advanced graduate students, the Philadelphia Louis Stokes Alliance for Minority Participation (LSAMP) program, which is housed at Drexel University will be leveraged. To aid in the identification of practitioners from underrepresented groups, faculty members and national leaders associated with professional societies that serve underrepresented groups, will be contacted and asked to nominate qualified participants.
# TABLE OF CONTENTS

For font size and page formatting specifications, see GPG section II.C.

<table>
<thead>
<tr>
<th>Section</th>
<th>Total No. of Pages</th>
<th>Page No.* (Optional)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cover Sheet for Proposal to the National Science Foundation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Project Summary (not to exceed 1 page)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Table of Contents</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Project Description (Including Results from Prior NSF Support) (not to exceed 15 pages) (\text{Exceed only if allowed by a specific program announcement/solicitation or if approved in advance by the appropriate NSF Assistant Director or designee})</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>References Cited</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Biographical Sketches (Not to exceed 2 pages each)</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Budget (\text{Plus up to 3 pages of budget justification})</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Current and Pending Support</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Facilities, Equipment and Other Resources</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Special Information/Supplementary Documentation</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Appendix (List below.) (\text{Include only if allowed by a specific program announcement/solicitation or if approved in advance by the appropriate NSF Assistant Director or designee})</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Appendix Items:</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.
Performance-based Infrastructure Asset Management (PBIAM)

Project Description

Overview of the Proposed Workshop
The proposed workshop will be organized and executed to strive for a consensus, facilitating interactions and fostering partnerships between international experts from North America, Europe and the Far East in the area of PBIAM of infrastructures and leveraging highway transportation as a particular case. Multi-disciplinary experts from USA, Canada, Europe and Japan will be invited. These experts will include participants from academe, industry and government, including government engineers serving as stewards of infrastructures. The most critical backgrounds that are needed include civil, mechanical, chemical and electrical engineering (with all their sub-disciplines, and especially environmental engineering), social sciences and management. We anticipate that our greatest challenge will be in bringing together experts from various sub-disciplines of civil engineering, such as transportation planning, operations, hazard mitigation, asset management, materials, pavements and various aspects of bridge engineering for consensus on how we may develop a holistic approach to managing the highway infrastructure.

The selection will be coordinated by the proposal writers as discussed further, in conjunction with NSF’s guidance. We will seek open-minded participants interested in discovering, in-depth, the reality of the human, natural and engineered systems and their interactions by observing their confluence in a real-life field laboratory, rather than assuming the generalized characterizations proposed for these systems in isolation from each other. The participants will take advantage of observing actual infrastructures in a different culture to enrich our understanding of how human systems in different parts of the world may interact and impact engineering and nature, controlling infrastructure performance. In addition to bringing together multi-disciplinary expertise and different stakeholder cultures, we will strive to have a balanced group in terms of age and gender, and make a special effort to identify and invite individuals from groups that have been traditionally underrepresented in science and engineering.

The three-day workshop will take place in Istanbul, Turkey. As required by the NSF, all workshop sites will be fully accessible to persons with disabilities. The workshop will be hosted by the Directorate of Turkish Highways Agency (TCK), in collaboration with the Middle East Technical University in Ankara, the Istanbul Technical University and the appropriate State and Municipal Emergency Management Agencies at Istanbul.

The workshop will focus on the discussion and exchange of experience, knowledge and technology know-how related to PBIAM of highway infrastructure. Of particular interest will be how seismic and other relevant risks may be incorporated in PBIAM within a multi-hazards approach. We anticipate about 15-20 participants from the US, including several graduate students, and about 5 from each of Canada, EC and Japan, respectively. The Turkish side is expected to provide about 10-15 contributors and many observers. We expect about 6-8 keynotes on the most critical policy and financing drivers for and the principal concepts embodied in PBIAM. These will be complemented by many shorter contributions addressing taxonomy, systems, sub-systems and element attributes, relationships, present and future performance metrics, domain knowledge and data needs, constraints, and, various asset management decision examples. A group of industrial and civil engineers will construct the ontology based on these contributions and following discussions, and this will be reviewed, modified, complemented and widely disseminated through the “Wikipedia” mechanism.

Another outcome of the Workshop will be an International Collaborative Research Agenda on PBIAM. This Agenda will incorporate an in-depth understanding and sharing of recent experiences and advances on PBIAM in Europe, the Far East and North America. It will also permit an understanding of how different social and cultural institutions and related human systems in different regions of the world impact PBIAM applications. Given the various new mechanisms for collaborative research between EC and USA through NIST, and also the history of collaborative research between Japan and USA through NSF and FHWA, we expect the Research Agenda to pave the way for future Workshops as well as research projects that require international infrastructure field laboratories.
In addition to the scientific merit and broader impacts discussed above, the proposed workshops will nurture a strategic relationship. The FHWA established a close relationship with TCK after the 1999 Turkey earthquakes and since then organized two workshops in Turkey to transfer information, expertise and technology for seismic retrofit and protective systems. The proposed workshops will comprise the Third in these series, and in fact will be responding to a request from TCK to continue such exchanges related to asset management. Continuing the relationship between Turkey and the USA, in collaboration with Japan, Canada and EC as discussed in the following, would be of interest to agencies and researchers from all of the participating countries and regions, especially given the increasing importance of globalization in education, research and the practice of civil engineering.

Host institutions in Turkey will solicit support from the Turkish Scientific and Technical Research Council (TUBITAK). Support from the European Community agencies as well as Japanese and Canadian government agencies for the participation of their respective researchers are expected. Naturally, NSF’s auspices will be the key for Turkish, EC and Japanese researchers to effectively solicit support from their respective agencies.

**Organization and Participants of the Workshop**

Drs. Emin Aktan and Hamid Ghasemi will be responsible for the successful organization and conduct of the Workshop, in addition to coordinating the development of the Ontology and its effective dissemination. To help them with the organization, an **International Steering Committee** with participants from US, Turkey, Europe and Japan will be formed. Dr. Wen-huei Yen and Steven Gaj from FHWA, Drs. D. Wenger and Joy Pauschke from NSF, Dr. Jacob Haines (UV), Dr. S. Madanat (UC Berkeley), Dr. Louise Comfort (UPitt), Dr. M. Shinozuka (UC Irvine), Dr. D. Frangopol (Lehigh), Dr. de Neufville (MIT), Dr. Michael Meyer (Georgia Tech), representatives from AASHTO and leading transportation asset management industry such as Cambridge Systematics, Inc., Parsons TG and PB will be amongst those who will be invited to form the steering committee from the US. We will also invite participants from US Army Corps and NIST in order to explore expanding multi-agency collaborations in the area of PBIAM. Finally, we anticipate NSF support will provide for the participation of several graduate students at the Workshop.

Dr. A. Mufti, Manitoba University and President of ISHMII ([www.ishmii.org](http://www.ishmii.org)) will coordinate the Canadian participation. Drs. Helmut Wenzel (VCE Holding, Austria) will serve as the coordinator of EC participation. Dr. Masahiro Dogaki from Kansai University and Dr. S. Unjoh of Japan Public Works Research Association will coordinate the participation from Japan and the Far East.

It is noteworthy that Japan has established a close relationship with Turkey, offering financial credit support and expertise to evaluate and mitigate the seismic risks to the suspension bridges and viaducts at Istanbul. Leading Japanese consultants such as the “Bridge & Structure Institute, Inc.” of Japan have been working in Istanbul with the support of the Japanese Government to help TCK address this agency's seismic retrofit design concerns. The Japanese government and academic researchers have developed excellent measures for mitigating and managing the seismic risk to their expressway network in Japan following the lessons of the Great Hanshin Earthquake in 1995, but this has come at a very high financial cost. The Japanese government has now privatized nearly the entire interstate highway transportation infrastructure, and is interested in exploring performance-based engineering and integrated asset management of infrastructures as a means of controlling the financial burdens resulting from risks and long-term asset preservation needs of the system. Preliminary discussions have indicated that representatives from Japanese academe, government and industry are very interesting in participating with their own resources.

From the host country, Turkey, General Director of the Turkish Highways Agency and the President of Istanbul technical University will be “honorary” members. They have appointed a steering committee from Universities and government to help in organizing the Istanbul Workshop as the local coordination Committee. The CO-PI’s Drs. Aktan and Ghasemi have developed close relations with the Turkish coordinators, and will work with them and their appointees for a successful local organization. In addition to NSF, FHWA and TUBITAK, the workshops will be under the auspices of AASHTO, TRB, ASCE, IABSE, IABMAS and ISHMII representing US and international professional organizations with expert committees on various infrastructure concerns.
Tentative Workshop Program
A multi-disciplinary committee of engineers, social scientists and IT experts will be appointed by the International Steering Committee to develop the Ontology. Productivity Apex, Inc., an IT/IE company with extensive experience in constructing Ontology, together with Drs. Moon, Gurian and Montalto from Drexel University, respectively representing structural, organizational and environmental systems engineering expertise, and Dr. DesRoches from GeorgiaTech, an expert in multi-hazards mitigation, will serve as the core members of the "Ontology Development Committee." This Committee will participate in the development of a final Agenda of the Workshop by starting to draft the Ontology so that they may finalize the Workshop Agenda to ensure expert coverage of the critical concepts, at a sufficient level of granularity, and including specific case examples so that a sufficiently complete and meaningful Ontology may be constructed. This Ontology will be widely disseminated to researchers and practicing engineers and their input will be solicited by following the "Wikipedia" example. Modifications and any additions to the Ontology will be controlled by the Ontology Development Committee.

The first day of the Workshop will be dedicated to the Opening Ceremony, Introductions, and the keynote presentations, to be concluded by a Panel meeting. The presentations will cover and overlap all of the critical paradigms and concepts that have been identified as key to advancing the engineering and management of infrastructures, and in particular, the highway transportation infrastructure. The second day will be dedicated to parallel Sessions with shorter presentations and discussions. We envision that based on the preliminary work done by the Ontology Development Committee, and the exchanges during the first two days, the participants will have reached consensus on an understanding of: (a) Applied systems analysis (operations research-options analysis), (b) infrastructure economics, (c) transportation politics and policy, (d) transportation planning, financing and impact analysis, (e) transportation infrastructure performance definition and performance measures incorporating interdependency, resiliency and multi-hazards, (f) uncertainty, risk management and insurance, (g) hazards and multi-hazards, hazard mitigation and emergency management, including resilience, (h) organizational management, (i) lifecycle benefit/cost, (j) operations and ITS, (k) maintenance management of highways and bridges, (l) current status of asset management and integrated asset management expected in the future, (m) system-identification and health monitoring; (o) case studies and examples illustrating general domain knowledge needs and constraints, as well as country-region-culture-specific issues that impact current practice.

During the Third day, the multi-disciplinary Ontology Committee will present their understanding of PBIAM, the linkages and relationships between the topics, to stimulate discussion and solicit input from the participants. A separate Committee will develop and present an International Collaborative Research Agenda on PBIAM following the presentations by the Ontology Committee. The Workshop will be concluded with a Panel discussion on the integration of concepts and paradigms discussed in relation to PBIAM for effective, sustainable infrastructure engineering and management.

We should note that the steering committee members, some of whom have been tentatively identified earlier, represent a multi-disciplinary group of engineers and scientists from academe, government and industry that have not come together in the past due to the fragmentation within and between engineering and sciences, between academe, government and industry, and especially between the different cultures of NSF and FHWA. For example, we note that the TRB has currently more than 300 Committees, and even those Committees on steel and concrete bridges do not always have effective liaison. Bringing these individuals and others that will be selected by the steering committee together will be providing a unique opportunity for coordinated multi-disciplinary input and the discussions required for the Ontology.

Istanbul Transportation Infrastructure as a Backdrop
The highway transportation infrastructure network connecting Europe to Asia in Istanbul has been planned, financed and constructed piecewise over a period of more than 50 years. This infrastructure includes two of the world’s longest suspension bridges and more than a dozen major viaducts of record height and span, comprising a rare civil engineering accomplishment. However, some of the bridges and highways are now over 30 Years old, exhibiting many signs of deterioration and distress. The 1999 Izmit Earthquake resulted in movements and low-level damage which required repair and retrofit of nearly every element of the infrastructure on the Asian side. A large earthquake with an epicenter in the Marmara Sea is now
considered highly probable, and it is anticipated that the resulting ground motion will comprise a major
hazard affecting the metropolitan Istanbul and its vicinity within the next 30 Years.

Meanwhile, the transportation system has come close to its operational saturation point, and there is a
pressing need for instituting a systemic inspection, condition assessment, preventive maintenance, repair
and retrofit program along with taking effective measures for operational management and demand
control. The Turkish engineers and government officials are interested in asset management, especially
given the multi-risk hazards that their infrastructures face. Therefore, the proposed Workshop will serve an
invaluable purpose in illustrating to Turkish authorities the importance of developing a PBIAM program for
Istanbul’s highway transportation infrastructure. At the same time, the participants will benefit from such a
backdrop of Istanbul’s conditions, risks and concerns in their conceptualization and discussions on PBIAM.

**Workshop Deliverables**
The principal deliverables for the proposed workshop, in addition to the final report submitted to NSF, will
be a PBIAM Ontology, an International Collaborative Research Agenda on PBIAM, as well as refereed
journal articles and conference presentations/papers outlining the discussions from the workshop with a
particular focus on the challenges identified, research needs, and strategies put forth to overcome the
current fragmentation related to infrastructure management. To aid in the development and broad
dissemination of these deliverables, a website for the Workshops will be established by Drexel University.
This site will serve as a vehicle for announcements, invitations, and agenda development prior to the
workshop as well as a means to review and comments on papers and presentations following the
workshops. The web site will also serve to distribute the Ontology on PBIAM for infrastructures and
highway transportation infrastructure in particular. The organizers will leverage the web site to maintain an
active forum for promoting the continuation of discussions that began during the workshops.

To promote widespread use, the website (including the Ontology and forum) will be linked through
Wikipedia and promoted during sessions focused on this theme at the Transportation Research Board, 7th
International Workshop on Structural Health Monitoring, 4th International Conference on Structural Health
Monitoring of Intelligent Infrastructure, 4th International Conference on Bridge Maintenance, Safety and
Management, etc.

**Workshop Assessment**
A longitudinal assessment framework will be employed to identify the effectiveness of the workshop and
the developed ontology. This assessment will consist of three surveys which the workshop participants will
complete (a) prior to attending the workshop, (b) at the conclusion of the workshop, and (c) after reviewing
the final ontology and International PBIAM Research Agenda that are developed. The assessment will be
led by Co-PI Dr. Gurian who has extensive experience developing, implementing, and interpreting the
outcome of surveys. By comparing the participants understanding and appreciation of the challenges and
opportunities associated with infrastructure AM during these three stages, the success of the workshop
and the ontology will be established. In addition, the final two surveys will also elicit recommendations for
future workshops on the subject as well as modifications to the ontology.

**Recent Meetings on Similar Subjects**
The expertise groups and stakeholders who are required to contribute to a Thesaurus on PBIAM
incorporating multi-hazards risks come from many engineering and science disciplines that are currently
fragmented and distributed to multiple professional societies and agencies throughout a large number of
Committees and Bureau’s. The most pertinent and currently distinct sub-disciplines are: (a) transportation
asset management; (b) bridge management; (c) pavement management; (d) operational (traffic)
management; (e) multi-modal transportation management; (f) earthquake engineering – structural,
geotechnical and seismological aspects; (g) performance-based engineering and TQM; (h) multi-hazard
engineering; (i) uncertainty, risk and reliability; (j) lifecycle cost analysis incorporating multi-hazards; (k)
system-identification and health monitoring; (l) emergency preparedness and response management; (m)
urban land-use and infrastructure planning (financing, policy, politics, impacts); (n) organizational systems;
(o) operations research - applied systems analysis.
Academic, government and industry experts on the above sub-disciplines are currently available at several dozen federal government agencies and their bureaus, state agencies, pseudo-public organizations and utilities, hundreds of committees under a large number of professional organizations such as TRB, AASHTO, ASCE, IABSE, IAEE, IABMAS, ISHMII, JSCE, etc. There has been little collaboration or even communication between these entities. For example, although the synergies between the infrastructure and constructed systems research carried out under the auspices FHWA, NSF and NIST are obvious, coordinated and systemic communication and collaborations between these agencies are lacking. A Nationally Coordinated Infrastructure Renewal Research Program, analogous to the well-known NEHRP, would be highly desirable.

While several meetings which have discussed individual components of the PBIAM paradigm take place on a regular basis through the organizations listed above (e.g. 2007 ASCE Structures Congress, Long Beach, CA, 2007 IWSHM, Palo Alto, CA, 2007 TRB, Washington, D.C., 2006 3rd IABMAS, Porto, Portugal, 2006 AASHTO Annual Meeting, Portland, OR, etc.) the comprehensive and multi-discipline nature of the proposed workshop is novel. Although many advances relevant to the state-of-the-art in PBIAM have been accomplished over the past decade, these were not effective in transforming the state-of-the-practice since PBIAM by itself is not sufficient for such a transformation. Additional “enabling” paradigms and concepts, and their integration as discussed in the proposal are necessary.

Fragmentation of research, education and practice in civil engineering and other disciplines related to engineering and managing infrastructures is a major obstruction to coordinated, collaborative research that will effectively bring together and integrate the large spectrum of disciplines so that systemic integrative research and demonstrations can be accomplished. Infrastructure systems that will serve as real-life laboratories for such research are needed. NSF is perhaps the only agency that has the intellectual critical mass that is necessary to launch such research, but effective progress requires NSF’s partnership with agencies that have a deeper understanding of the challenges in effective technology integration and leveraging and those that can actually provide access to operating infrastructure systems. While NSF has predominantly focused on infrastructure research on generic models of infrastructures, effective infrastructure research requires an integration of field research on actual infrastructure systems with generic studies leveraging the physical laboratory and the computer.

We note that the FHWA, in conjunction with state transportation agencies, AASHTO and TRB offers a unique synergy to NSF in this regard. The writers have been striving to bring FHWA and NSF together for a long-term, meaningful and highly synergistic partnership for such coordinated, collaborative and integrative research leveraging real-life highway transportation networks as field laboratories. The proposed workshop is expected to serve as a mechanism to further investigate such an opportunity. Meanwhile, there has been little if any effort made to identify the synergies and linkages of the PBIAM and the related enabling paradigms and concepts in order to develop an integrated approach to infrastructure management. Currently there are no professional organizations specifically focused on this integration and thus current conference and committee structures do not have the broad appeal to bring together the necessary participants for the proposed workshop.

We conclude by a positive note, recognizing an effort by TRB Committees on “Transportation Asset Management,” and “Transportation Economics,” FHWA’s Office of Asset Management, AASHTO, American Public Works Association and the National Association of County Engineers to organize a meeting at New Orleans during Nov 6-8, 2007, entitled, “to Spotlight New Approaches to Asset Management.” One of the tracks in this meeting will be “the Integration of Maintenance and Operations into Transportation Asset Management” (FOCUS, April 2007). Some of the Steering Committee members have participated at this meeting, and they will help connect the Workshop to the experts whose participations will be important for the integrative effort that they are proposing.

Resilience, Sustainability and PBIAM

The PBIAM paradigm, described further in the proposal along with other related paradigms, will naturally incorporate the constraints arising from interdependence, and the objectives of resiliency and sustainability amongst others, within a multi-objective constrained optimization problem. The goal is to optimize the lifecycle performance of the integrated natural, human and engineered systems that make up
the highway transportation infrastructure, while recognizing its connections and interdependencies with other infrastructures. Linkages between various transportation modes and between transportation and water, power, fuel, gas and IT that are physically interconnected with highways and bridges give rise to many known cases of interdependence. Various additional mechanisms, associated with natural and human systems, also create interdependencies and some of these remain unknown until hazards strike.

Resiliency, given the strategic importance of the highway network connecting Europe with the Middle East, and its importance for economic sustenance, as well as emergency response management and economic recovery in the case of hazards, will have to serve as a central element in any objective function for PBIAM.

We note that Turkey is a candidate for joining the European Community (EC) and sustainable development is a priority of the EC (http://ec.europa.eu/environment/eussd/). EC Science Commission has supported a number of significant multi-country research projects focused on sustainable development given multi-hazards risks, and the experience and knowledge resulting from these Projects would be invaluable to all researchers.

Developing the proposed Ontology related to the engineering and management of 21st Century infrastructures is therefore expected to serve a critical role for effective multi-disciplinary and multi-cultural research. It would be tempting to perform such research in the academic realm based on the network theory, uncertainty, risk and reliability theory, or, other generalized systems engineering theories, however, we believe that problem-focused and integrated analytical and experimental research that will incorporate real-life infrastructures as field laboratories will offer the greatest benefit/cost, and is in fact essential for transforming the status quo. This requires access to actual infrastructures as field laboratories.

**Relationship to FHWA and NSF Research Programs**

Recently the USDOT, the FHWA, and many state and local transportation agencies have developed fairly congruent strategic plans, which identify safety, reduced congestion, environmental stewardship, and, security-related issues as strategic goals, and in some cases recommend a set of target quantitative performance metrics. While it seems we have reached a general consensus regarding appropriate aims for our transportation system, the identification and merging of innovative paradigms to achieve these goals have been elusive. The proposed workshops will develop a working taxonomy that will begin to overcome this critical barrier and usher in a new, more rational approach to infrastructure management.

We note that a new crosscutting NSF initiative “Resilient and Sustainable Infrastructures (RESIN)” initiative that was announced in July 2007 indicates that “research is needed to expand the theoretical frameworks for understanding, modeling, and simulating interdependent infrastructure systems at multiple time scales, i.e., under short-term disturbances and over the longer term. Research is also needed to advance the fundamental engineering science that will enable interdependent infrastructures to be both resilient and sustainable.” The subject-matter of the workshop is congruent with this initiative, and will provide an international group of experts overview of the problems articulated in NSF’s RESIN initiative.

**Critical Paradigms and Concepts Embodied In PBIAM**

**Integration of Innovative Paradigms and Concepts**

A hierarchy of the paradigms and concepts discussed below is postulated in Figure 1. The hierarchy is based on the societal, organizational and professional buy-in required for the adoption of the specific paradigms. We note that *adoptions in concert* are critical, as unlike other engineering disciplines, civil engineering reform cannot occur without parallel policy and legal reforms by societal institutions, especially federal and state government agencies and quasi-government organizations such as toll-road and toll-bridge managers and utilities.
Performance-Based Engineering

Performance-based engineering of a constructed system is defined as an integration of planning, feasibility analysis, financing, design, construction, operation and maintenance so that one may assure and guarantee, with a long-term warranty if needed, that the constructed facility will meet a set of objective performance metrics through its lifecycle. A recent paper by Aktan et al. (2007) reported on the consensus recommendations of an ASCE Technical Committee that was charged with the task of evaluating how the civil engineering profession may transform its practices from specification-based to performance-based approaches. The Committee suggested a rational approach for formulating performance metrics for infrastructures and their engineered systems and elements. Performance based engineering and management of infrastructure systems is a paradigm requiring both societal and organizational reform as well as innovating civil engineering education and training. Many impediments to performance-based engineering were identified by the ASCE Committee, two most important ones being: (a) the common mechanisms for financing, bidding and contract delivery; and, (b) the highly fragmented ownership, stewardship and responsibility for various performance categories.

The broader civil engineering profession is expected to move from the current specification-based approach to a performance-based one in several stages. Both for highway bridges and buildings, seismic design codes as well as retrofit recommendations in the US now refer to expected performance requirements (Aktan et al, 2007) but these remain subjective, and objective or measurable criteria are not yet established. The International Code Council's 2006 International Building Code also incorporates expected performance criteria without offering specific measurable indicators for assuring and warranting performance. However, we do expect objective and measurable criteria in the near future that would serve as a basis for warranty and as a driver for integrating the currently disconnected phases of design, construction, operation and maintenance.

Asset Management (AM)

The origins of AM go back to "operations research" developed during World War II, and the paradigm has been applied extensively in economics, finance and manufacturing. The authors define the goal of AM as the effective management of large and complex systems in an integrated manner, through explicitly considering the dynamic interactions between all of the heterogeneous elements within the system. As such, AM aims to provide information about the trade-offs associated with various decisions, which can be used as a basis for reconciling many conflicting objectives and constraints, with the aim of enhancing system performance rather than individual performances of elements. The first application of AM to civil engineered systems, termed “Applied Systems Analysis,” was pioneered by de Neufville (1990) who subsequently demonstrated how this concept may help enhance the design and optimize the operations of airports (2003).

Perhaps the most advanced application of AM to transportation infrastructure is on-going in the Netherlands, where the Directorate-General for Public Works and Water Management recently set forth a procedure for implementing an integrated AM framework for the management of Dutch roads, bridges and waterways (Kletter and van der Vusse, 2006). In addition, we observe similar efforts to adopt AM principles by different infrastructure agencies, such as water utilities, in various parts of the world. For example, various utilities in Canada, Great Britain, Australia and New Zealand claim benefits of AM (Aktan et al, 2006). In spite of such considerable interest, and isolated success stories, there is currently no consensus on how best to transform this concept to the management of a transportation infrastructure system. The proposed Workshops will enable further discussion on how to apply this critical concept to highway infrastructure in its most effective manner.

Lifecycle Cost

According to National Institute for Standards and Technology (NIST), “life-cycle cost analysis (LCCA) is a method for assessing the total cost of facility ownership (www.wbdg.org).” According to Christensen (2005), LCCA is more than a means to assess total cost of ownership or to distinguish between alternatives; it is the most relevant objective throughout the entire design and operation process. The often listed design goals of maximizing reliability, manufacturability (constructability), durability, maintainability, etc., are clearly all desirable; however, when these objectives compete with one another there is no
clearly-defined recourse. In contrast, basing designs on life-cycle cost removes the need for arbitrary rankings of attributes, and provides a basis for identifying trade-offs related to the bottom line. Christensen (2005) attributes this approach to procurement guidelines of both US and Canadian armed forces and notes that in 1960, US Department of Defense officials reported that 75% or more of the total cost for a weapons system is due to operations and support costs.

It follows that lifecycle cost and in some cases lifecycle benefit/cost analysis is a critical concept for making investment decisions, and therefore should be incorporated in the engineering and management of infrastructure systems. Several important questions remain before one may conduct a meaningful LCC analysis, however. These relate to the determination of the lifecycle of a new, maintained, rehabilitated or retrofitted structure and its expected performance along the lifecycle. The impacts of uncertainty in estimating the risk involved in establishing appropriate demand envelopes for various limit events are significant for LCCA in design and in maintenance management.

**Multi-Hazards Risk Mitigation**

A multi-hazard approach to adapting and mitigating risks affecting urban areas is a relatively new concept, which we may trace back to 1995 in the US (FEMA, 1997). Following the Disaster Mitigation Act of 2000, many states and local governments have prepared their multi-hazard mitigation plans. California’s Imperial County’s Emergency Operations Plan, issued by Imperial County Office of Emergency Services (July, 2007, 128 pages) is an excellent example.

In the research arena, efforts related to a single-hazard approach to earthquake or hurricane started in the US and Japan decades ago. More recently, US researchers have begun to recognize the importance and benefits of multi-hazard approaches, for example, see Grigoriu (2006). During the 2004 reauthorization of the NEHRP program by the US Congress, NIST testimony indicated that “NEHRP has a unique opportunity to provide national leadership in charting the course for a multi-hazard approach to risk mitigation, while continuing with its important risk reduction mission for earthquakes. The development of the HAZUS regional loss estimation model – that now covers earthquakes, wind, and floods – is an excellent example of this kind of leadership,” (http://gop.science.house.gov).

**Structural Identification, Health Monitoring, and Smart Structures/Infrastructures**

The “structural identification (St-IId)” concept refers to the construction of field-calibrated computer models of a structural system by correlating simulated and measured responses (Moon and Aktan, 2006). The health monitoring concept (borrowed from the medical field) involves the continuous or quasi-continuous monitoring of objective condition indicators. It is now well understood and universally accepted that long-term well-being requires proactive monitoring of health as opposed to seeing a doctor when we get sick. Most health problems may be easily cured if they are diagnosed and treated at an early stage, but they may become crises if they are not treated until they progress. The same concept applies to constructed systems, a problem as benign as a clogged drainage system may lead to irreversible structural deterioration if it is not diagnosed and corrected at an early stage.

These concepts and their corresponding technologies have been researched for over two decades and have been demonstrated on various structures in the world. We refer to the Proceedings of International Workshops on Structural Health Monitoring held biennially at Stanford University since 1997 (http://structure.stanford.edu/), and the Workshops of the International Society of Health Monitoring for Intelligent Infrastructures (ISHMII) organized biennially since 2001 (www.ishmii.org).
References


Haimes, Yacov Y. “Phantom system models for emergent multiscale systems,” Journal of Infrastructure Systems, v 13, n 2, June, 2007, p 81-87

Haimes, Yacov Y. “On the definition of vulnerabilities in measuring risks to infrastructures,” Risk Analysis, v 26, n 2, April, 2006, p 293-296


Special Report: The Infrastructure Crisis, Civil Engineering, Jan 2008, Vol 78, Number 1, pp: 40-65