This grant was for partial support for organizing an international workshop on performance-based infrastructure asset management with focus on highway transportation. The FHWA contributed an additional $30,000 through the Center for Advanced Infrastructure and Transportation, a University Transportation Center at Rutgers University. Istanbul Technical University and Turkish Highways Agency supported the workshop as hosts and contributed to local activities. Participants from Canada, the European Community and Japan were supported by their respective research support agencies.

There were 33 delegates from North America, Europe and the Far East, and an equal number from Turkey. Of the 24 US delegates, 21 were civil engineers representing transportation, structures, materials, pavements, geotechnical, environmental and systems disciplines, in addition to one government policy and social science expert and two industrial engineers. As the workshop was organized, efforts for outreach were extended to various government agencies and professional organizations. In addition to dialogues with NSF, FHWA, NIST, EPA and US Army Corps of Engineers, connections were made with the state transportation agencies of New York, New Jersey and Pennsylvania and with professional organizations including ASCE and TRB in addition to ISHMII, IABSE and IABMAS.

The organizers are quite aware of the need for seeking additional contributors and potential contributors from applied systems engineering, social science, economics and finance, transportation systems planning, water and sustainability expertise areas. The long-term goal is to build a community of multi-disciplinary experts to serve as a critical mass for advancing the state-of-the-art. Therefore, outreach continues with the goal of establishing a National Committee on Infrastructure Asset and Risk Management under the auspices of ASCE and/or TRB. This Committee will maintain linkages with relevant asset management research and applications in the world, and serve as a repository of contacts, information, knowledge on the best-practices for asset management of transportation, water, and energy infrastructures.

Conclusions and Recommendations from the Workshop
1. Participants unanimously agreed on the importance of asset management as a paradigm promising greater transparency, objectivity and cost-effectiveness of decisions related to infrastructure systems. Asset management provides a logical framework for more effectively integrating and leveraging additional innovative paradigms and technology, such as system-identification, health monitoring, intelligent systems, life-cycle engineering and performance-based engineering. There is value in framing and linking all isolated infrastructure technology development efforts (e.g. sensors) under an asset management umbrella.

2. Infrastructures are viewed through significantly different perspectives by researchers from different disciplines and cultures. Participants from different fields agreed that performance metrics for infrastructures should be formulated at the global, regional and local levels; in terms of different asset groups such as roadways, bridges, operations; and, in terms of the human, natural and engineered systems that make up each of the asset groups. It was possible to reach consensus on many of the broader global-level performance measures for infrastructures such as safety, choice, efficiency, transparency, etc. However, performance measures for individual asset groups--human, natural and engineered--have proven to be difficult to formulate. The intersections, interactions and interdependencies among different domains, asset groups and infrastructures have made it very difficult to identify definitive performance measures at higher resolutions. Presently no determination can be made on the correlation between performance criteria at the local levels...
and at the global level, because the inner workings of these systems and the expenditures within these systems are largely unknown to others, and often unknown to their stewards.

3. The knowledge engineering and knowledge management aspects, (i.e., identifying the keepers of heuristics, information and knowledge elicitation, its hierarchical structuring and visualization) needed to identify infrastructures are challenging. Methods to elicit complex domain knowledge from diverse groups are still only poorly developed and this area appears promising for further work. Once a multi-domain system is identified, ontology remains a valuable and promising mechanism for arriving at a common terminology and world-view by a diverse group of stakeholders.

4. Critical elements for an International Research Agenda emerged as:
(i) Many important characteristics of infrastructures are non-stationary. The intersections, interactions, interconnections and interdependencies may emerge and reveal themselves during a critical time window and then disappear. To identify and model infrastructures as multi-domain systems at various limit-states, actual operating infrastructures have to be observed and characterized. On the other hand, observing, measuring and perturbing multi-domain infrastructures for their system-identification require new observation, measurement and modeling strategies and analytical, experimental and IT tools. Development of a new and broad, multi-disciplinary knowledge-base on multi-domain systems engineering is in order (Hansman et al (2006)).

(ii) Field laboratories where researchers may observe, measure, analytically model and identify the behavior and performance of each of the human, natural and engineered elements and systems that make up infrastructures are critical. Current efforts towards modeling infrastructures are in their infancy. The dynamic interactions and interdependencies between different domains, asset groups and entire infrastructures should be identified and characterized based on concrete examples and when they reveal themselves before they may be simulated. Only after such an effort we would be able to formulate meaningful performance measures for each element, domain or asset group, and understand how local-level performances contribute to the regional and global performances of the entire system.

(iii) The linkages between infrastructure planning and asset management are critical. Recently there has been considerable attention to “smart growth” and the challenges in decisions regarding investment of scarce resources into highway construction versus public transportation. Such infrastructure planning decisions often prove to be far more consequential than decisions related to which bridge to repair or which highway to repave. Infrastructure planning and asset management decisions can no longer be segmented or divorced from one another. Asset management research should include exploring how the portfolio of infrastructure assets under management could change if various mass transit options were given equal consideration, and if we accept removing roads and highways from service as an option. As part of asset management we should be able to compare the energy costs, air quality impacts, noise, and other impacts of moving freight by rail and water as opposed to moving freight by truck. We cannot separate asset management and sustainability decisions from each other.
(iv) Life-cycle cost analysis of infrastructure projects both during planning and during operation should incorporate many hidden costs, intangible benefits and uncertainty that are not currently incorporated. For example, costs should include the energy embodied in the sourcing, construction, operation, maintenance, and use of a particular transportation infrastructure, as well as the value of the materials embodied in that infrastructure if they were not to be used for this purpose. Social issues related to economical fairness, environmental justice, democracy, civic participation, cultural identity and heritage cannot be excluded from benefit-cost analysis. Research on asset management should more explicitly recognize the importance of social systems in setting performance standards for infrastructure assets, and making decisions about the most sustainable and cost-effective way of meeting these standards. Effective mechanisms promoting long-term, effectively coordinated and integrative research by social scientists and engineers on actual infrastructure systems are needed.

(v) There are daunting challenges to exploring how infrastructure systems, such as highway transportation, water and power distribution, may be transformed into field laboratories inclusive of their human, natural and engineered domains, and for developing the tools and application standards for their observation, measurement, modeling and simulation. Yet these are the prerequisites to meaningful asset management because there is currently too much uncertainty regarding how to estimate the true costs and benefits, and too many undiscovered system behaviors. Unless we identify multi-domain systems we cannot establish and collect element-level and asset-group level condition and performance data. Without such data we cannot identify all of the critical parameters and mechanisms that impact condition and performance along the lifecycle. Developing “performance metrics” with a multi-disciplinary approach including all stakeholders, and based on research on actual infrastructures is a prerequisite before we may reap the benefits of systems-level performance-based asset and risk management of infrastructures.

In terms of intellectual merit, why is this outcome notable and/or important?
The intellectual merit is in bringing actual infrastructure owners and researchers from many cultures and disciplines and reaching consensus on the importance of asset management research. The need for a new multi-domain systems discipline for infrastructure research had been observed by applied systems researchers at MIT and CMU some years ago. The Workshop concurred with this observation and furthered this view by advocating coordinated multi-disciplinary research on actual infrastructures as field laboratories as a means of growing and advancing this new discipline and meaningfully applying the applied systems research.

In terms of broader impacts, why is this outcome notable and/or important?
Just as Einstein formulated the Theory of Relativity by observing and conducting thought experiments on clock towers at Zurich, system engineers and scientists have to be exposed to actual infrastructures and individuals who are currently responsible for managing these before we may expect any rewards from the recent and current research on applied systems engineering for advancing infrastructure planning, engineering and management.

Does this highlight represent transformative or potentially transformative research?
Yes, since the highlight illustrates the need to transform the current civil and environmental engineering education and practice into an integrative, multi-domain systems framework in order to serve the societal needs related to transportation, water and power infrastructures.

Does this highlight represent Broadening Participation?
Yes, multi-domain infrastructure research, especially for the renewal of urban infrastructure offers unusual potential for broadening participation in related education and research from all segments and backgrounds.

Are there existing or potential societal benefits of this research?
Yes! It is not far-fetched that we may save ~25% of the current Hundreds of Billions of Dollars being spent on infrastructure while also greatly improving our quality of life as a society if and only if we could recognize the importance of investing into asset management research and applications. The Nation is currently grappling with the selection and prioritization of infrastructure projects that should be included in an economic recovery initiative. Now is the time for a formal NSF, FHWA, EPA, NIST partnership to foster a new era of merit-based, multi-domain infrastructure systems research, development and applications.