# TRANSPORTATION NETWORKS PROGRAM OF THE MID-AMERICA EARTHQUAKE CENTER

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**ABSTRACT:**

This paper describes the Transportation Networks Program of the MAE Center and some of the research activities that are being pursued to achieve the objectives of this Program. The transportation network includes substantial portions of the nation's highway and railroad systems, major waterways and shipping facilities on the Mississippi, Missouri, and Ohio Rivers, and airports that serve as hubs for the nation's airline and air freight operations. Extensive damage to any of these systems has national economic and security ramifications, and would seriously impact emergency response and recovery operations. As a result, the initial coordinated program in the networks track of the MAE Center concentrates on these transportation networks.

**KEY WORDS**

*Transportation, Lifelines, Earthquakes, Vulnerability, Economic Loss, Retrofit, Bridges, Locks*

## INTRODUCTION

The Mid-America Earthquake (MAE) Center (http://mae.ce.uiuc.edu) assembles researchers from seven core institutions across six states with complementary talents in seismology, geophysics, geotechnical and structural engineering, social science, economics, risk assessment, and urban planning. The Center's focus is directed at the infrequent, but high consequence, earthquake hazards of the eastern and central United States. All research efforts are coordinated through two parallel programs on *facilities* and *networks* that will evolve over the lifetime of the Center. (Education, implementation, outreach, and collaboration activities are also integrated among the core institutions.)

The Mid-America region hosts an extensive transportation network that serves local, regional, and national interests. Highway and railroad traffic across the major rivers is constrained to relatively few long-span crossings, e.g., there are only nine interstate highway crossings of the Mississippi River. The national economic consequences of just a few outages would be extreme. Experience suggests that these crossings are vulnerable; structural damage, loss of bearing support, damage to approach spans, and loss of foundation support due to liquefaction and lateral spreading may occur.

Some of the largest liquefaction-prone deposits in the nation lie along rivers in the central United States. Damage to river, port, and waterfront structures due to liquefaction, lateral spreading, earth pressures, and subsidence of soils, as well as vibrational damage caused to structures, could cripple the transport of goods across the central United States and impact shipping and distribution systems nationally.

Major airports in the region serve as hubs of many passenger airlines and air freight operations. Lambert International Airport in St. Louis is one of only two passenger hub airports in the U.S. that are in areas of moderate to high potential seismic activity. Federal Express operates its major hub airport in Memphis. Airport control towers, fueling equipment, and terminal support systems are subject to vibrational damage and operation of runways may be disrupted by liquefaction, lateral spreading, and subsidence of soils. Loss of service at these facilities could have major repercussions nationally.

The consequences of failure of a transportation system from earthquake shaking could involve: (a) direct loss of life due to collapse or structural failure, (b) indirect loss of life due to an inability to respond to secondary catastrophes, such as fires, and/or provide emergency medical aid, (c) delayed recovery operations, (d) release of hazardous materials and environmental impact, (e) direct loss of property and utility service, (f) economic losses due to interruption of access to a transportation system, and (g) disruption of economic activity across the region and nation. The Transportation Networks Program will not yield substantive results if all of these items are addressed, since funding constraints would limit the depth of coverage. The program will therefore examine in depth the disruption of economic activity (item g), since losses to the national network of transportation are expected to be a significant percentage of the total loss expected when the next major earthquake strikes in Mid-America.

## PROGRAM OBJECTIVES

The primary objectives of the Transportation Networks Program are to: (a) assess vulnerabilities and estimate potential economic losses in the national transportation network, and (b) identify effective retrofit methods for reducing these potential losses. The immediate goal of the program is to focus on the Mid-America earthquake problem. However, the methods developed should also apply to regional transportation networks in other parts of the nation and world.

Because the subject of national transportation networks is broad, priorities have been established among the various modes of transportation. Substantial discussion has taken place within the Mid-America Earthquake Center Leadership Team and at an End User Focus Group Meeting in St. Louis on January 8, 1998, that was attended by representatives of the major transportation modes, including highways, railways, waterways, and airways. Based on this meeting, highway and waterway systems were given the top priority over railway and airway systems. Since these modes interconnect, the total national shipping system depends on all four modal networks. The program will address all of them, but the depth of coverage will be greater for highway and waterway modal networks than for railways and airways.

## PROGRAM DESCRIPTION

The Transportation Networks Program is outlined in the flow chart in Figure 1. Relations between individual research (rectangular shapes) and implementation (octagon shapes) projects are shown to illustrate the integration and reliance of one project on another in the Transportation Networks Program. Projects representing the end products of the program are shown at the top of the flow chart. The phasing or sequencing of the projects is shown on the timeline for the Transportation Networks Program in Table 1. A more detailed flow chart and timeline are presented in the MAE Center website (http://mae.ce.uiuc.edu).

Projects in structural and geotechnical engineering will combine with those in hazard identification and economics to study the vulnerability of the national transportation network and develop improved methods of rehabilitation to help reduce earthquake losses on a national scale. Nonlinear force-deflection relations for specific nodes of transportation modal networks (e.g. bridges, port facilities, lock and dam structures) will be identified through structural engineering research. These relations will serve as needed input for development of fragility curves that will define damage probabilities for various ground motion intensities. Synthetic ground motions will be developed and serve as the basis for these fragility curves. Fragility curves for the critical nodes of a modal network will then serve as input for development of network fragility models. Network fragility will then be subsequently used to estimate economic losses.

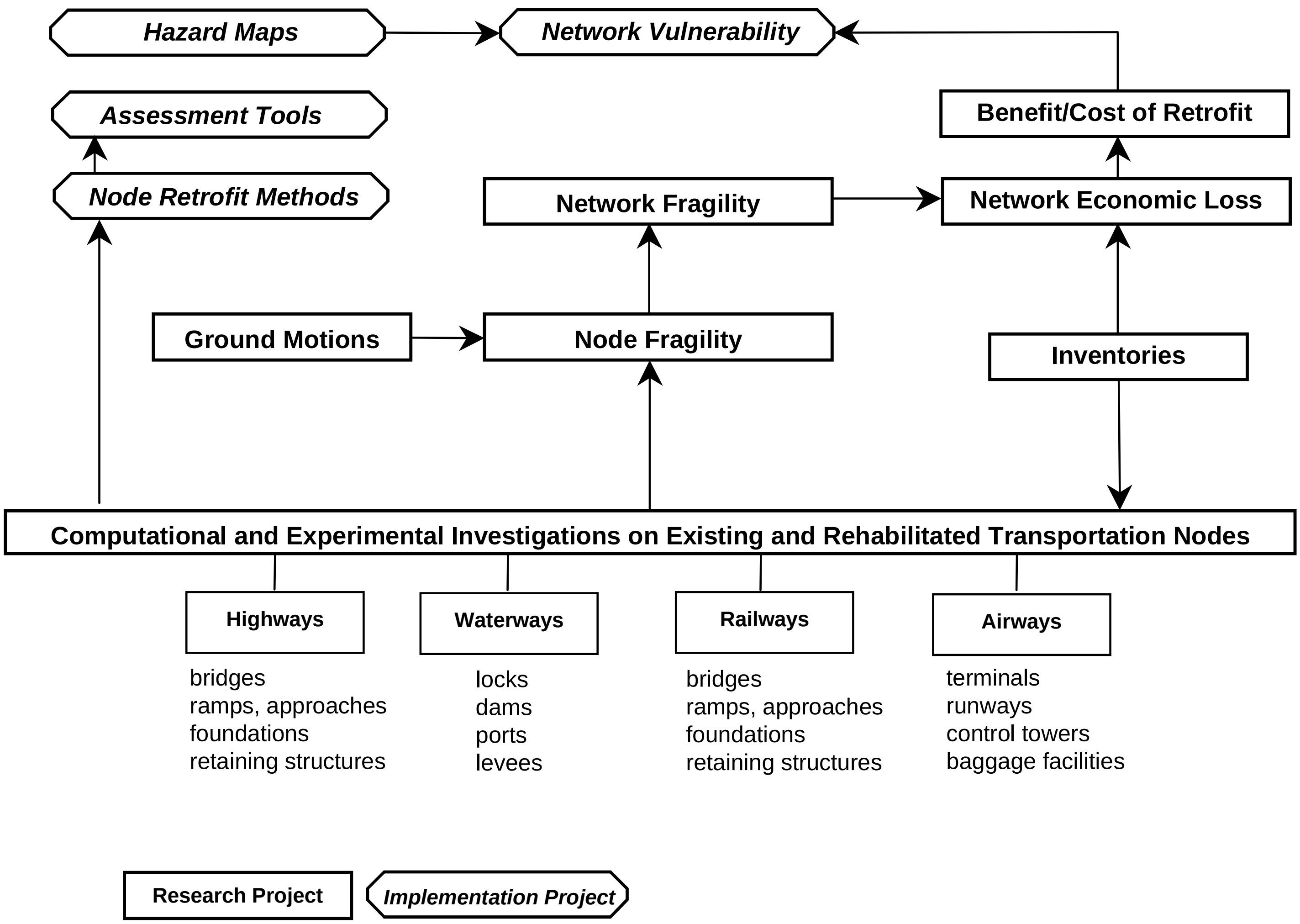


Figure 1. Coordination of Tasks for Transportation Networks Program

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The impact of retrofitting a particular group of critical nodes on reducing national economic loss will be studied by examining the differences in network loss estimates for systems that have been retrofitted and those that have not been retrofitted. Information on economic loss will also be used with new hazard maps to investigate national network vulnerability. Structural engineering assessment tools and retrofit methods will also be provided to practicing engineers as a direct product of the engineering research. A general overview of the projects in the Transportation Networks Program is given in the following subsections according to technical discipline. A detailed task statement for each project is given on the MAE Center website.

## INDIVIDUAL RESEARCH PROJECTS

The following research projects are planned for the Transportation Networks Program. The sequencing of the projects and the investigator(s) conducting the research are shown in Table 1.

### Structural Engineering Projects

Research collaboration will be developed with state departments of transportation in a multi-faceted program to improve the safety, performance, and reliability of major bridges. Using ground motions that reflect regional seismicity, the performance of bridges crossing major rivers will be studied with an aim to develop feasible rehabilitation schemes. Response of bridge structural systems will be researched through laboratory and field testing of components, as well as full-scale structures in the field. Computational models will be developed for seismic analysis and evaluation of existing and retrofitted bridges crossing major rivers. This research will involve both highway and railway bridges. The models will be verified with experimental data from laboratory and field tests. The computational models will also be made available to structural engineers in a user-friendly format for assessment purposes. The highway and railway research is being conducted in cooperation with the Illinois Department of Transportation and American Association of Railroads, respectively.

A multi-state inventory of highway and railroad bridges will be compiled from state departments of transportation and railroad companies, and will be entered into a GIS database. Maps showing potentials for bridge failure will be developed for use by policy makers and emergency response officials. The costs and benefits of retrofitting to various performance levels will be explored. Methods will be developed for establishing retrofit priorities considering network reliability theory. In addition, new retrofit techniques will be sought, e.g., the use of innovative materials or systems to cost effectively retrofit bridges in areas of infrequent, but high consequence, earthquakes.

### Geotechnical Engineering Projects

The high liquefaction potential in river basins creates a unique vulnerability for bridges and other transportation facilities in Mid-America. A multidisciplinary investigation will develop new techniques for assessing site-specific liquefaction potential under major river crossings in Mid-America and its impact on the structural response of bridges. Analytical and insitu research will be conducted to investigate the effectiveness of remedial measures for bridge foundations. This research will lead to new and more cost-effective techniques for improving bridge foundations and/or foundation soils, to reduce structural vulnerabilities caused by liquefaction and earthquake shaking.

Locks, dams, and port facilities are integral parts of the navigable waterways in the Central United States. Seismic response of river and port facilities will be examined with computational models that represent interactions between the structural systems, soil, and water. In particular, the seismic performance of concrete lock structures and waterfront facilities will be investigated. Soil-fluid-structure interaction analyses will be used to estimate the response of major lock systems to seismic motion. Nonlinear soil behavior, separation, gapping, and energy dissipation mechanisms will be considered in the analyses. As a result, improved analytical procedures will be developed to assess seismic performance of shipping locks. Seismic performance of a lock system will be investigated for site specific ground motions as determined from the hazards studies. The analytical results will be verified using case histories and/or physical model tests. This research is being conducted in collaboration with the U.S. Army Corps of Engineers.

Methods for assessing seismic performance of waterfront facilities will also be developed. Improved analytical models will be developed for estimating seismic earth pressures and stability under vertical ground motions. Estimated bedrock acceleration histories will be used to predict surface ground motions using multi-dimensional site response analyses. Anticipated seismic performance of lock and waterfront structures will be incorporated into the fragility models to assess vulnerability of the national transportation network. This research is also being conducted in collaboration with the U.S. Army Corps of Engineers.

Airport pavements can be vulnerable to soil liquefaction. The susceptibility of pavements to ground movements will be studied using a collaborative effort between the Mid-America Earthquake Center and the FAA Center for Excellence at the University of Illinois. The synergism of earthquake engineers and pavement researchers will provide a unique blend of talent that is necessary for this problem. In addition, the seismic behavior of structural and non-structural systems in an airport terminal will be studied. This research is being conducted in cooperation with Lambert International Airport in St. Louis and the Memphis International Airport.

**Societal Response and Economic Projects**

Network theory concerns the reliability with which a given network will operate under various scenarios by considering redundancy in the network and probabilities that a sufficient number of its nodes and links will be operable during any time frame. Analyses of network reliability allows key points of vulnerability to be established, along with probabilistic descriptions of corresponding losses. Evaluations will be made of performance characteristics for various bridge, pavement, waterway, and airport facilities. These evaluations will be incorporated into network reliability models. Economic loss estimates based on probabilities will be determined, considering the possible damage states to these facilities. Interactions, such as flooding that results from liquefaction of levees or the failure of water retaining structures, will also be considered.

To accomplish this research, GIS-based inventories of critical transportation facilities will be assembled. Structural characteristics will be identified in a detail necessary to guide future research efforts and to support subsequent damage modeling. Basis capacity and traffic flow information critical to estimating the economic impact associated with their damage will also be collected. Descriptive statistics will be produced describing the number, value, size, function, and structural characteristics (e.g. steel span girder bridge built in 1955) of these facilities by location. A regional economic model will be developed based on the GIS inventory that is sensitive to commodities and personal travel on all modes of the transportation system. National economic impact due to loss of key transportation infrastructure components will be evaluated.

Anticipated economic losses will be estimated based on the inventory information, the network fragility curves, and the information on regional economic flows. The economic loss estimates will be caused by a disturbance of the national network as a result of a scenario earthquake event in Mid-America and will be based primarily on interruptions in shipping and business. The vulnerability of the national transportation network to an earthquake event in Mid-America will be studied using the previously described loss estimation model and hazard maps. The fragilities of and losses to various modal networks will be combined in an inter-modal model representing the national transportation network. This task will serve as a capstone project that will summarize the results of the entire Transportation Networks Program, and will be completed in Year 5.

Mitigation measures necessary to assure various levels of operability of these networks will be defined. Cost-benefit analyses will be performed to prioritize actions. The costs of achieving various levels of network reliability will be compared with corresponding reductions in property damage and business interruption losses, to establish optimal levels of rehabilitation. Methodologies developed for assessing business interruption losses will be applied in future programs on industrial and commercial facilities as well as for telecommunication and power networks.

**Risk and Reliability Projects**

To support the study of social and economic consequences of damaging earthquakes and to develop reliable economic assessment tools for evaluating potential seismic rehabilitation measures, it is necessary to quantify anticipated damage to transportation network nodes and systems in terms of predicted ground motion intensities, via fragility curves. The development of fragility curves will synthesize anticipated ground motion characteristics with anticipated network damage levels. The damage levels will support the development of cost-benefit models for use in the decision-making process. Damage probabilities will be determined for various intensities of ground motions for specific nodes of transportation systems. Data on nonlinear force-deflection properties of those nodes studied in depth with structural engineering research projects (e.g. bridges and waterway facilities) will be used to develop these fragility curves along with synthetic ground motions developed in accompanying risk and reliability projects. Fragility of national transportation networks will be determined using the previously described node fragility curves. Network fragility will be based on a scenario earthquake occurring at various locations in Mid-America. These network fragility models will be used to quantify economic loss estimates and study the cost-benefit of retrofit.

## SUMMARY

The Transportation Networks Program of the Mid-America Earthquake Center has developed an integrated, multi-disciplinary approach to assess the vulnerabilities, and estimate potential economic losses, in the national transportation network due to an earthquake in the eastern and central United States. To accomplish this integrated and multi-disciplinary research, investigators from seven core institutions with expertise in seismology, geophysics, geotechnical and structural engineering, social science, economics, risk assessment, and urban planning have been assembled. The methods developed by the Transportation Networks Program of the Mid-America Earthquake Center will be applicable to transportation networks in other parts of the world.