Argonne NATIONAL LABORATORY

... for a brighter future

In cooperation with the

U.S. Department of Transportation

Northern Illinois University

and the

University of Illinois

U.S. Department of Energy

UChicago Argonne LLC

A U.S. Department of Energy laboratory managed by UChicago Argonne, LLC

TRACC

Transportation Research and Analysis Computing Center

Presented by: ***David P. Weber, Ph.D.***
Research Program Director
and TRACC Director
Energy Systems Division
Argonne National Laboratory
dpweber@anl.gov
http://www.anl.gov/TRACC/

In cooperation with the U.S. Department of Transportation, Northern Illinois University and the University of Illinois

DEPARTMENT OF TRANSPORTATION UNITED STATES OF AMERICA

Argonne: One of DOE's Largest Research Facilities

- Located 25 miles from the Chicago Loop, it was the first national laboratory, chartered in 1946
- Operated by the University of Chicago for the U.S. Department of Energy
- Major research missions include basic science, environmental management, and advanced energy technologies
- About 3,000 employees, including about 1,000 scientists and engineers, of whom 750 hold doctorate degrees
- Annual operating budget of about $475 million (80% from DOE)
- Since 1990, Argonne has worked with more than 600 companies and numerous federal agencies.

The Opportunity: Create a National User Facility to Meet DOT Advanced Computation Needs

- DOT and DOE transportation research programs, private industry, and state and regional transportation agencies are moving to simulation-based design and analysis for improvements in efficiency, economics, and safety
- Higher fidelity analysis in areas such as crashworthiness, aerodynamics, combustion, thermal management, weather modeling, and traffic simulation require access to state-of-the-art computational and visualization facilities
- Argonne has the necessary expertise in high-performance computing and transportation system analysis to provide both a national HPC user facility and a focal point for computational research for transportation applications

TRACC – High-Performance Computing for Transportation Research and Applied Technology

Thermal Management *

Crashworthiness *

Bridge Hydraulics*

Occupant Safety Assessment and Crash Biomechanics *

Bridge Structural Analysis *

Aerodynamics *

Intelligent Transportation Systems*

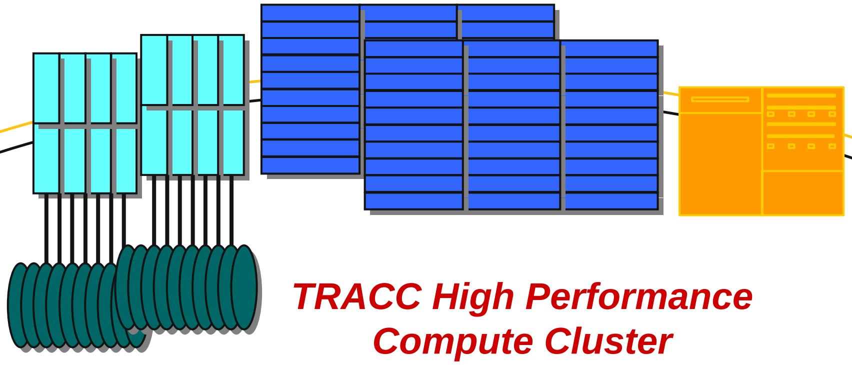
Road Weather Research *

Traffic Modeling *

** Additional Information/slides hyperlinked*

TRACC Is Being Built as a National DOT Supercomputer Facility

240TB Global Parallel File System Disk Storage



LTO-3 160TB Archive/Backup Tape Storage

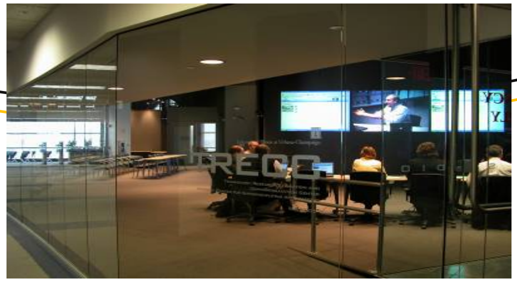
TRACC High Performance Compute Cluster

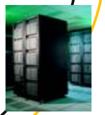
Linux Networx LS-1 512 core /1 28 compute nodes

(two dual-core AMD 2216 Opteron CPUs 4GB of RAM)

High-bandwidth connectivity to the Illinois Wired/Wireless Infrastructure for Research and Education (I-WIRE) and Internet2.

TRECC Visualization, Virtual Reality, Access Grid, and Digital Conferencing



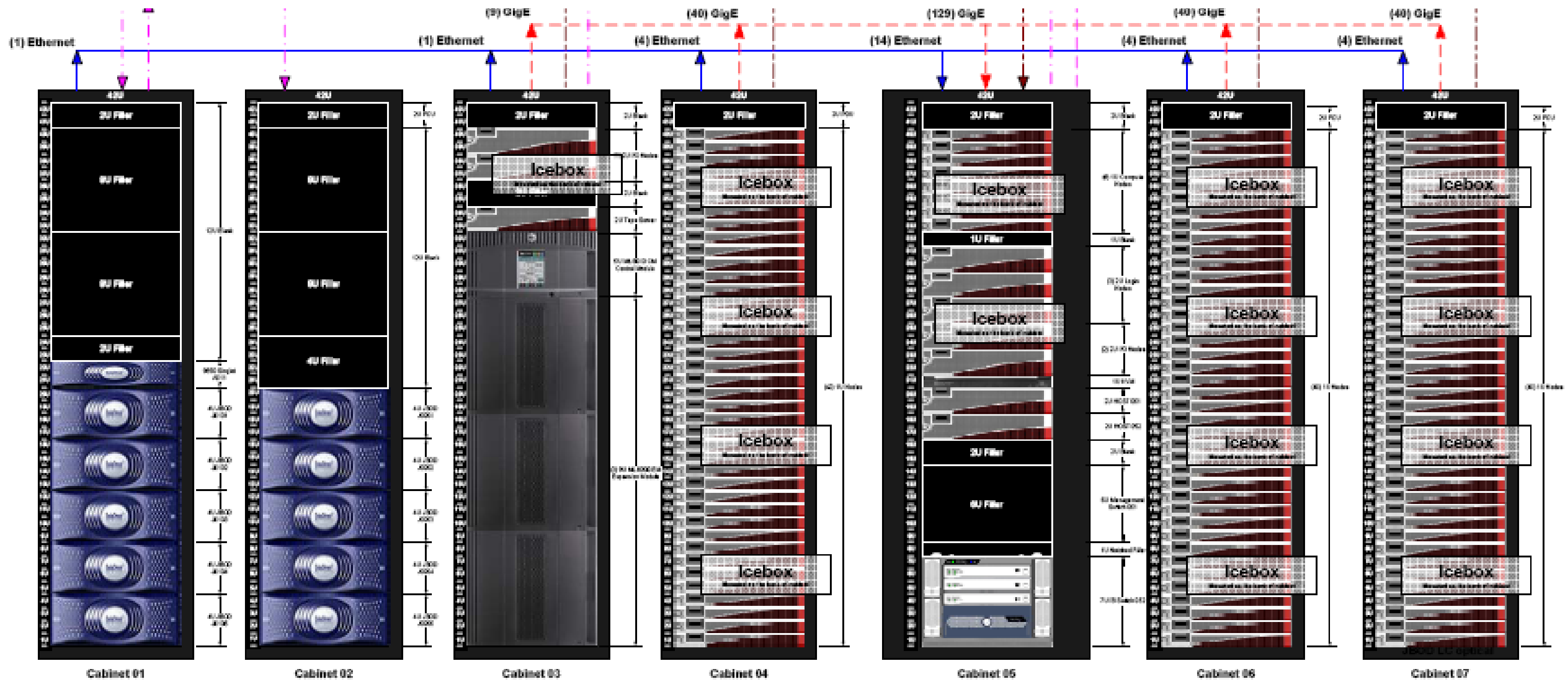


Argonne Nuclear Enginering Division Linux Cluster 10Gb Dedicated Access

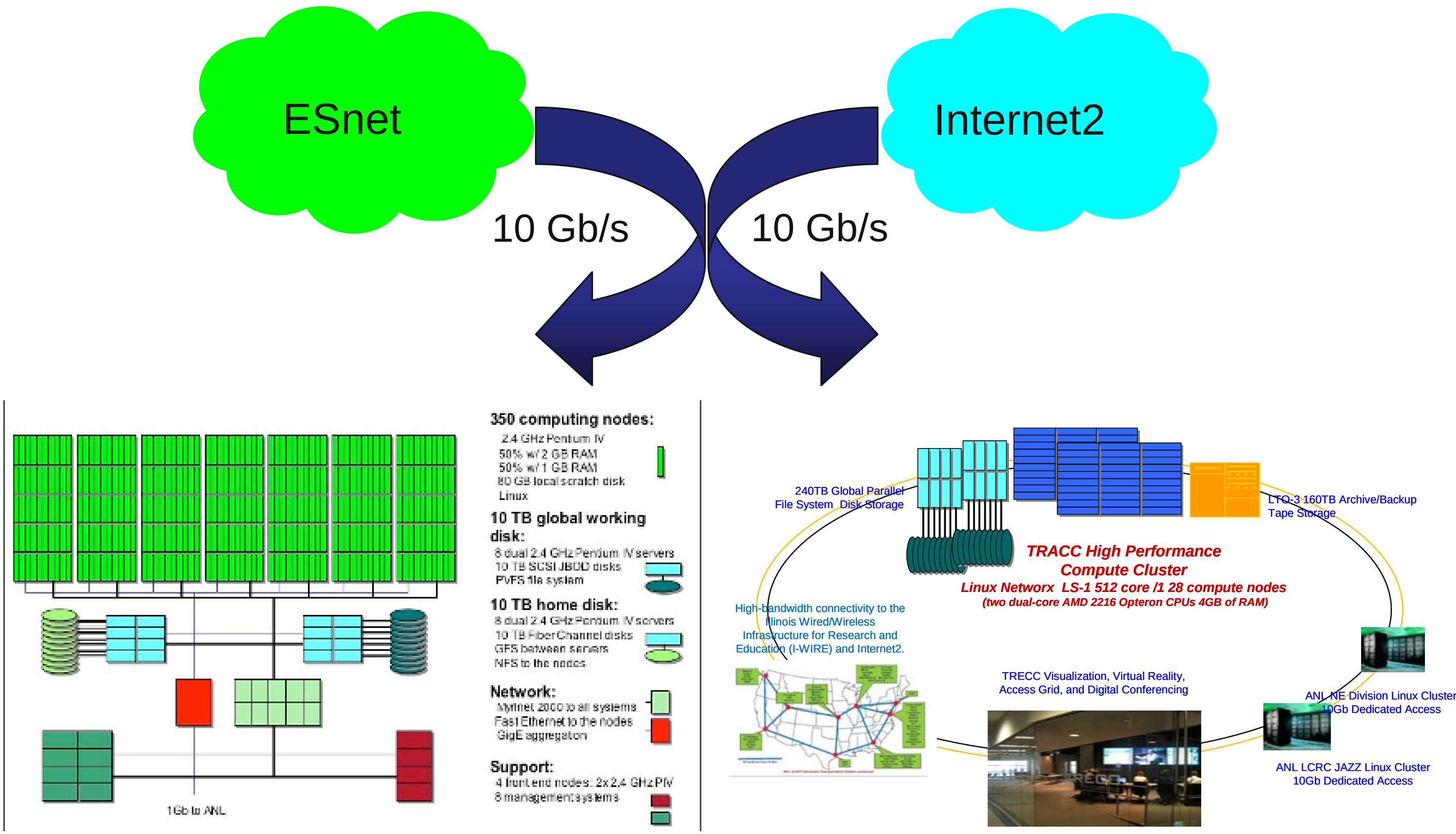
Argonne LCRC JAZZ Linux Cluster 10Gb Dedicated Access

TRACC HPC Configuration Diagram

The TRACC computational cluster is a customized LS-1 system from Linux Networx consisting of 512 core 128 compute nodes, each with two dual-core AMD 2216 Opteron CPUs and 4GB of RAM, a DataDirect Networks storage system consisting of 240TB of shared RAID storage, expandable to 750TB, a high-bandwidth, low-latency InfiniBand network for computations, and a high-bandwidth Gigabit Ethernet management network. The system will also include the highest-performance compiler and MPI library available for the AMD Opteron architecture. with a peak performance of ~2 TFlops

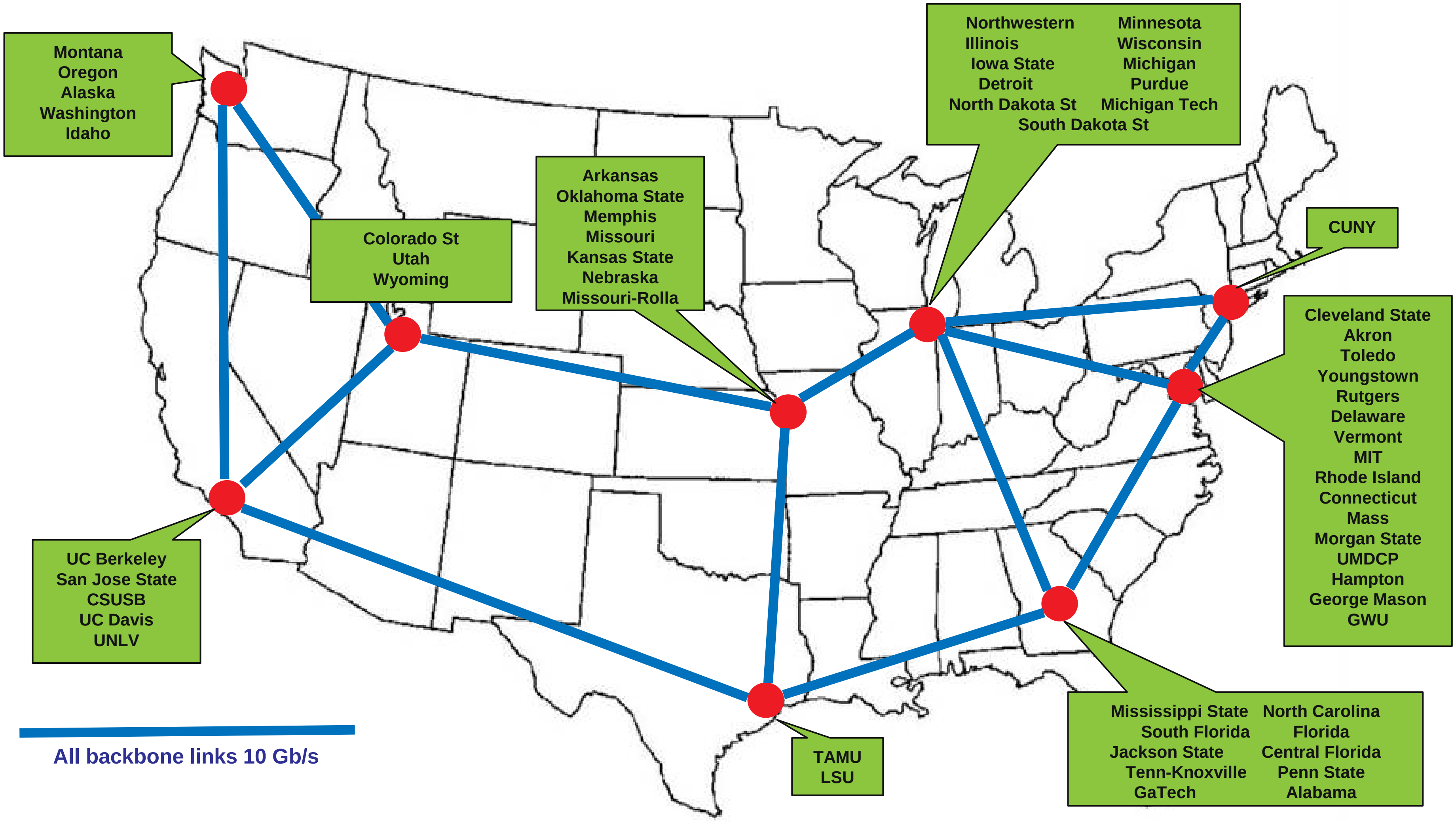


Argonne HPC External Access



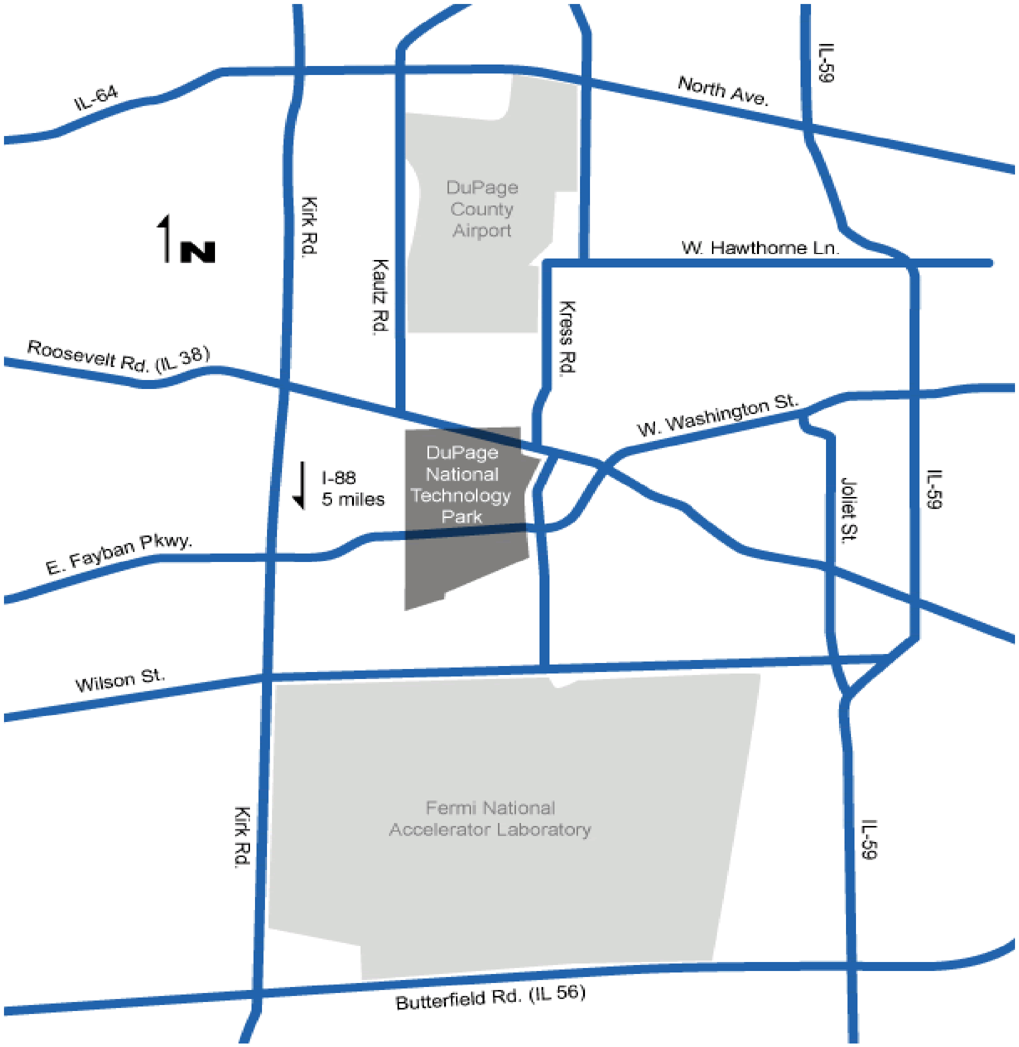
Jazz- aggregate access 2 Gb/s

Internet2 Network



94% of DOT University Transportation Centers connected

DuPage National Technology Park (DNTP)



Argonne/DOT Transportation Research and Analysis Computing Center (TRACC) at DNTP

Communications Technology at DNTP

University Partners (Illinois and NIU) at the DuPage Tech Park Add Expertise

- Outreach
- Education
- Tech Transfer
- Connectivity

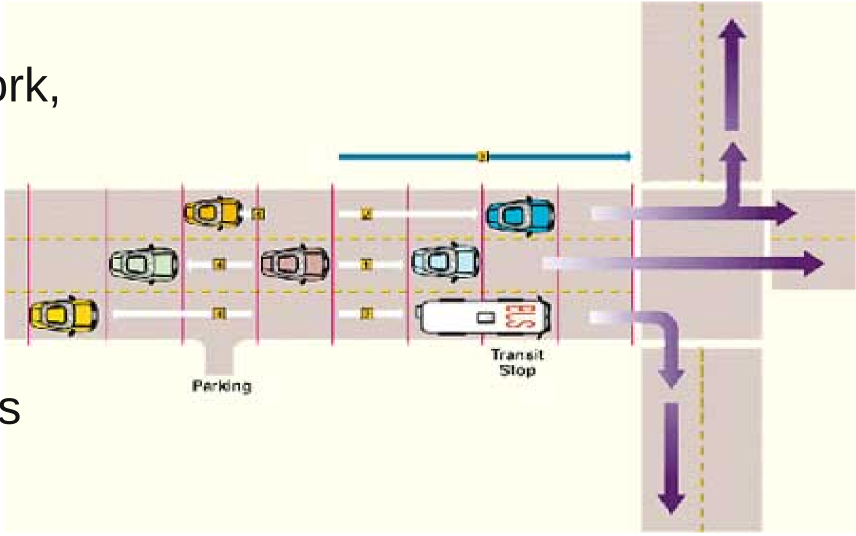
DuPage Airport Authority Flight Center
Interim TRACC Facilities

Initial DOT Application Areas

- Traffic Modeling and Simulation and Emergency Transportation Planning
- Multidimensional Data Visualization
- Computational Fluid Dynamics for Infrastructure Analysis
- Computational Structural Mechanics for Transportation Applications

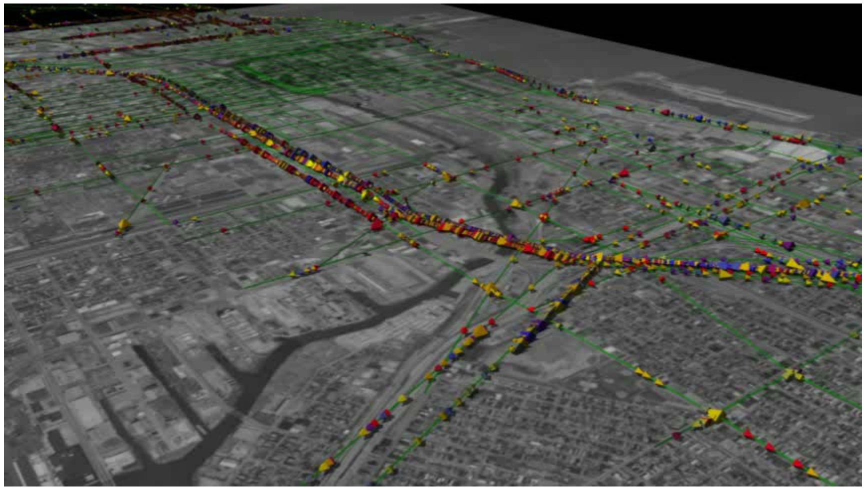
Traffic Modeling and Simulation and Emergency Transportation Planning: TRANSIMS

- **TR**ansportation **AN**alysis **SIM**ulation **S**ystem
  - Developed under multiyear programs by DOT, DOE, and EPA and available for large-scale deployment
- TRANSIMS represents a new generation of activity/agent-based models
  - Creates a virtual representation of an entire region
  - Simulates second-by-second movement of all travelers and vehicles
  - Incorporates activity-based modeling
  - Analyzes traffic over the entire network, including local streets and highway ramps
- Helps planning analysts
  - Mitigate congestion
  - Develop emergency evacuation plans
  - Analyze air quality issues

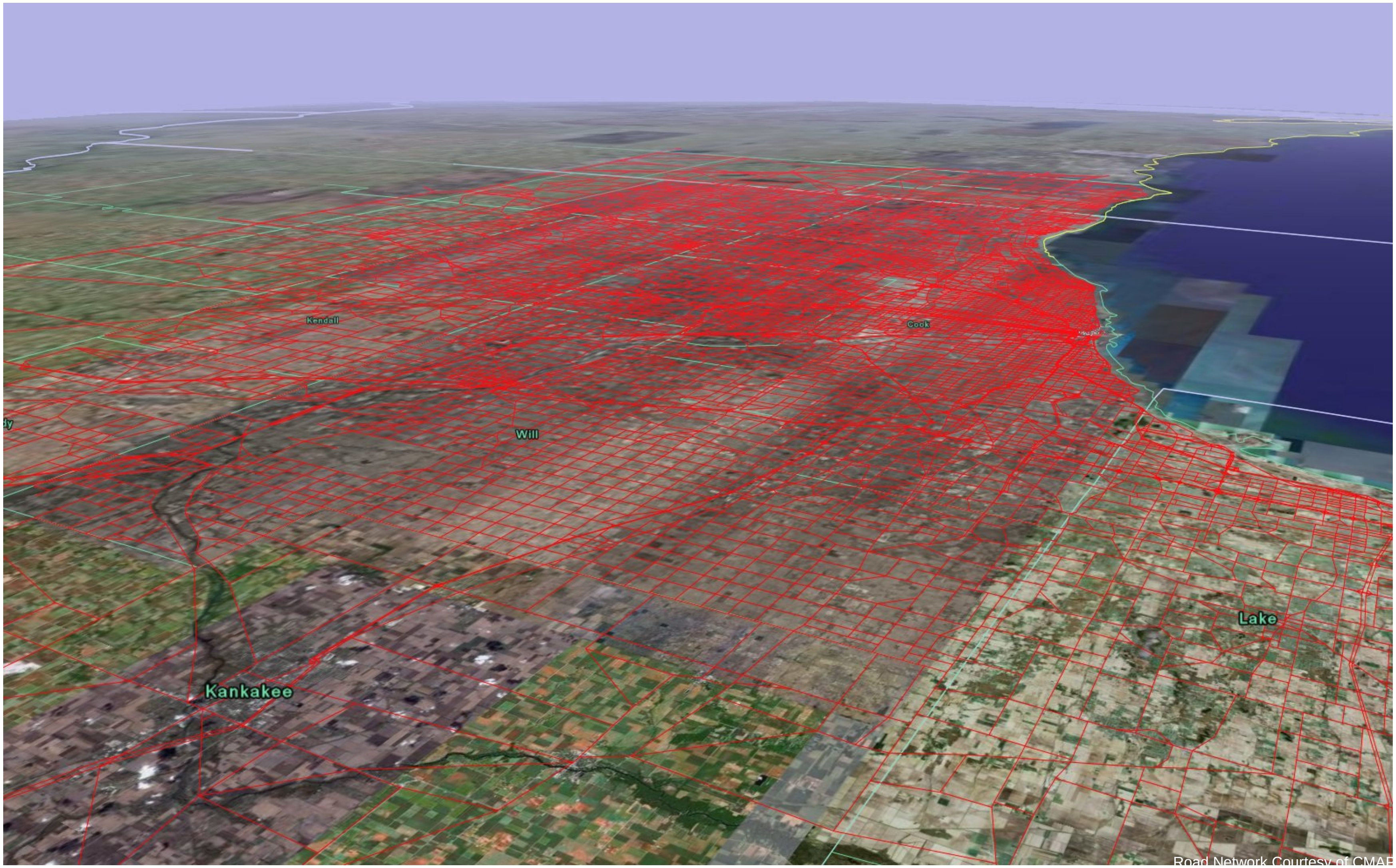


TRANSIMS Application

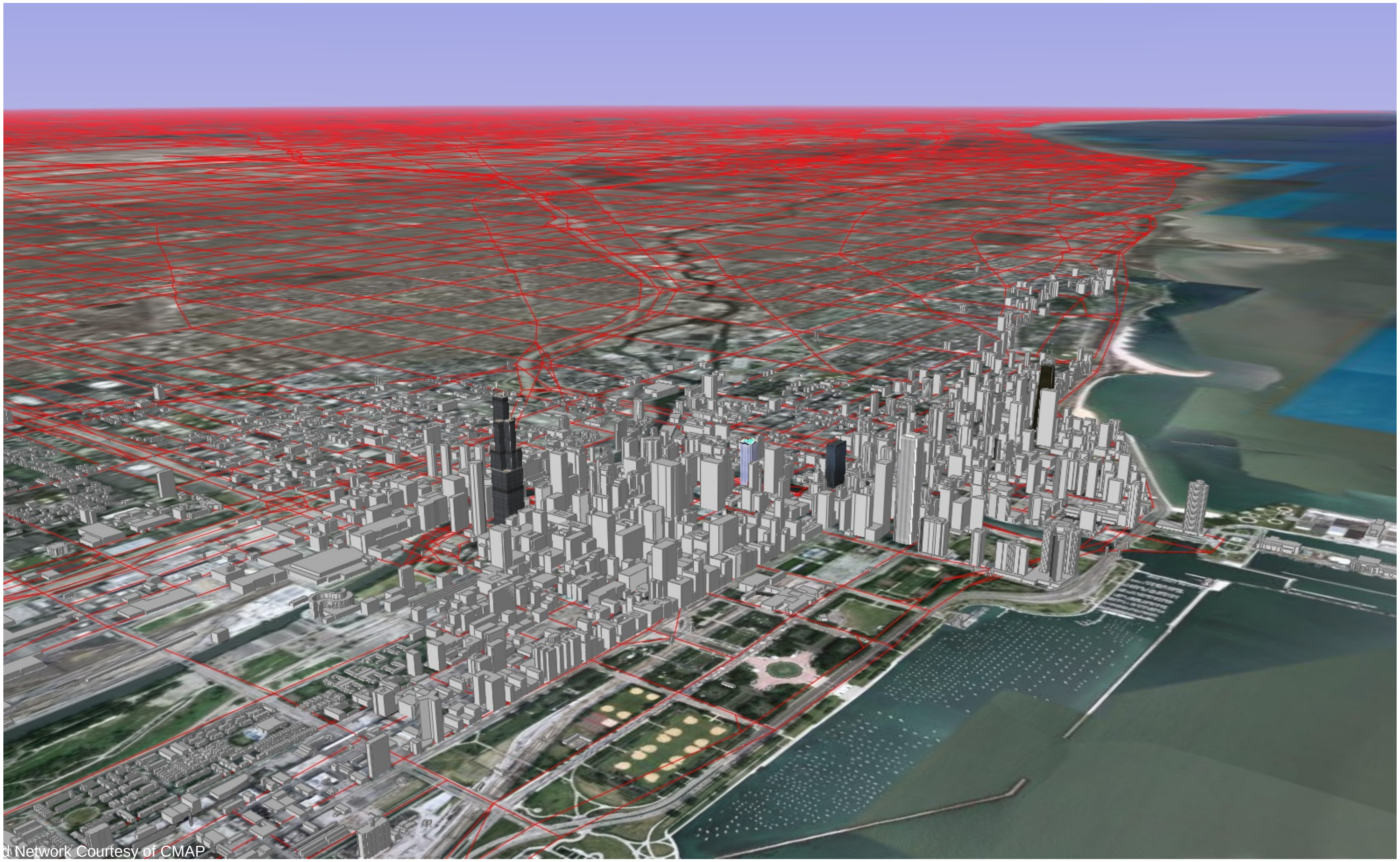
- Development of a detailed Chicago Metropolitan Area (CMA) model for TRANSIMS
  - TRANSIMS employs a new paradigm in traffic planning by tracking individuals during their daily travel
  - Extensive routing and microsimulation using cellular automata provides a high-fidelity simulation
- Detailed road network has been provided by CMAP (Chicago Metropolitan Agency for Planning)
  - This includes detailed trip data by purpose and diurnal distribution, as well as complete transit information



Chicago Metropolitan Area Road Network (in red) Chosen for the Chicago TRANSIMS Model



Road Network, from CMAP, is Very Fine-grained in Chicago Downtown Area -- only Representative Major Roads for Outlying Areas

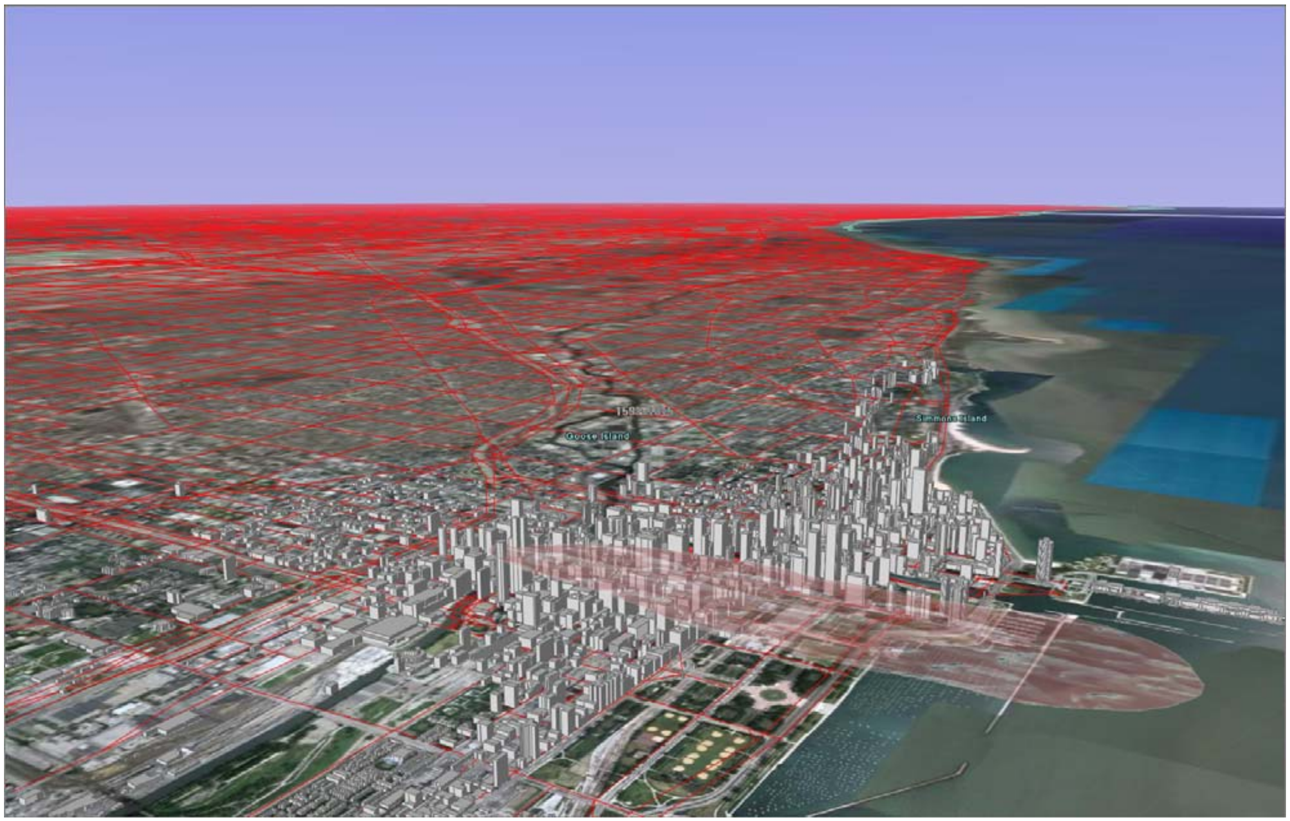


Parallelization of TRANSIMS

- Implemented by NIU (Northern Illinois University) under subcontract with Argonne National Laboratory
- Currently under development: A parallelized version of the router that will make use of multiple cores (multithreading) on single machines, as well as multiple computing nodes by use of MPI (Message Passing Interface)
- Future Plans: A parallelized version of the microsimulator, similar to the microsimulator in version 3. The code base has changed significantly, and multithreading needs to be utilized in addition to the previously employed MPI logic. Therefore, the parallelization will be likely very different from the previous implementation.
- All code development is being performed in very close collaboration with DOT and AECOM.

The ITTF Project

- Goal: Development of a model for the simulation of an emergency evacuation scenario in the Chicago Business District

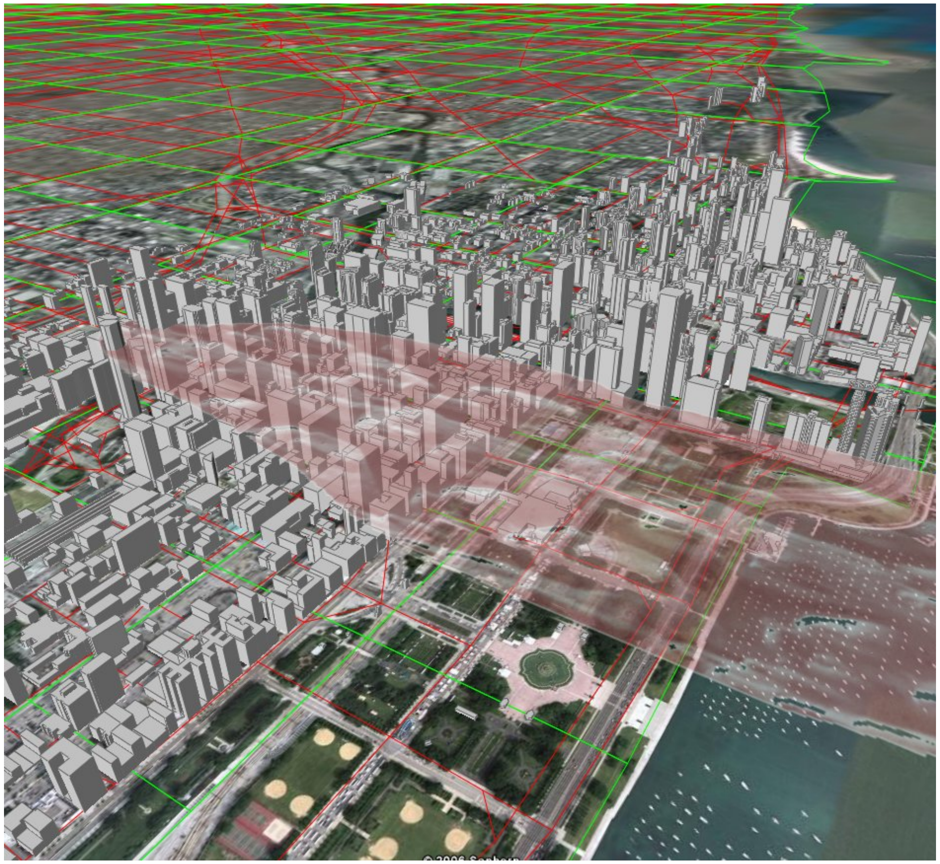


Sponsored by state and city agencies:

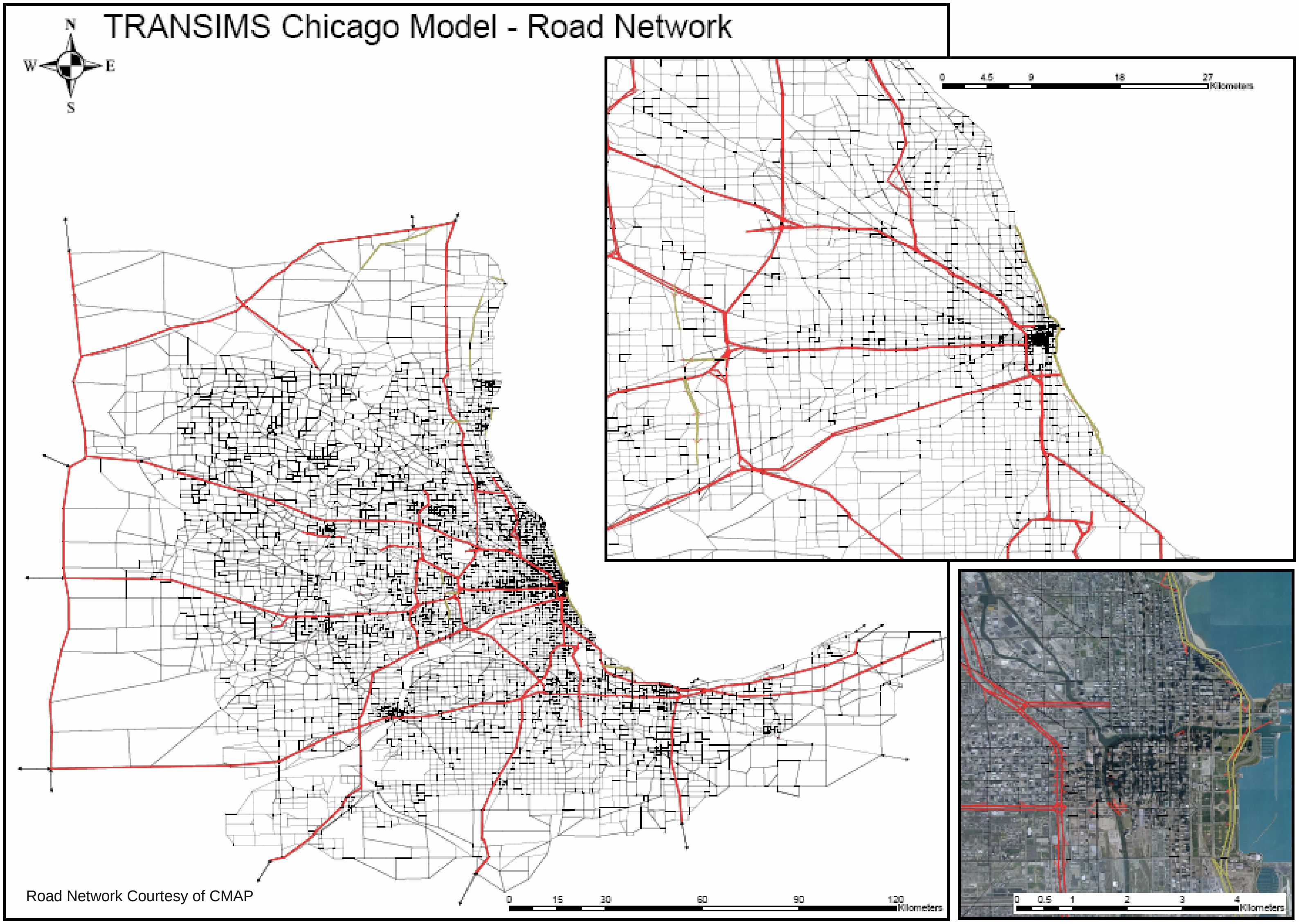
- **ITTF: Illinois Terrorism Task Force**
- **IDOT: Illinois Department of Transportation**
- **IEMA: Illinois Emergency Management Agency**
- **IEPA: Illinois Environmental Protection Agency**
- **DOT/FHWA: U.S. Department of Transportation Federal Highway Administration**

The TRANSIMS Model

- The Chicago Metropolitan Area is the largest freight-handling hub in the United States, and the third-largest in the world
- The chosen scenario postulates a radioactive release following an explosion at the base of the Sears Tower
- For security reasons, the scenario has been arbitrarily chosen and is not based on existing worst-case scenarios

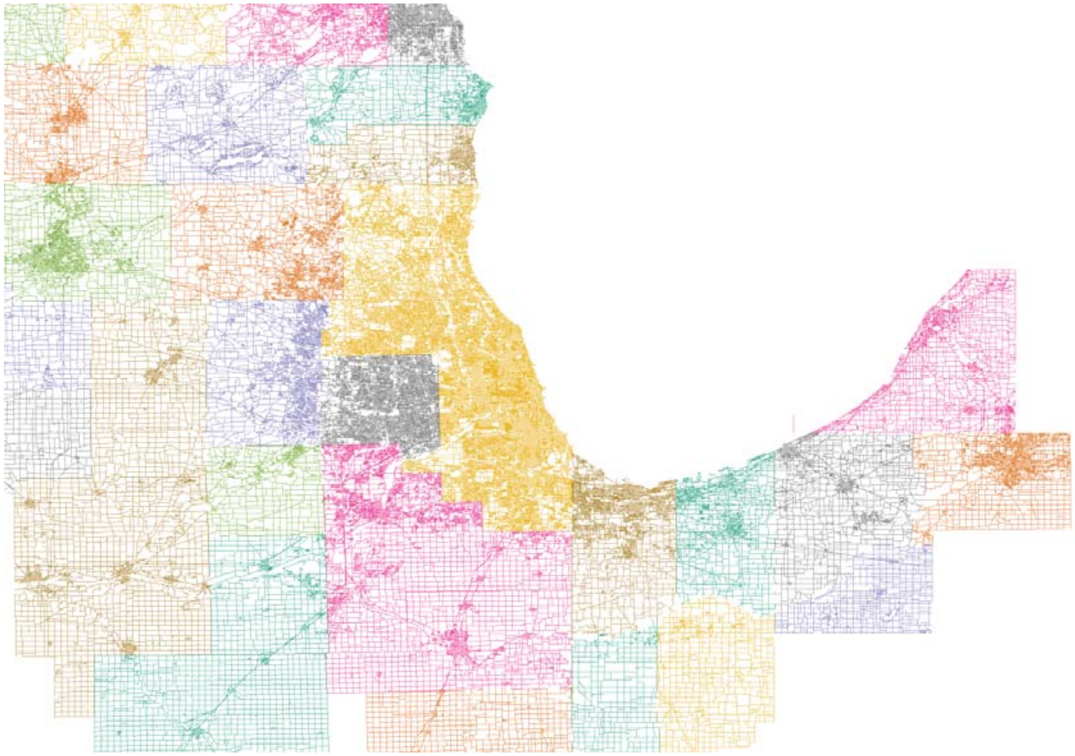


The Chicago Metropolitan Area Model



The TRANSIMS Model

- CMAP is supporting the project by providing their expertise and existing data in an ongoing effort. A subcontract for future work is under development.
- The road network, transit data, and trip data has been received from CMAP for use in the TRANSIMS model
- Area covers about 25,000 square kilometers
- The CMAP network is a reduced resolution network with about 22,300 links and 13,700 nodes
- Boundaries: Milwaukee in the north, Rockford in the west, and Gary in the south (GCM Corridor)



Computational Fluid Dynamics for Infrastructure Analysis

- Objective
  - Study computational fluid dynamics (CFD) based simulation techniques in support of hydraulics research for transportation applications
- Collaborators
  - FHWA Turner Fairbank Highway Research Center
    - Dr. Kornel Kerenyi – Office of Infrastructure R&D
  - Argonne National Laboratory
    - Dr. Tanju Sofu
  - University of Nebraska
  - Northern Illinois University
- Facilities and Software
  - Massively parallel computers at Argonne – JAZZ and TRACC
  - Fluent and Star-CD commercial CFD codes

Technical Objectives

- Availability of parallel computers and analysis capabilities of state-of-the-art CFD software provide an opportunity to complement the lab-scale tests with analysis support for hydraulics research
- When validated using the extensive experimental database, the CFD simulations can
  - Allow expanded parametric analysis
  - Provide a means of evaluating directly the effects of scaling
  - Broaden the scope of research capabilities to real life applications
- Applicability of the commercial CFD codes Star-CD and Fluent for open channel flow will be investigated, and the agreement between the code predictions and experimental data will be evaluated for various modeling options
  - Modeling practices that provide best match with experiments will be identified and reported

CFD for Open Channel Flow

- Assessment of applicable phenomena and identification of appropriate models
  - 2D vs. 3D to include the effects of channel wall
  - Appropriate flow profile at the inlet
  - Free surface
  - Surface roughness at the bottom surface
- Mesh sensitivity study
  - Evaluation of various meshing techniques based on tetrahedral, hexahedral, trimmed, and polyhedral grid structures
  - Determining the proper mesh size for grid-independent solutions
- Turbulence model evaluations: CFD's weakness!
  - Turbulence at high Reynolds number
  - Transition from laminar to turbulent flow

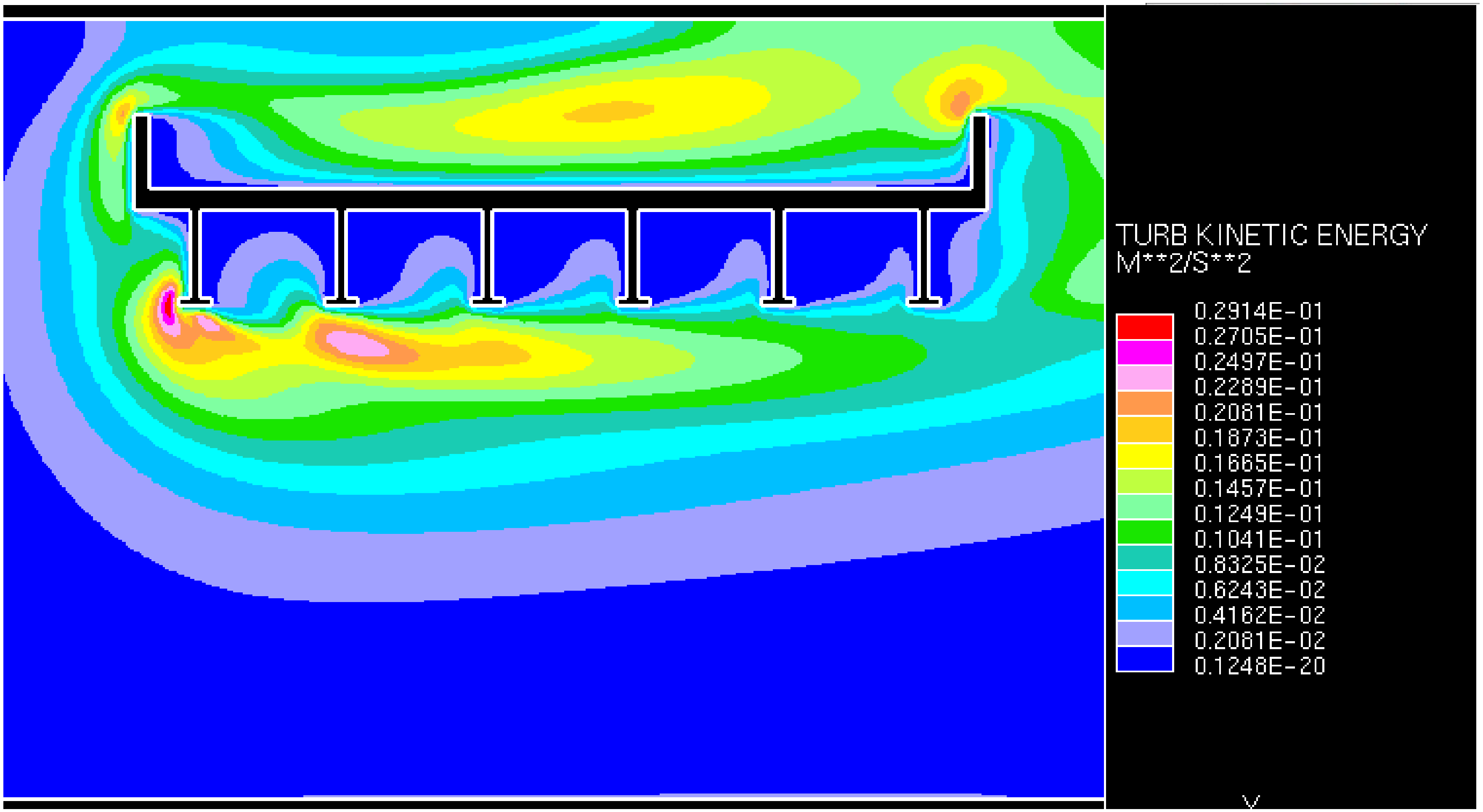
CFD for TFHRC Hydraulics Research

- Initial focus on bridge decks for validation of CFD models using data from TFHRC experiments
  - Analysis of lift and drag forces under flooded conditions
  - Optimization of bridge deck shapes to minimize scour
  - Evaluation of scour countermeasures using fluidic devices
- Future Research
  - Analysis of lateral/vertical wave forces and moments on typical bridge structures as a function of
    - *Vertical location relative to the still water level*
    - *Wave height and steepness*
    - *Wave period and spectra parameters*
  - Assessment of fish passage in culverts

Availability of TRACC Computing Center for Hydraulics Research

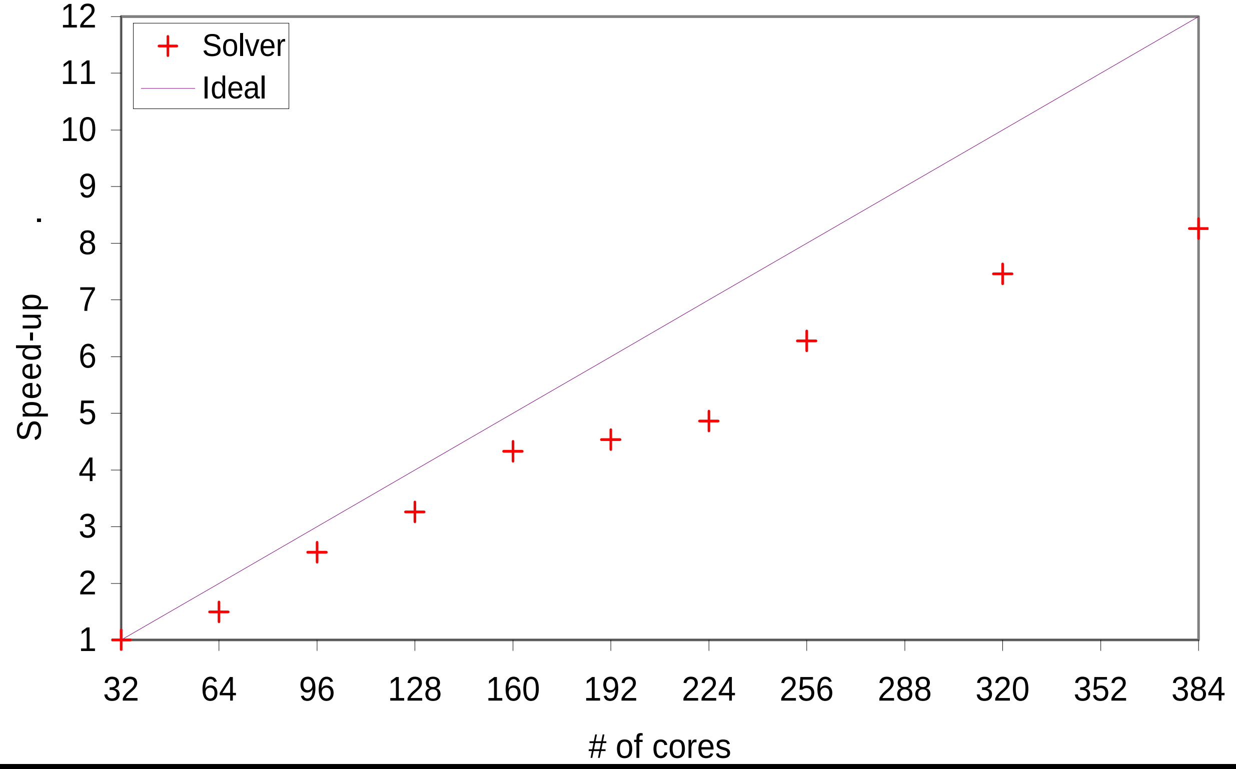
- Parallel CFD
  - Small models (millions of cells) can be studied with workstations
  - Large models (tens of millions of cells) require cluster of computers/processors
  - Very large simulations (hundreds of millions of cells) feasible on HPCs
- Full-scale bridge simulations in a practical time-frame may require large, multi-physics CFD models
  - 3D full-scale hydraulics analysis for inundated bridge decks with free surfaces
  - Eulerian multiphase fluid flow for analysis of sediment transport
  - Time-dependent analysis of wave forces on highway bridge decks
- TRACC is being established at Argonne to provide a high-performance computing platform to support such research

Example: 2D STAR-CD Model for Reduced Scale Inundated Bridge Deck



Comparison of Solver Performance to Theoretical Speed-up

- 32-core decomposition as the base case with the 3D STAR-CD model distributed to different number of processors.
- When such a small model is partitioned to a fairly large number of processors (up to 384 in these tests), inefficiency associated with message passing between the partitions leads to deviation from ideal behavior.
- demonstrated scaling is a significant improvement over a conventional cluster system highlighting the importance of high-speed interconnects between individual nodes in high-performance computing



Technical and Analysis Support for Hydraulics Research in Transportation Applications

- Phase I (April – September 2007)
  - Technical Support for CFD Simulations
  - Analysis of Lift and Drag Forces on Inundated Bridge Decks
- Phase II (October 2007 – September 2008)
  - Analysis of Optimum Bridge Deck Slopes to Minimize Pressure Flow Scour
  - Analysis of Pier Scour Counter Measures using Fluidic Devices
  - Fish Passage in Large Culverts with Low flows
  - Wave Forces and Moments on Typical U.S. Highway Bridge Decks
  - Preparation of Semi-Annual and Final Project Reports

Computational Structural Mechanics Applications: Crashworthiness

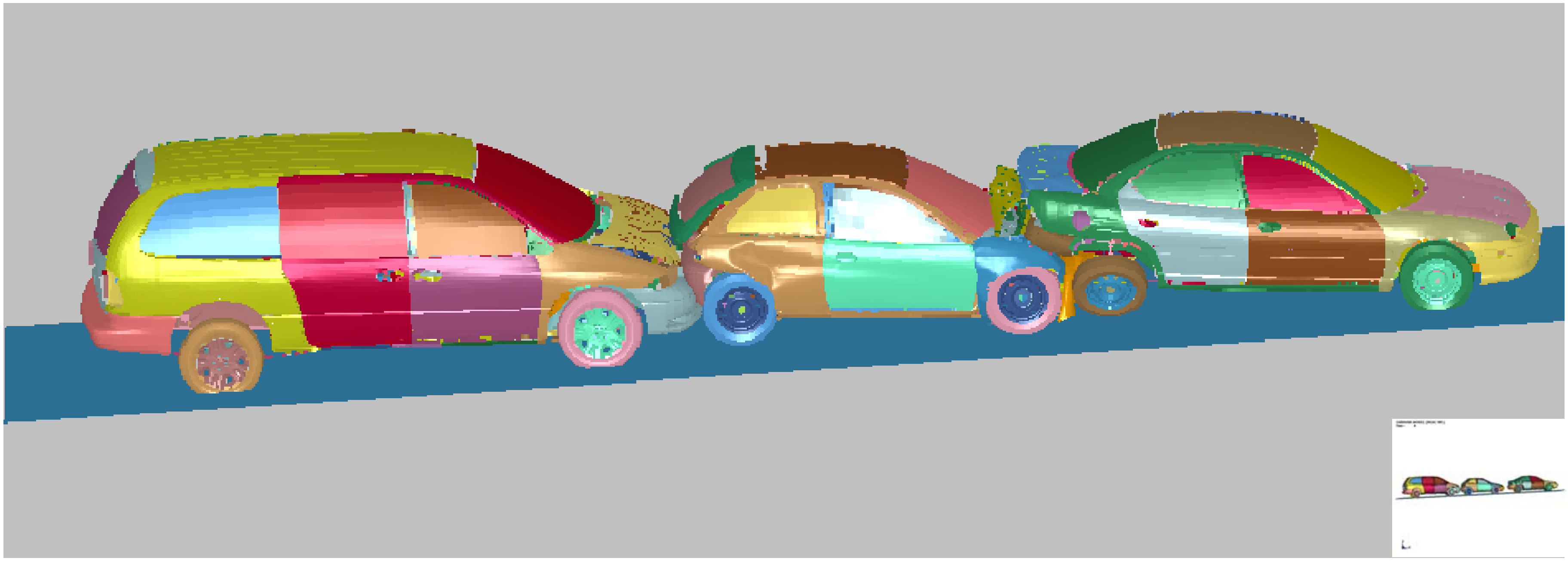
- Modeling and simulation of crashworthiness is currently being performed by DOT
  - FHWA: Optimize design of roadside hardware
  - NHTSA: Achieve the next level of vehicle safety and occupant and pedestrian injury reduction
  - FRA: Understand interactions of colliding passenger trains
  - FAA: Improve structural crashworthiness of aircraft and survivability of occupants
- Utilization of TRACC's high performance cluster computer will:
  - Allow higher fidelity models to be used
  - Produce result in much shorter times
  - Allow more simulations to be performed

Response of Roadside Hardware to Vehicle Crashes

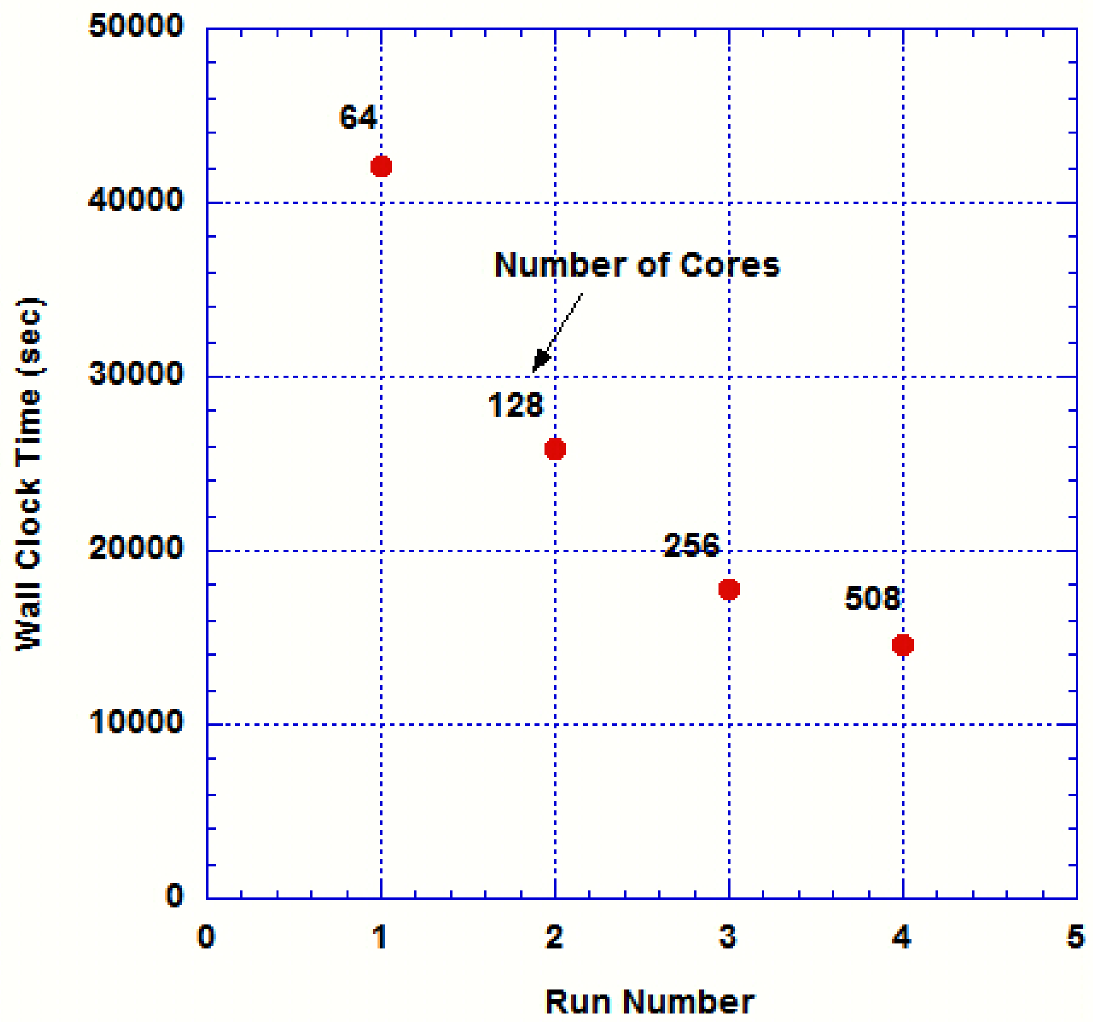
- Problem
  - Crash testing of a large variety of vehicles into roadside hardware is an extremely expensive proposition **(~$500,000 & 10,000 man-hours/test).**
  - Complexity and a current diverse fleet of automobiles and trucks as well as the next generation vehicles such as hybrid, electric and fuel cell automobiles add significantly to future crash testing cost.
- Significance to DOT (FHWA)
  - High-fidelity crashworthiness simulations provide economical alternatives to evaluate crashes and provide data to optimize the design of roadside hardware that is sensitive to vehicle characteristics (mass and height of center of gravity), bumper and hood geometry, and roadside geometry (slopes, embankments, ditches, etc.).

Multiple-Vehicle Crash Simulation

- Multiple-vehicle crash simulations (using LS_Dyna code) performed on cluster computers represents the state-of-the-art
- Subdividing the complete model into smaller domains (via domain decomposition) and computing each domain on a single processor significantly reduces total compute time

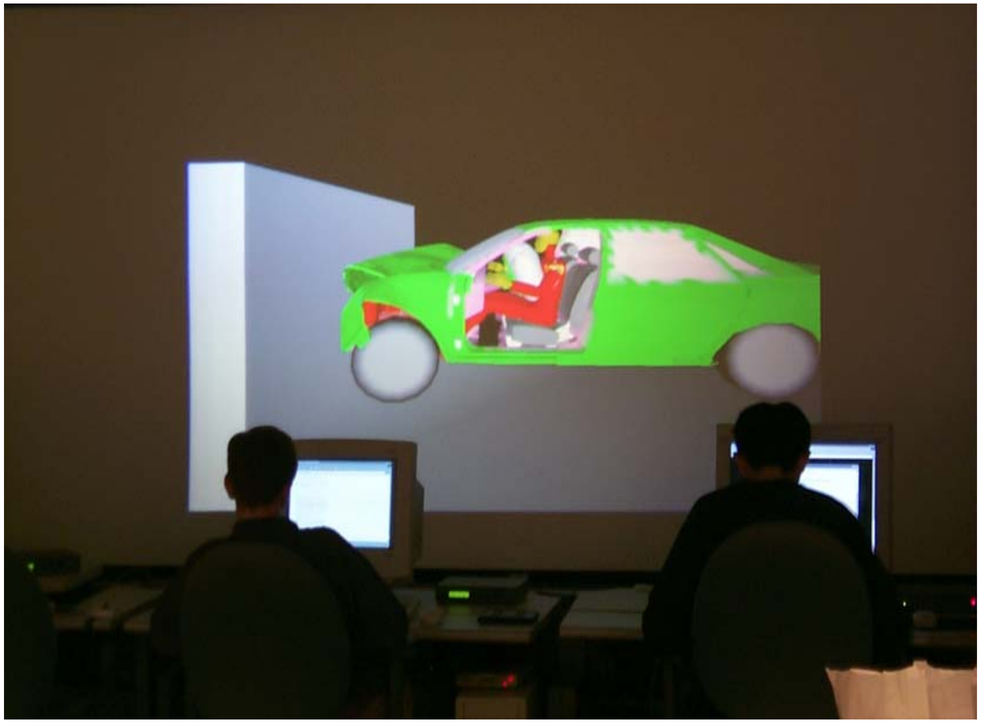


Reduction in Compute Time with Number of CPUs for a Two-Car Crash Simulation



Visualization of High-Fidelity Simulations

- Visualization is an essential element to understanding the complexities involved in crash analysis
- Virtual reality hardware (CAVE, 1-wall CAVE, Head-Mounted VR, etc.) drastically reduces the time needed to understand crash analyses

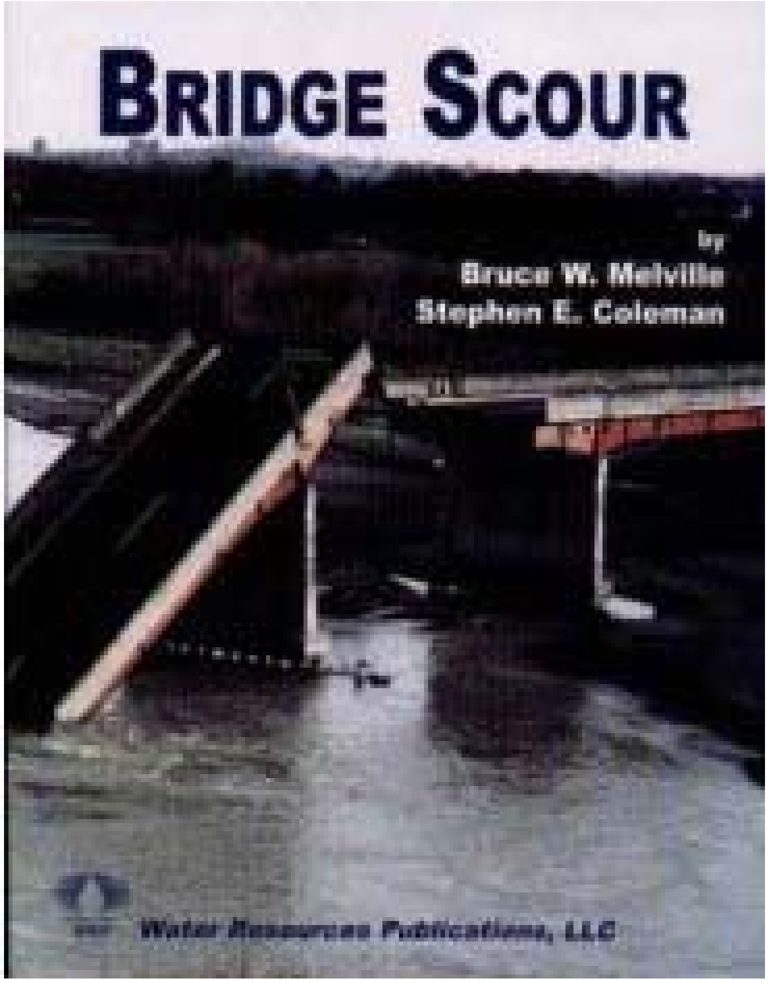


Computational Structural Mechanics Applications: Bridge Response

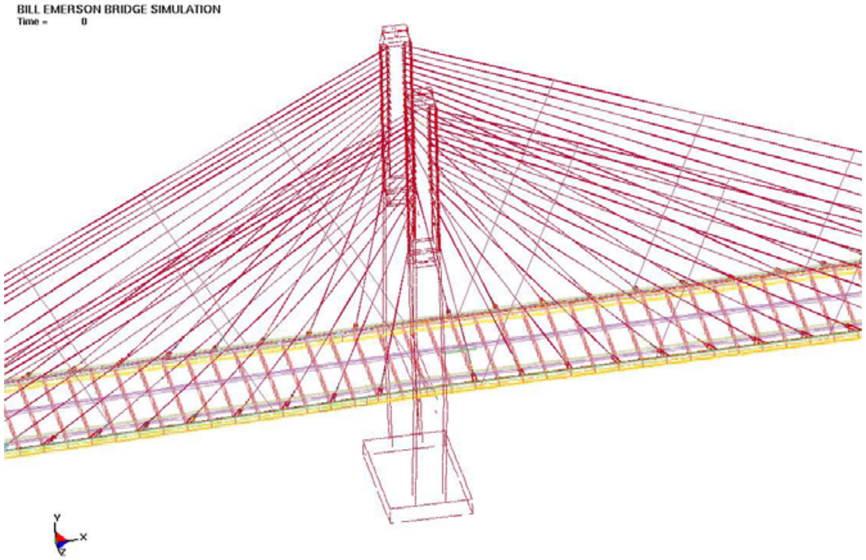
- The dynamic response of bridges during extreme loading conditions — such as high winds and severe storms — is a major concern for the FHWA
- This type of loading involves coupling of aerodynamic loading and the structural movement of the bridge
- Both modeling and simulation and experiments are needed to characterize this behavior
- The use of coupled computational structural mechanics and computational fluid dynamics codes on the TRACC high-performance cluster computer will lead to a basic understanding of this phenomena and provide insight for improved designs

Bridge Pier Scour

- Bridge pier foundations can be vulnerable to scour (i.e., removal of river bed material due to rapid flows)
- Significant scour depth can affect the stability of pier foundations causing bridge failure, resulting in transport disruption, economic loss and an occasional loss of life
- The factors influencing scour are complex and vary according to type of structure
- High-fidelity modeling and simulation is required to accurately predict scour and determine time to structural failure and failure modes



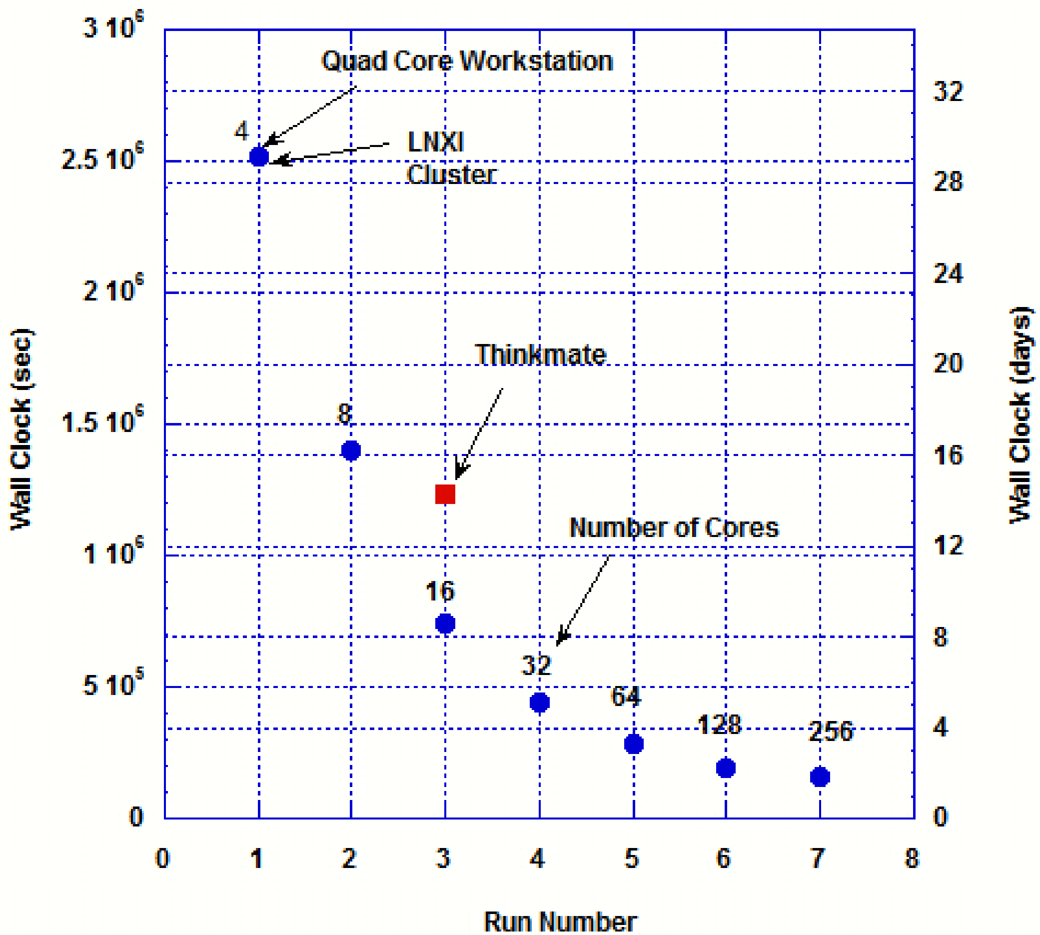
High-Fidelity Bridge Modeling and Simulation



- To accurately determine the structural response of bridges to loadings from traffic, high winds, river currents, and earthquakes, it is necessary to develop high-fidelity numerical (finite element) models and perform transient dynamic analysis using state-of-the-art cluster computers
- The figure on the left shows the Bill Emerson Memorial Bridge that spans the Mississippi River between Illinois and Missouri near Cape Girardeau, Missouri; the figure on the right is a high-fidelity model consisting of over 500,000 elements representing the important structural elements of the bridge

Comparison of Wall Clock Times for Different Number of Cores and Several Computing Platforms

- The three-dimensional finite element model for one of the two major structural subsystems of the BEMB consists of over 500,000 finite elements to represent the bridge structural components including the stay cables. .
- estimated 60 second simulation time. for the TRACC cluster, a DELL quad core workstation and the TFHRC Thinkmate 16 core machine.
- 4 cores of TRACC cluster or the quad-core Dell, = compute time ~ 29 days.
- 256 cores reduces wall clock time
  - to 0.03 of a day for 1 second simulation
  - 1.84 days for the 60-second simulation -- a large reduction in turnaround time.
  - Note: run using 512 cores -- Wall Clock Time is greater than the time for 256 cores and even slightly greater than the time for 128 cores.



Computational Structural Mechanics at TRACC
Multi-physics of bridge dynamics

- Assessment of CSM and CFD software for bridge dynamics analysis
- Demonstration and validation of CSM and CFD models
- Development of integrated CSM and CFD analysis methodology for bridge integrity assessment
- Dynamic response of cable stay bridges
  - *Development of 3D FEM models for bridge structural components and stay cables*
  - *Analysis of bridge response to wind loadings and fluid structure interaction*
  - *Analysis of bridge response to traffic loading*
- Bridge Integrity Assessments
  - *Development of 3D FEM models of key Midwest bridges, in coordination with IDOT*
  - *Assessment of structural stability of bridges subjected to pier scour*
  - *Assessment of structural stability of bridges with models that account for existing damage (stress corrosion cracks, fatigue cracks, etc.) as reported in state DOT inspection reports*

TRACC Contact Information

- http://www.anl.gov/TRACC/
- tracc-help@anl.gov
- Director's Office
  - Dave Weber, Director
  - Mike Boxberger
- Systems Administration
  - Jon Bernard
- Traffic Simulation
  - Hubert Ley
- Computational Structural Mechanics
  - Ronald Kulak
- Computational Fluid Dynamics
  - Tanju Sofu

Discussion