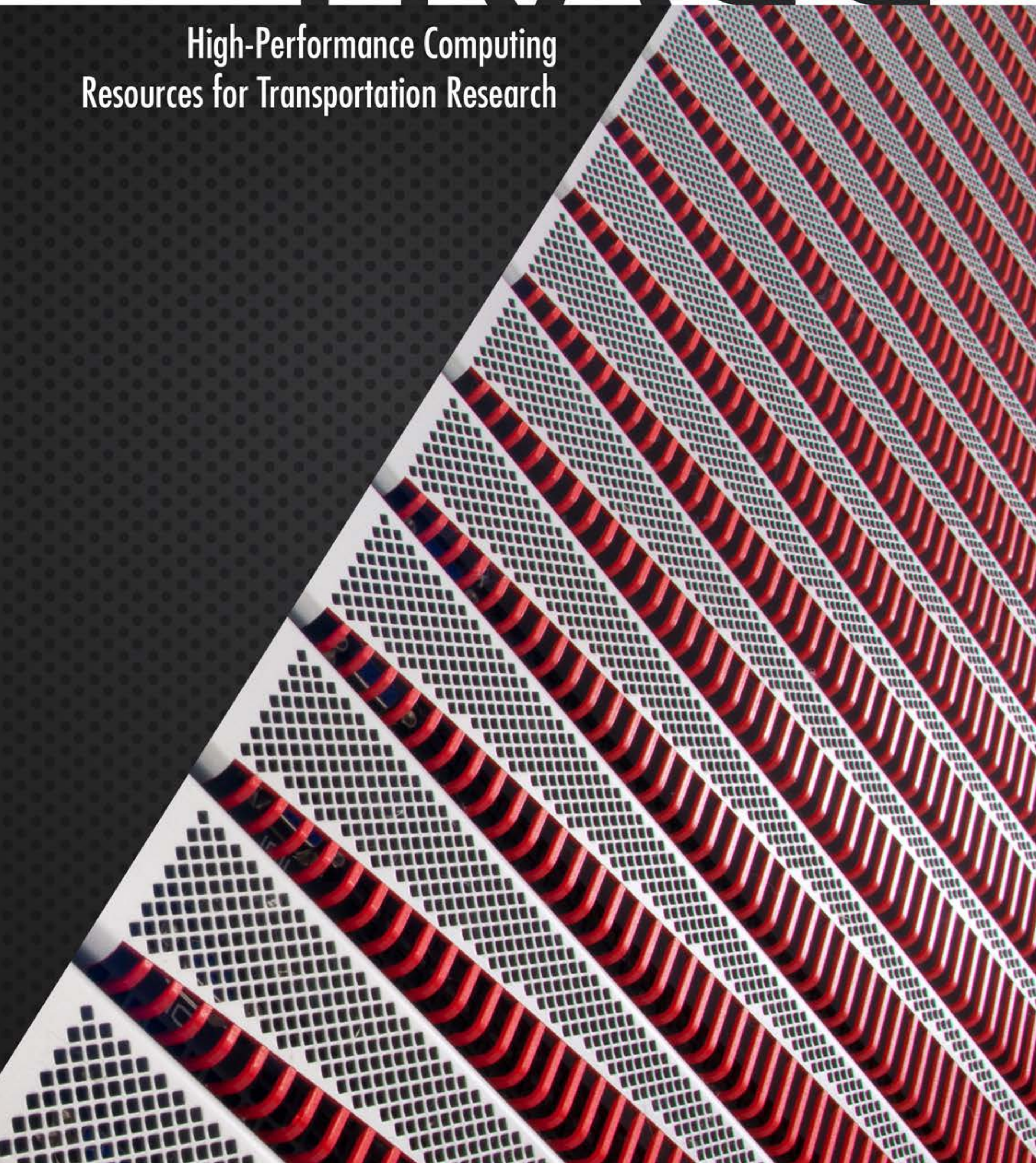
Argonne
NATIONAL LABORATORY

TRACC

High-Performance Computing Resources for Transportation Research

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OVERVIEW

Chartered in 1946 as the nation's first national laboratory, Argonne enters the 21st century focused on solving the major scientific and engineering challenges of our time: sustainable energy, a clean environment, economic competitiveness, and national security. Argonne is pursuing major research initiatives that support the U.S. Department of Energy's goals to create innovative and game-changing solutions to national problems, including state-of-the-art transportation research.

In today's world, increased productivity and the quick adoption of new capabilities are essential to maintain a competitive edge. This is particularly true for the complex transportation system in the United States, which is the backbone of much of its economic success. This complex network of highways, bridges, port facilities, and rail lines has been built over many decades, and modern operation of these facilities pushes traffic to the limits. Congestion in many major metropolitan areas is rampant and a major cause of lost revenue, and congested transportation systems are an enormous challenge for large scale evacuations in case of natural or man-made disasters. Bridges and highways are hard to maintain in tough economic times, and the demands on our transportation system are expected to grow continuously.

To respond to these challenges, the U.S. Department of Transportation (USDOT) wants to deploy state-of-the-art modeling and simulation capabilities. As an effective strategy, this requires not only the development of appropriate computational tools, but also the development of a work force that is trained in deploying such tools, the scientific research that validates the deployed methodologies, and the availability of computational resources to achieve the targeted goals.

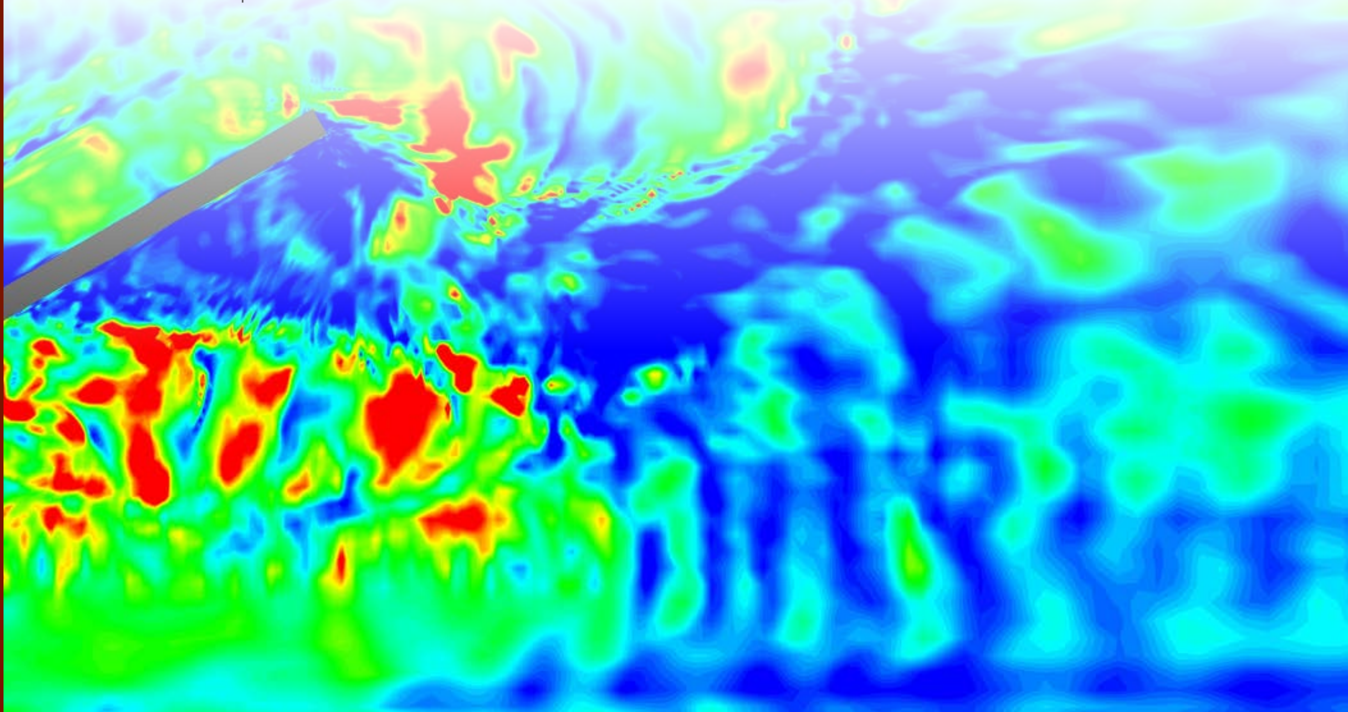
Argonne's Transportation Research and Analysis Computing Center

TRACC, the Transportation Research and Analysis Computing Center, was established to address these challenges. It was established in 2006 at Argonne National Laboratory through a congressional grant to acquire and operate the USDOT's largest high performance computer systems as a platform provided free of charge to USDOT's transportation research projects across the nation.

The facility is co-located with the Argonne Leadership Computing Facility (ALCF), part of the U.S. Department of Energy's (DOE's) effort to provide leadership-class computing resources to the scientific community. The TRACC High Performance Computing (HPC) Cluster is a production platform that is being used by more than a hundred remote users across the U.S. TRACC system administrators support these users with services such as software installation, adaptation of software applications, management of resources, backups, system security, data transfer and remote access, and effective resource sharing.

The TRACC HPC Cluster platform is the basis for addressing the overall needs of the research community. The establishment of advanced computing methodologies (including the verification and validation of newly developed models) is essential, and goes hand in hand with user support and group interaction to develop shared best scientific practices. TRACC scientists with expertise in supercomputing hold training courses on a regular basis to interact with the user community, both on basic use of the systems and advanced uses of the software provided on the system. As needed, workshops are held to bring the user community together, both physically as well as virtually, through the extensive use of videoconferencing and the use of other remote collaboration tools.

As a national user facility, TRACC promotes collaboration between widely dispersed users using advanced collaboration tools. Videoconferencing services are provided to promote collaboration across the nation and TRACC provides a number of offices for visiting scientists. Students from nearby universities often work on their theses using the TRACC HPC Cluster as a resource and TRACC's experts as advisors.



Key Areas of Expertise at TRACC

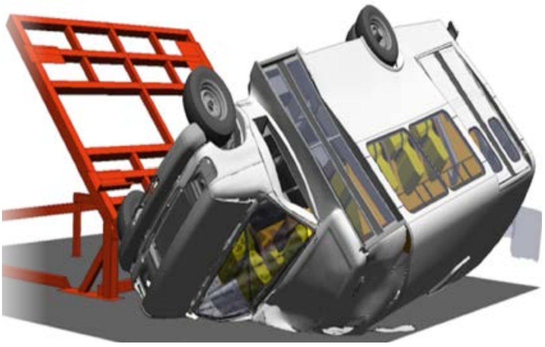
In addition to facilities for advanced computing, visualization, and high-speed networking in the TRACC facility, advanced modeling and simulation applications research is being conducted by TRACC scientific applications staff in coordination and collaboration with USDOT researchers.

TRACC provides a large scalable production platform for simulation-based design and analysis. Users of the facility include:

- USDOT and DOE transportation research programs,
- State and regional agencies, and
- Private industry.

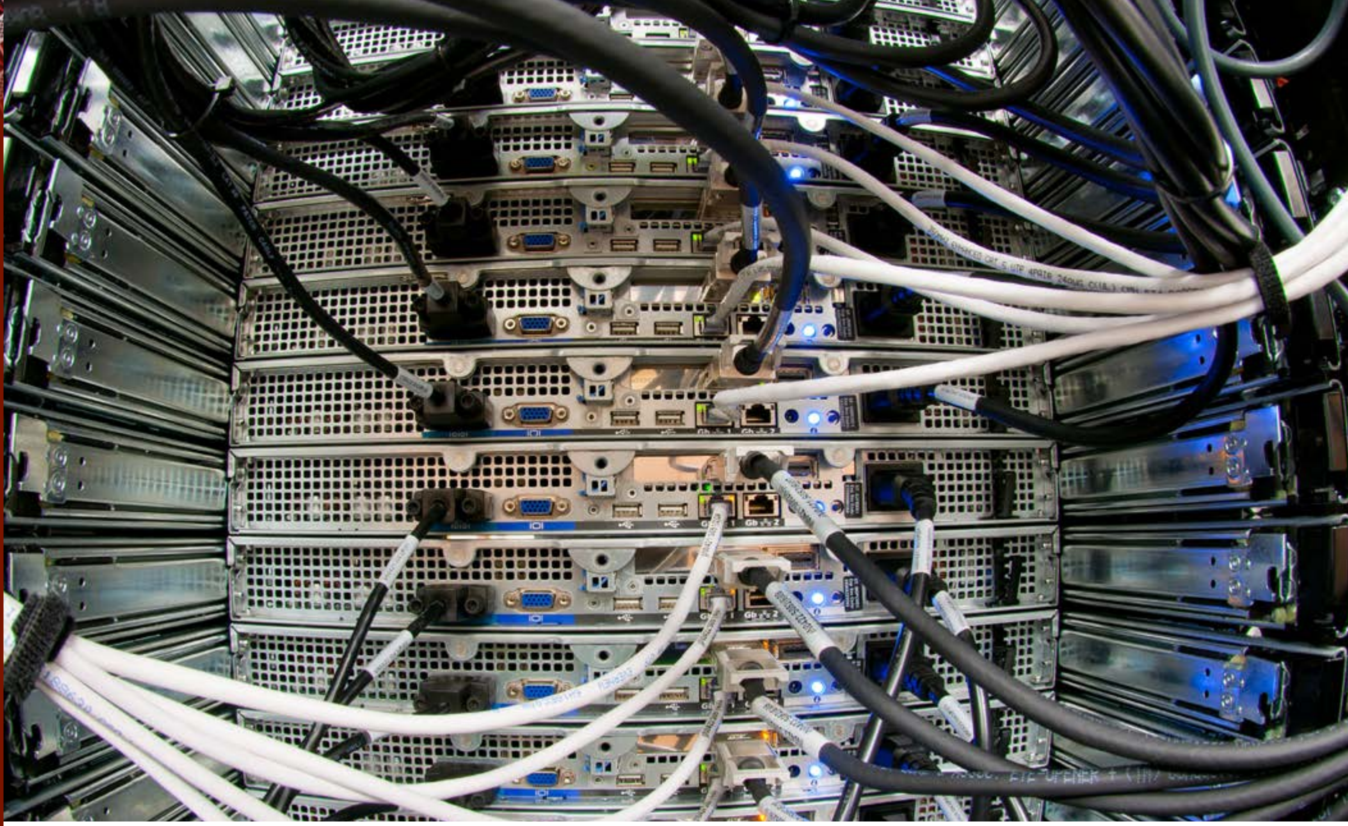
High fidelity analysis research areas include:

- Transportation system modeling,
- Crashworthiness,
- Aerodynamics,
- Wind Engineering,
- Weather modeling,
- Bridge hydraulics and riverbed erosion,
- Bridge structural analysis, and
- Combustion.



The safety of paratransit buses in rollover accidents is being investigated by Jerry Wekezer and his research team at Florida Agricultural and Mechanical University-Florida State University. This modeling and simulation effort relies heavily on TRACC's cluster computer, computational mechanics software, and TRACC's expertise.

Are bridges and roads safe after floods erode riverbanks and the riverbed around foundations and supports? Engineers get more accurate answers with advanced analysis.



Transportation Systems Modeling

Advanced transportation modeling is a key component in solving some of the nation's most important challenges in the coming decades. Our highways are an essential part of the infrastructure that makes the country competitive and with congestion levels that routinely take a significant bite out of the nation's productivity, the advanced understanding of the root causes of congestion, as well as the ability to effectively manage existing and future resources, is of the essence.

TRACC researchers focus on the development of advanced agent-based transportation system simulation tools for USDOT. These tools are not only useful for understanding congestion issues and the evaluation of mitigation strategies, but also for the improvement of emergency evacuation plans based on solid simulation results for specific metropolitan areas.

Researchers from a dozen or more universities, companies, government agencies, and metropolitan planning agencies are using the TRACC HPC cluster to address a wide variety of transportation issues. TRACC staff assists with training classes, software development, and software integration to make this process efficient and cost-effective.

Computational Fluid Dynamics

Severe storms, hurricanes, floods, and major snow storms are frequently in the news with reports of damage to roads, bridges, and other structures. Designing transportation infrastructure to withstand these events and assessing safety of existing structures in severe weather events is difficult because of the complexity of wind and water flows. Computational fluid dynamics, with extensive physics modeling, is capable of detailed analysis of extreme weather events. This type of advanced analysis requires the use of a large computer cluster.

TRACC's computer resources can compute the details of wind and water flow at tens and even hundreds of millions of points in space: far beyond what can be done on a workstation. Advanced flow analysis is an essential tool helping researchers develop new engineering guidelines to improve designs and ensure public safety in transportation.

Advanced Visualization

From the onset, TRACC focused on the development of advanced visualization methods to allow scientists to better understand the sheer insurmountable amount of data generated by today's current computer models. The reduction to simple numerical results is often counterproductive, and advanced visualization allows the human visual system to become part of the computation process itself. If presented appropriately with computer-generated motion video and high resolution graphics, the human brain is very effective in detecting subtle artifacts in the image that would be difficult to find computationally.

Effective visualization strategies lead to the quick identification of model inconsistencies, as well as real world issues that are part of the results of a specific computation. Modern off-the-shelf graphics hardware and programming strategies derived from modern game development lead to inexpensive tools that complement high performance computing very effectively.

TRACC is currently developing high resolution, 4-dimensional (space and time) visualization of TRANSIMS results, a code developed by USDOT over the last fifteen years to compute the second-by-second movements of all travelers in a large metropolitan region such as Washington, D.C. or Chicago. The software operates on both commodity hardware as well as high-end graphics workstations with multiple screens.

Many of our nation's bridges fail during floods due to riverbed erosion that undermines the support at the bottom of the pier. TRACC's computer modeling simulations agree with bridge pier failure caused by a flash flood.

Computational Structural Mechanics

The complexities of advanced crash analysis and the design of transportation infrastructure such as bridges benefits greatly from modern computation tools. Computational structural mechanics, especially with its modern multiphysics capabilities, is computationally intensive and typically requires the use of high-end workstations, even for smaller problems.

TRACC has resources that can run these models on up to 500 processors at a time. Compared to a typical workstation environment, this allows for significantly larger models, or for running large sets of optimizations that would take years to compute on a single workstation.

Visualization of high stress areas at a rectangular pier in a flood helps engineers determine where riverbed erosion prevention measures may be needed.

Transportation Systems Modeling Group

The Transportation Systems Modeling Group at TRACC is a multi-disciplinary group that develops transportation system models, advanced application software, and visualization applications in support of TRACC's operation as a supercomputing center for the U.S. Department of Transportation. In addition to these targeted research programs, the group supports many external users of the TRACC facility with technical assistance, training sessions, and capabilities assessments.

As part of their targeted research programs, the group also develops new methodologies and applications for modeling traffic management systems at the operational and planning levels. The group has developed several state-of-the art models for simulating transportation network conditions during a "normal day," as well as during a no-notice evacuation.

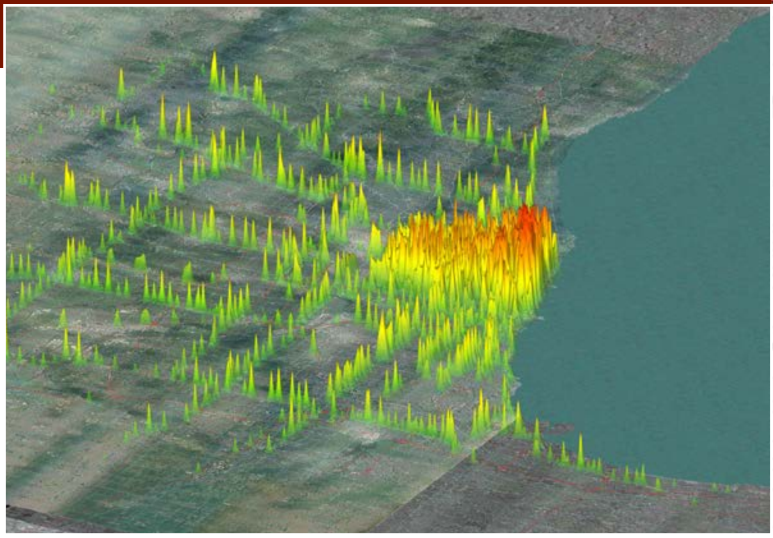
The models built by the group are based on the TRANSIMS (TRansportation ANalysis and SIMulation System) software. The TRANSIMS code represents the latest generation of traffic simulation codes developed jointly under multiyear programs by the U.S. Department of Transportation, the U.S. Department of Energy, and the U.S. Environmental Protection Agency. It is an activity- and agent-based model that simulates the second-by-second movement of all travelers and vehicles in a region. TRANSIMS is an open-source software package and group members actively contribute to the TRANSIMS development effort to enhance core functionality and develop new features.

RTSTEP

The Regional Transportation Simulation Tool for Evacuation Planning is a decision support tool for evacuation planners that can be used while establishing emergency response plans that are constrained by an existing transportation system. This project is sponsored by a Department of Homeland Security (DHS) grant and is managed by the Chicago OEMC (Office of Emergency Management and Communications). The project team includes five private and public organizations: Argonne National Laboratory, AECOM, the Chicago Metropolitan Agency for Planning, the Illinois Institute of Technology, and Northern Illinois University.

Features

- Integrated tool for the prediction of public response to government warnings, simulating the complex multi-modal transportation network conditions during the evacuation period;
- Simulates the impact of changed trip destinations, mode of transportation, and route choice decisions on overall transportation system performance;
- Easy to configure for specific evacuation scenarios or special events;
- Effective evaluation and improvement of operational strategies deployed by first responders;
- Fully simulates event-related transportation network changes, such as road closures, traffic signal timing changes, lane restrictions enforced by responders, and more;
- Fully integrated user interface for configuration of scenarios and detailed visualization of results



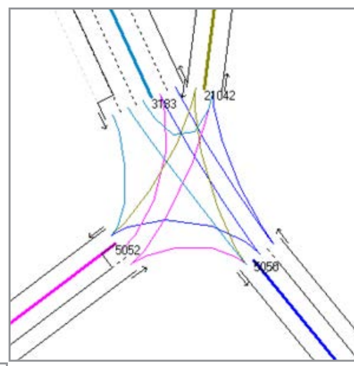
Advanced visualization of local congestion patterns can be represented regionally by a "heat plot" algorithm. Slow and standing vehicles create a lot of virtual heat, while moving vehicles do not contribute to the abstract three-dimensional surface.

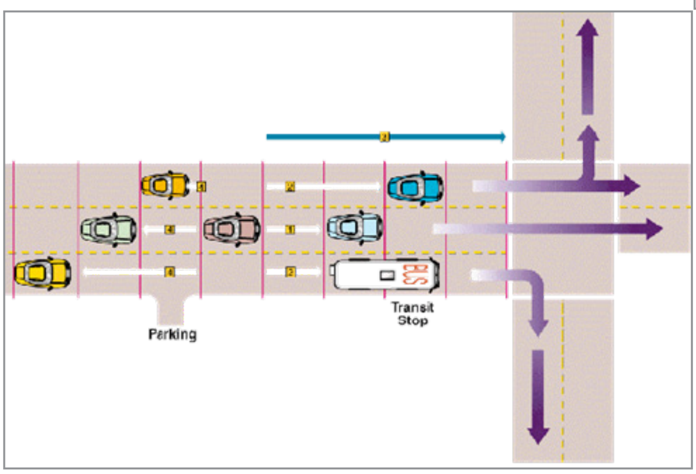
Visualization

TransimsVIS is OpenGL-based, high-performance interactive visualization software that allows users to properly set up the parameters of a TRANSIMS model, as well as visualize the results of a simulation.

Features

- Ability to display and analyze the sub-second movements of nearly half a million travelers simultaneously traveling throughout metropolitan areas;
- Exposes complex internal results of a model with animated data plots, seamless 4D navigation (space and time), on-demand ortho-imagery, and model identification tools;
- Plays an integral role in the RTSTEP tool, serving as the platform to interactively configure and review the results of evacuation and special event scenarios;
- Enables users to effectively present their scenarios and results to sponsors by capturing high resolution still images and high fidelity movies with cinematic camera sweeps; and
- Easily portable to any city or region modeled using the open source TRANSIMS transportation simulation software.





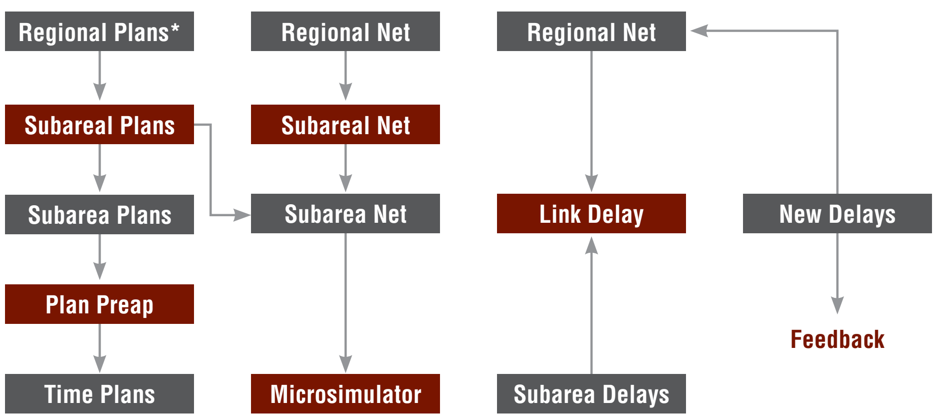
TRANSIMS Studio

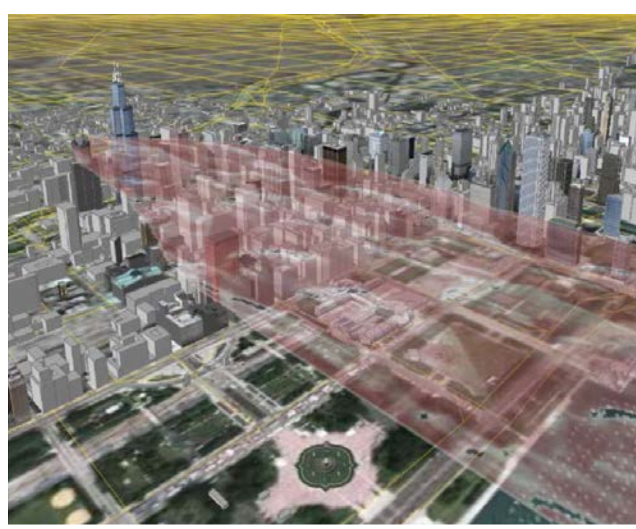
The TRANSIMS Studio application is an integrated development environment (IDE) for TRANSIMS. Components include a run time environment to execute TRANSIMS in parallel, as well as a full-featured graphical user interface (GUI).

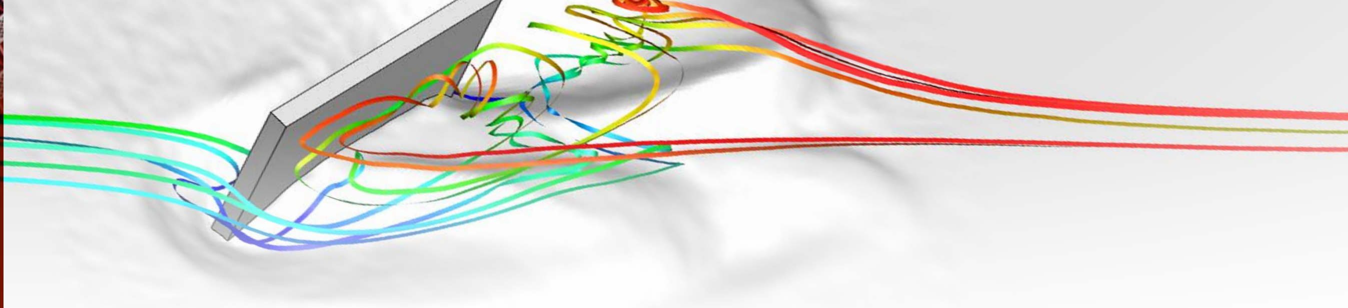
Features

- Built-in editors for script and data file editing;
- Built-in version control support for source code control and model sharing between developers;
- Built-in highway and network editor (optimized for high performance on large networks);
- Built-in help system (complete cross-referenced key and tool documentation);
- TRANSIMS runs within the GUI (similar to the Visual Studio IDE model);
- Full integration with the job submission system on a Linux cluster; and
- Interaction with the run time environment to build a tree structure with automatic access to all input and output files for each tool, as well as control files, warning messages, and numerical results.

TRANSIMS Studio Integrated Development Environment
Transportation Research Computing Center at Argonne National Laboratory

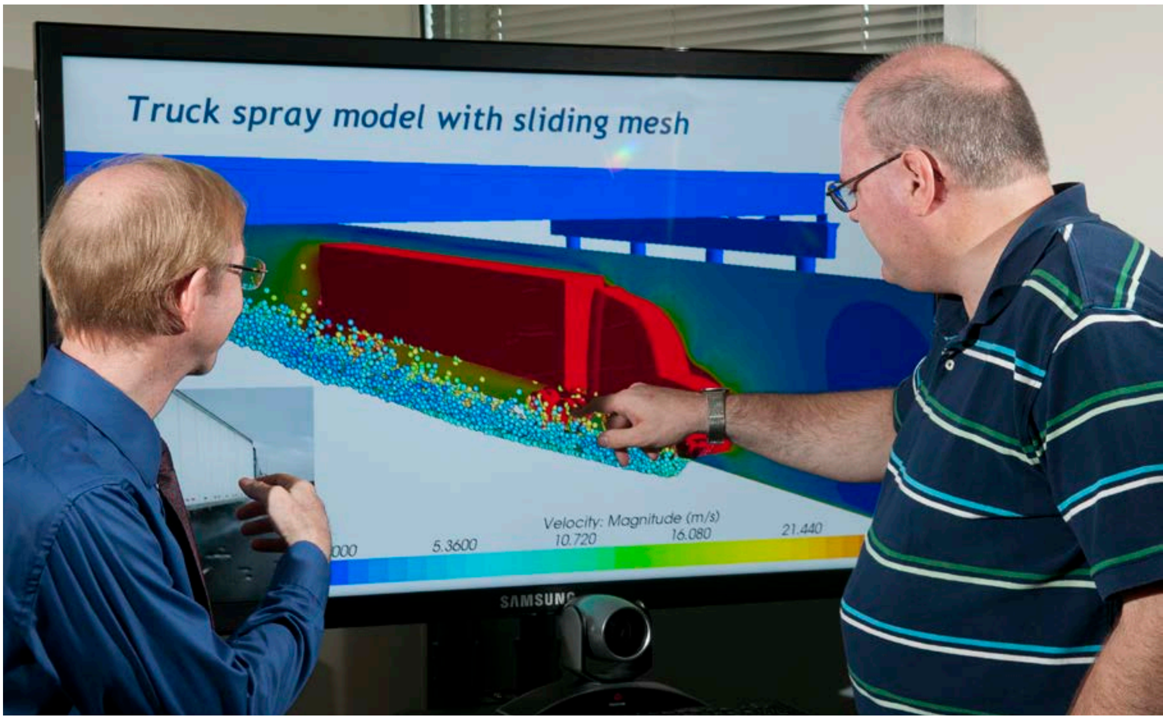






Computational Fluid Dynamics in Transportation Research

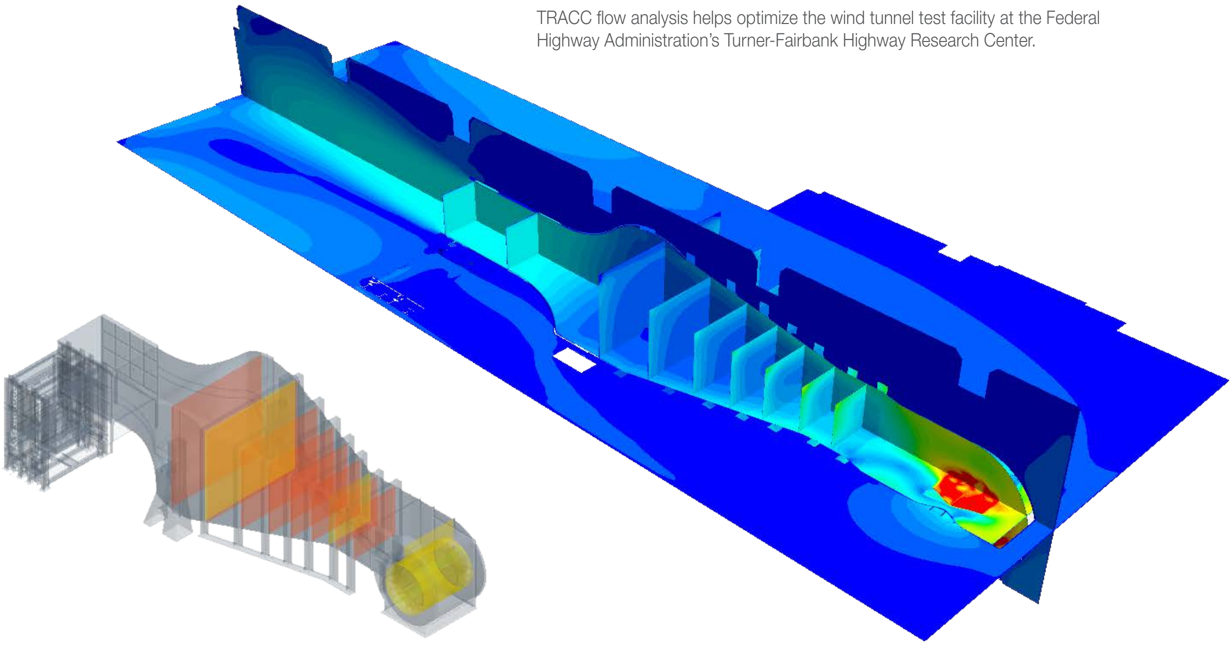
Computational fluid dynamics (CFD) is now routinely used in many industries to accelerate and improve product design. It is also used to increase the safety and reduce the costs of transportation infrastructure renewal. Renewing the nation's aging transportation infrastructure is a high priority goal that is difficult to meet in challenging economic conditions. Engineers increasingly use CFD analysis tools to reduce failure risks of bridges and other structures during storms and floods, while also reducing construction and maintenance costs. One in twenty of the nation's bridges over water are classified as "scour critical" (scour is the removal of sediment from around bridge piers or abutments). On average, twenty bridges per year fail due to scour (about one failure every 20 days).



Truck tire salt spray analysis helps identify causes of rapid rusting in bridges using weathering steel.

TRACC's Virtual Hydraulics and Wind Engineering Laboratory

In the past, new ideas were tested with expensive small scale laboratory experiments or limited full scale field studies that could not resolve all the questions of interest. CFD analysis on high performance computers is being used to test full-scale designs in a virtual environment at high speed and low cost. For many applications, three-dimensional CFD models can provide the most accurate and detailed analysis results for use by engineers and planners.



TRACC flow analysis helps optimize the wind tunnel test facility at the Federal Highway Administration's Turner-Fairbank Highway Research Center.

High Performance Computing User Facility

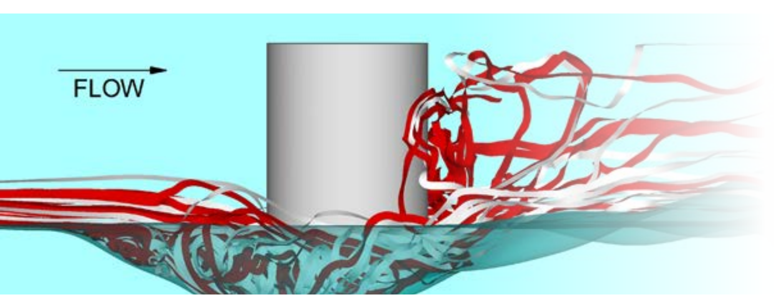
Expert scientific staff is available to assist in the use of TRACC's computing facilities and software analysis tools. Training courses focus on the application of CFD software to the analysis of problems in hydraulics and transportation infrastructure. These courses are held periodically at TRACC and at remote locations using videoconferencing and web meeting software.

STAR-CCM+ commercial software is available on the TRACC cluster and is capable of defining the geometry and physics of large problems, computing the solution, and performing a wide variety of post-solution analysis and visualization. OpenFOAM open source CFD software is also available.

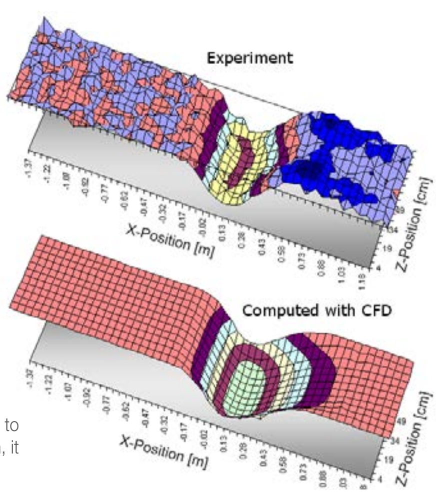
CFD Research Meets the Infrastructure Challenges of Today

Working with the Federal Highway Administration and university collaborators, TRACC analysts use CFD to study problems related to renewing the nation's transportation infrastructure, including:

- Storm forces on bridges,
- Riverbed erosion at bridge supports during floods,
- Culvert design for fish passage during normal flow and runoff during storms,
- Salt spray interaction with bridges constructed with unpainted weathering steel, and
- Dispersion of pollutants or toxic agents in urban environments.



Ribbon streamlines show complex vortex flow that causes erosion at the base of a pier.



Computed scour hole under flooded bridge deck compared to experimental data. To maintain an engineering safety margin, it is important not to under-predict the depth of the hole.

Computational Structural Mechanics Modeling and Simulation

Structural/multiphysics mechanics computations performed on TRACC's high-performance computers greatly reduce the time needed to perform transient dynamic bridge analysis, crash analysis (auto, train, and aircraft), vehicle stability assessment, and human injury assessment. Computational structural/multiphysics mechanics (CSM) is a well-established methodology for the design and analysis of many components and structures found in the transportation field. Modeling and simulation of CSM on TRACC's high performance computer are key components in revitalizing the aging transportation infrastructure; evaluating passenger, vehicle, and roadside hardware response to accidents and crash conditions; and evaluating bridges in extreme loading conditions, such as extreme wind, blast and earthquake.

Multiphysics Mechanics Software

TRACC has a 500-core license with Livermore Software and Technology Corporation for use of the LS-DYNA® suite of codes and a license with Altair for 21 units of Hyperworks®. The codes are continually being updated and contain many features that can handle the complexities embedded in the U.S. Department of Transportation's structural and media-structure interaction problems. In addition, the Large-scale Atomic/Molecular Massively Parallel Simulator (LAMMPS) open source code is available for researchers working on molecular simulations of pavement materials. Between the three codes, the capabilities exist to rapidly develop and analyze complex models of real transportation structures.

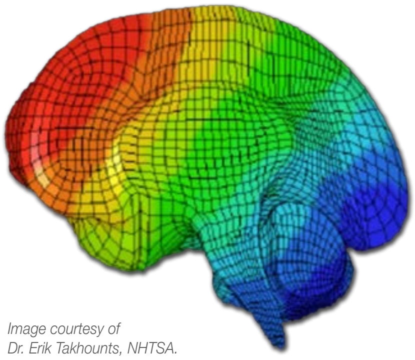
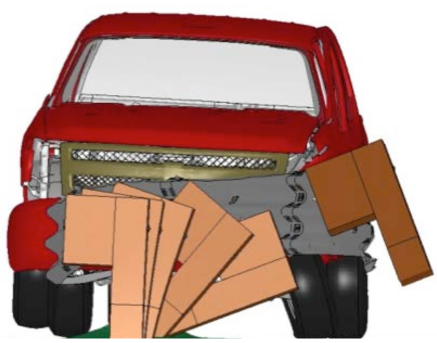
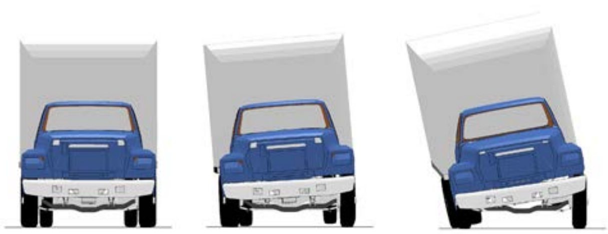


Image courtesy of Dr. Erik Takhounts, NHTSA.

Motor vehicle crashes are the major cause of traumatic brain injury in the United States. Numerical modeling by the National Highway Traffic Safety Administration (NHTSA) at TRACC provides valuable insight into brain response during crashes.



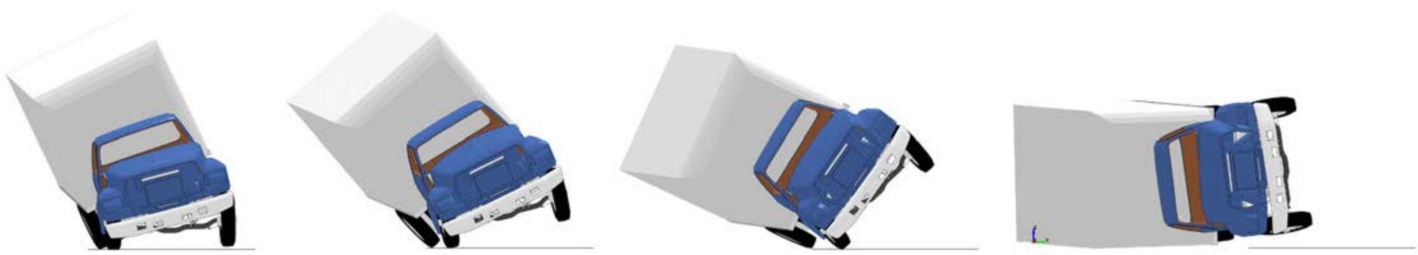
Researchers at the Texas Transportation Institute evaluate the behavior of roadside barriers to vehicle crashes.

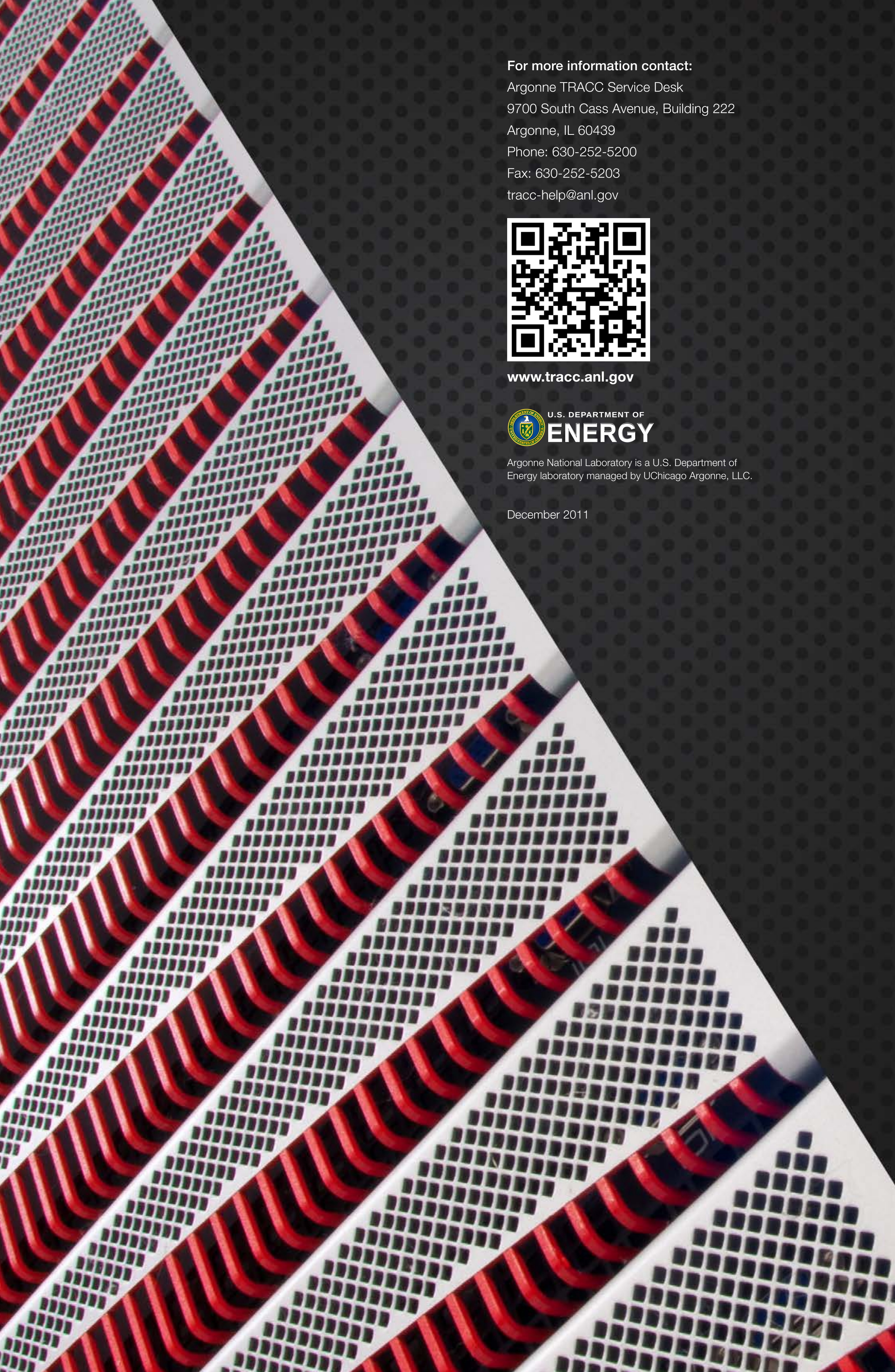


Numerical simulations of high crosswind loading on a Single Unit Truck can identify wind speed thresholds for sideslip and rollover.

For Users

Expert staff is available for consultations on computational multiphysics mechanics issues and development of collaborative projects. A graphical user interface has been developed for ease of use of the LS-DYNA software, and for job submission and monitoring. Desktop virtualization is available to users, enabling them to interact with the cluster from a remote location. The NoMachine NX server is installed on the cluster and the NoMachine NX client is available at no cost to the user, providing an efficient and easy way to view finite-element models, develop and modify input files, and display computational results. TRACC's computational mechanics group also holds training classes for users and other interested parties to promote the use of advanced simulation methodologies and to establish their use as a best practice throughout the practitioner's community.





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