The Simulation of Emergency Evacuations in the Chicago Business District Using TRANSIMS

Dr.-Ing. Hubert Ley
Transportation Research and Analysis Computing Center
Argonne National Laboratory

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TRACC Is Being Built as a National DOT Supercomputer Facility

TRACC High Performance Compute Cluster
512 core / 128 compute nodes
(two dual-core AMD 2216 Opteron CPUs 4GB of RAM)

240TB Global Parallel File System Disk Storage

LTO-3 160TB Archive/Backup Tape Storage

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

TRACC Training Center

Argonne Nuclear Engineering Division Linux Cluster
10Gb Dedicated Access

Argonne LCRC JAZZ Linux Cluster
10Gb Dedicated Access
TRACC: Location and Connectivity

Internet2 Network

Maximum capacity 64 10 Gb/s channels

94% of DOT University Transportation Centers connected

All backbone links 10 Gb/s
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.
Example: 2-D STAR-CD model for reduced scale inundated bridge deck
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.
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 (see Figure).
- 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.
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 US DOT (FHWA)

High fidelity crashworthiness simulations provide economical alternatives to evaluate crashes and provide data to optimize the design of roadside hardware which 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

• Multi-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
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.
**TRANSIMS Background**

- TRANSIMS is an integrated set of tools to conduct regional transportation system analyses based on a cellular automata microsimulator.

- TRANSIMS is an abbreviation for:
  - TRansportation ANalysis and SIMulation System

- The TRANSIMS approach is based on the new paradigm of modeling individual travelers and their multi-modal transportation based on synthetic populations and their activities.

- Compared to traditional traffic planning approaches, TRANSIMS requires a significant amount of data and computing resources.

- The software was initially developed at Los Alamos National Laboratory; it is now being made available and furthermore developed as an open source project:
  
  **http://www.transims-opensource.net**

**TRANSIMS Background**

- TRANSIMS is a tool for regional analysis
  - High demands on CPU time and storage capacity
  - Runs on current high end Windows and Linux workstations
  - TRANSIMS accommodates
    - Large road and transit networks (>>100,000* links)
    - Large populations (>>25,000,000* travelers)

- General approach
  - Simulate the travel behavior of each synthetic individual throughout an entire 24 hour period based on representative activities derived from survey data
  - Based on highly detailed road and transit networks, individuals are traced for every second of the day while analyzing their local interactions
  - Routes for travelers are determined by a routing module that considers time-dependent link delays throughout the 24 hour period

* TRANSIMS has been run successfully with networks and populations of these sizes, but does not enforce actual size limitations. Newer 64-bit operating systems do in fact accommodate even much larger networks and populations, typically limited by memory and operating system constraints.
Background

- TRANSIMS results
  - Detailed snapshot data: the location of each individual traveler, car, or transit vehicle is known for every second of the day
  - Statistics on traffic flow, congestion, queues at intersections, and much more
  - Time-dependent link delays for the entire road and transit network

- Additional background information
  - TRANSIMS was initially planned to be used as an emissions estimate tool. It is now mostly used as a regional traffic analysis tool.
  - Version 3 (developed by Los Alamos) required the use of a Linux cluster; Version 4 runs on standard Windows and Linux machines, but is currently not a parallel application.
    - Parallelization of TRANSIMS for standalone multi-core machines as well as high performance cluster environments is currently being implemented
Scope of TRANSIMS Input Data

- Input Data for Modules
  - Transportation Network
    - Streets, Intersections, Signals
    - Transit Routes and Schedules
    - Land Use Data, Zoning Information
  - Transit Lines and Schedules
  - Census Data for Population
  - Household Activity Surveys
  - Itinerant Travelers and Trips
  - Vehicle Characteristics and Prototypes

Generalized TRANSIMS Flow Chart
**Basic TRANSIMS Methodology**

- The goal is to load traffic onto the network and iterating towards the Nash equilibrium
  - Travelers cannot achieve significantly better routes when trying to choose a shorter path, meaning that each traveler chooses the route that’s best for the overall population

- Important constraint
  - Travelers choose a mode of transportation according to travel surveys; they are not optimizing their travel by choosing modes

- This is simplified
  - Typically, some activities will need to be modified as well to avoid unrealistic travel constraints
Emergency Evacuations of the Chicago Business District

- This project has been implemented to model the effects of a no-notice event on the multi-modal regional transportation system in the Chicago metropolitan area.
- The chosen scenario postulates a radioactive release following an explosion at the base of the Sears Tower.
- This project deals with the dynamic effect on the transportation system.

Road Network Courtesy of CMAP
**Fundamental Capabilities of the TRANSIMS Approach**

- **Multi-modal transportation** (vehicles, buses, trains, walking, bicycles,…)
- Extremely **large simulation areas**, e.g. Chicago (10,000 square miles)
- Fully time-aware routing of **each individual traveler** for all travel modes
- Microsimulation for large metropolitan areas to determine the interactions between travelers and vehicles to determine **second by second movements**
  - Determination of **vehicle interactions**, such as lane changes, speed changes, passenger loading and unloading, …
  - **Interaction with the road network**, e.g. with traffic signals, speed limits, turn lanes, transit vehicles, …
- This approach overcomes the limitations of traditional traffic forecasting models:
  - Delivering **transportation system performance** as a full function of time instead of static solution for a few time periods (e.g. am and pm peaks)
  - Microscopic interaction between vehicles and travelers delivers **accurate results** compared to simple volume delay functions and aggregate data.
- Main challenges: **Massive demands on computation time** and a need for extremely detailed input data
10,000 Square Miles Simulation Area
Available Data Sources and the Types of Data Needed

- CMAP and TRACC Network Improvements

- Main focus is on network topology, in particular:
  - Connectivity
  - Number of Lanes
  - Functional Classes
  - Speed Limits
  - Coded Length
  - Capacities, etc.

- For visualization and more precise modeling:
  - Exact geographic locations
  - Shapes along links
  - Correct integration of transit links and stops, etc.
Google Maps and Street View
Network Editing
Current Status

- Each individual lane is modeled
- Pocket lanes are modeled
- Lane Connectivity
- Signals
  - Phasing
  - Timing
- Parking
- Many more details

Road Network Courtesy of CMAP
The Regional Road Network

- ~10,000 square miles
- Road network
  - 40,000 links
  - 14,000 intersections
  - 250,000 locations
- ~28 million vehicle trips
- ~1.5 million transit trips
- Trip tables
  - Break-down by purpose (work, truck, airport, and many more)
Some Preliminary Results

- The metropolitan road network accommodates the trips reasonably well (~1% problems)
- Traffic volumes per lane are shown as an indicator of congestion (e.g., 8:00 to 8:15)
- The TRACC cluster has reduced computing time for 27 million routes to less than 15 minutes using just 48 processors (of 512)
CBD Emergency Scenario Progression

Figure 1: Location of No-Notice Event

Figure 2: Limited Effects in the Immediate Surroundings

Figure 3: Extent of Airborne Plume 6 Minutes after Detonation.

Figure 4: Extent of Airborne Plume 12 Minutes after Detonation.
CBD Emergency Scenario Progression

Figure 5: Extent of Airborne Plume 18 Minutes after Detonation

Figure 6: Extent of Airborne Plume 24 Minutes after Detonation

Figure 7: Extent of Airborne Plume 30 Minutes after Detonation. Assumed to be the maximum extent of the area exposed to radioactive materials since most of the airborne contaminants have moved out over Lake Michigan by this time.
**Evacuation Trips**

- An initial methodology has been developed to deal with evacuation trips
  - Trips originating in the evacuation zone after the event are moved forward in time and are assigned a new departure time
  - A special distribution of trip origination time is applied (evacuation response curve)
Preventing Trips to Enter the Affected Area

- Trips need to be rerouted so that travelers are not sent into the evacuation area.
- Likewise, evacuation trips from the area are directed out of the area into a specific direction.

This is achieved by setting lane restrictions and turn restrictions, both of which can be in effect for selected time periods.
Congestion Caused by Evacuation Trips in 10 Min Intervals

Methodology
**Directional Evacuation**

- Directional evacuation minimizes exposure to the plume
  - Turn prohibitions are used to assure proper re-routing and to keep travelers from entering the area
  - Lane restrictions are used to restrict two-way traffic on LaSalle Road
Example Case Study: Evacuation with Transit to a Shelter

- Scenario:
  - The Emergency Response Team secures a few suitable transit stations
  - People in the Evacuation Area are directed to walk to these stations
  - Transit transportation is provided to take them to a shelter location (e.g. United Center)

- TRANSIMS is already able to simulate for each individual person:
  - Delays in leaving buildings
  - Walking towards the closest evacuation stop
  - Flow of buses within congested roads and/or on reserved lanes
  - And more …
Complex Evacuation Strategies

Scenario 4: Evacuation via Transit to Shelters

Transit Route

Shelter
Examples for High Resolution Visualizations
Examples for High Resolution Visualizations
Chicago 2016 Illustrations
WHATS – White House Area Transportation Study

RUN: 421.BwOps, TOD: 07:45:00
WHATS – White House Area Transportation Study
TRACC Contact Information

- Director’s Office
  - Dave Weber, Director  
    dpweber@anl.gov
  - Mike Boxberger  
    boxberger@anl.gov

- Systems Administration
  - Jon Bernard  
    bernard@anl.gov

- Traffic Simulation
  - Hubert Ley  
    hley@anl.gov

- Computational Structural Mechanics
  - Ronald Kulak  
    kulak@anl.gov

- Computational Fluid Dynamics
  - Tanju Sofu  
    tsофu@anl.gov