Trails and Tribulations of High Performance Computing

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AECOM

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Transportation Modeling

- Transportation modelers are charged with preparing credible forecasts of:
  - The impacts and benefits of proposed highway, transit, pedestrian, and bicycle improvements
  - Mobile source emissions for conformity analysis and for quantifying greenhouse gases (GHG), energy consumption, and particulates
  - The impacts of policy decisions and pricing or operational strategies designed to influence or manage travel demand, system performance, land-use development, special events, and economic or financial viability
Advanced Practice Modeling

Population Synthesizer
- Households
- Persons
- Vehicles

Non-Household Travel
- External Trips
- Non-resident Tours
- Commercial Vehicles
- Special Generators

Activity Generator
- Activity Pattern
- Activity Location
- Time Schedule
- Travel Mode

Travel Simulator
- Route Planner
- Microsimulator
- User-Equilibrium

Traveler Response
- Time Schedule
- Activity Location
- Travel Mode
- Activity Pattern

System Response
- Adaptive Controls
- Transit Schedules
- Dynamic Pricing
- Traveler Information

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Analysis Requirements

- Finer resolution of space and time dimensions
  - Network-based locations; 15 minutes or less
- Traveler decisions based on household activities
  - Coordinated person travel for one or more days
- The operations of specific streets and facilities
  - Time dependent networks with dynamic operations
- Regional simulation of individual vehicles and persons to evaluate system performance
  - Detailed forecasts of speeds, queues, flows, riders, etc.
  - By time of day, vehicle/user type, lane, train, etc.
The Computational Challenge

- The generally “acceptable” computer processing time for traditional TDF models is ~24 hours
  - Large regions must trade-off model detail and complexity against computer hardware/software costs and complexity OR do most regional modeling in-house or through a service center
- Advanced practice models are significantly more complex and computationally demanding
  - High performance computing is required for “feasible” processing times
    - Most MPOs won’t accept run times over 48-60 hours
Case Studies

• Computational solutions and challenges for large traditional TDF models
  ▪ MWCOG / WMATA

• Advanced demand models integrated with traditional network models
  ▪ DRCOG / RTD

• Advanced demand models integrated with regional simulation models
  ▪ SHRP2-C10 Jacksonville
MWCOG / WMATA – DC/VA/MD

- MWCOG version 2.3 model
  - Traditional TDF model using Cube software
  - Expanded zone structure to 3,722
  - 25 million person trips, 1.6 million transit trips
  - New mode choice models use 22 transit paths
  - Assigns 4 periods, 6 user classes, to $10^{-4}$ or better
  - 5 global speed feedback loops

- WMATA post processing model
  - Models each trip purpose by time of day
  - Park-&-ride capacity constraints
Model Run Times

- Tested several options to gage run times
  - Congestion level (year), assignment algorithm, and distributed processing through Cube Cluster
  - Most regional agencies limited to 4 core computers

<table>
<thead>
<tr>
<th>Year</th>
<th>Algorithm</th>
<th>Cores</th>
<th>Hours</th>
<th>Days</th>
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</thead>
<tbody>
<tr>
<td>2007</td>
<td>Frank-Wolfe</td>
<td>1</td>
<td>95</td>
<td>4.0</td>
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<tr>
<td>2040</td>
<td>Frank-Wolfe</td>
<td>1</td>
<td>109</td>
<td>4.6</td>
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<td>77</td>
<td>3.2</td>
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<td>2007</td>
<td>Bi-conjugate FW</td>
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<td>75</td>
<td>3.1</td>
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<tr>
<td>2007</td>
<td>Conjugate FW</td>
<td>4</td>
<td>37</td>
<td>1.5</td>
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<td>2007</td>
<td>Bi-conjugate FW</td>
<td>4</td>
<td>33</td>
<td>1.4</td>
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<tr>
<td>2040</td>
<td>Bi-conjugate FW</td>
<td>4</td>
<td>48</td>
<td>2.0</td>
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</tbody>
</table>
Effect of Cube Cluster on Results

- Parallel assignments generated small VMT differences; some significant volume differences; and illogical convergence results
  - “Standardize” to 4 core computing as a result

<table>
<thead>
<tr>
<th>Year</th>
<th>Algorithm</th>
<th>Cores</th>
<th>VMT</th>
<th>% Diff</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>Conjugate FW</td>
<td>1</td>
<td>156,698,908</td>
<td></td>
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<tr>
<td>2007</td>
<td>Conjugate FW</td>
<td>4</td>
<td>156,653,683</td>
<td>-0.03%</td>
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<tr>
<td>2007</td>
<td>Bi-conjugate FW</td>
<td>1</td>
<td>156,697,741</td>
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<tr>
<td>2007</td>
<td>Bi-conjugate FW</td>
<td>4</td>
<td>156,674,456</td>
<td>-0.01%</td>
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</tbody>
</table>
Daily Volume Different by > 20%
Assignment Convergence Problem

Relative Gap: Ver. 2.3.34 travel model
BC Frank-Wolfe, 2040_final, 10^-6 relgap, speed feedback iteration 1
Network: Based on 2010 CLRP; Tolls: Not optimized

User equilibrium iteration
- AM nonHOV3+
- AM nonHOV3+
Performance Improvement Task

- Highway Skims (Composite)
- Transit Skims (Best Path)
- Trip Generation
- Trip Distribution
- Mode Choice
- Time of Day
- Assignment

Feedback

Identified for parallelization

4/29/2012 Integrated Transportation Modeling
Time Savings from Parallelization

- Highway and Transit Skims
  - Process time periods together
- Trip Distribution
  - Process trip purposes together
- Mode Choice
  - Process trip purposes together
- Highway/Transit Assignment
  - Process time periods together
  - Combine non-HOV and HOV
- ~40% savings for all steps
Relaxing the 4 Core Standard

- Parallelizing the WMATA post-processor
  - Using a 64 core server
- Implemented outside of Cube Cluster

<table>
<thead>
<tr>
<th>Process</th>
<th>Steps</th>
<th>Sequential</th>
<th>Parallel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Access Links</td>
<td>4 steps</td>
<td>35 minutes</td>
<td>2 minutes</td>
</tr>
<tr>
<td>Path Building</td>
<td>22 paths</td>
<td>66 minutes</td>
<td>3 minutes</td>
</tr>
<tr>
<td>Transit Fares</td>
<td>22 updates</td>
<td>60 minutes</td>
<td>3 minutes</td>
</tr>
<tr>
<td>Mode Choice</td>
<td>6 models</td>
<td>60 minutes</td>
<td>10 minutes</td>
</tr>
<tr>
<td>Assignment</td>
<td>22 tables</td>
<td>66 minutes</td>
<td>3 minutes</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>227 minutes</td>
<td>21 minutes</td>
</tr>
</tbody>
</table>
Lessons and Findings

- Significant computational saving can be achieved by simple parallel processing
  - The basic concept and processing mechanism is not well understood by traditional TDF modelers
  - Highway assignment is still the major bottleneck
- Changing the computing configuration should not change the model results
  - Single CPU, multi-threaded or computer cluster
DRCOG / RTD – Denver

- DRCOG developed tour-based FOCUS model
  - TransCAD 5.0, C# and SQL Server
  - Windows Enterprise Server, 32 CPUs, 64GB memory
  - 2,832 zones and activity points
  - 8 modes, 6 tour purposes – DaySim family (CS)
  - 10 highway time periods, 4 transit time periods
  - 3 feedback loops → 60 hour runs
  - Includes simplifying compromises to reduce run times

- RTD still uses older trip-based COMPASS model for FTA New Starts work
Basic Modeling Steps

<table>
<thead>
<tr>
<th>Model Component</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population Synthesizer</td>
<td>Households and Person Tables</td>
</tr>
<tr>
<td>Database Stored Procedures</td>
<td>Database Filled with Imported Zones, Prices, Derived Variables, Linkage Tables</td>
</tr>
<tr>
<td>PopSyn Output Processor</td>
<td>Household Person Cards</td>
</tr>
<tr>
<td>TransCAD General Pre-process</td>
<td>TransCAD Network Created</td>
</tr>
<tr>
<td>TransCAD Network Skims</td>
<td>nuts Matrices</td>
</tr>
<tr>
<td>TransCAD Multi-Period/Highway/Transit Price Process</td>
<td>Multiple Networks Generated: Preprocessed prices matrix</td>
</tr>
<tr>
<td>TransCAD DIA</td>
<td>BIA, Congestion, KDE, Highway and Transit Trip Matrix by time of day</td>
</tr>
<tr>
<td>Regular Workplace Location Choice</td>
<td>Persons Table Updated: Workers Given Regular Work Location Zone and Point</td>
</tr>
<tr>
<td>Regular School Location Choice</td>
<td>Persons Table Updated: Students Given Regular School Location Zone and Point</td>
</tr>
<tr>
<td>Auto Availability Choice</td>
<td>Households Table Updated: Households Given Number of Auto Availability, 0, 1, 2, 3, 4+</td>
</tr>
<tr>
<td>Aggregate Destination Choice Logsum Generation</td>
<td>Households Table Updated: Households Given Aggregate Mode Destination Choice Logsums</td>
</tr>
<tr>
<td>Daily Activity Pattern Choice</td>
<td>Persons Table Updated: Persons Given Daily Activity Pattern</td>
</tr>
<tr>
<td>Exact Number of Tours Choice</td>
<td>Out Number of Tours Created: Tours Table Created with Tours by Purpose and/or Persons</td>
</tr>
</tbody>
</table>

| 1 | Work Tour Destination Type Choice |
| 16 | Work-Based Subtour Generation Choice |
| 17 | Tour Time of Day Simulation |
| 18 | Tour Primary Destination Choice |
| 19 | Trip Time of Day Simulation |
| 20 | Tour Mode Choice |
| 21 | Intermediate Stop Location Choice |
| 22 | Trip Mode Choice |
| 23 | Trip Time Choice |
| 24 | Write Trips to TransCAD |
| 25 | Assignment, Convergence, Test, Summary and Speed Balancing |

4/29/2012 Integrated Transportation Modeling
Zone Points
Model Migration Plans and Issues

- Seeking FTA acceptance for New Starts work
  - How / where to freeze the “trip tables” for SUMMIT
    - Tour Mode Choice appears to be the best option
  - Improve model consistency throughout the process
  - Remove simplifying compromises in transit models
- Hardware/software distribution issues
  - Expensive purchase – ~$35,000 hardware/software
  - Hard to install and operate – locked server room
- Address run time bottlenecks
  - Current process is only using about 10% of CPUs
Optimize Database Interface

- Standard database software is not well suited to transportation applications
  - Designed for fast queries and interactive editing
  - Updating all data records by sequential or multi-threaded writes is expensive
    - Record locks and index/relationship maintenance is time consuming
  - Faster to re-create the database using a bulk load and relaxed relationship checks
    - Create a “trusted” partnership between the transportation models and the database software
    - Update indices and relationships “offline”
Park-&-Ride Partially Implemented

- **Only Tour Mode Choice**
  - No intermediate stops or trip mode choice → P-A loading
  - Impedance based on 2*outbound path
- **Not modeled like other modes**
  - TransCAD path building limitations
- **Suggested Improvements**
  - Build return trip skims through the outbound parking lot
    - Park-n-ride (O-P-D) + walk-transit (D-P) + drive (P-O)
  - Use the walk-transit and drive skims from the return trip time period
    - For example: AM outbound → PM return
  - Assign in O-D format like other modes
TransCAD Performance Issues

• Reading O→D and D→O matrix cells from 100+ tables is prohibitive
  ▪ Transpose D→O and attach to O→D rows
    • AM depart – AM, MD, PM, EL return

• Implementation options
  ▪ GISDK with cell reads/writes → 30 hours
  ▪ GISDK with vector reads/writes → 3+ hours
  ▪ Custom software using CaliperMTX.dll → 8 minutes
    • Read tables into memory, merge, and write

• Streamline other model components
Lessons and Findings

- Databases are nice for analyzing results, but need to be optimized for in-line modeling
  - Store data in memory or flat files and do bulk loads to the database at the end of the process or off-line
- “Standard” GISDK interfaces are not always the most efficient approach to TransCAD models
  - Manipulate files for processing efficiency
  - If you have memory, use it
SHRP2-C10 – Jacksonville

- **DaySim tour-based demand model**
  - Parcel-based, 30 minutes activity schedules
    - 22 time periods (30 mins. in peaks) by 1335 zone skims
  - Outputs person activities assigned to one minute schedules and TRANSIMS activity locations

- **TRANSIMS regional simulations**
  - Dynamic user-equilibrium simulation
    - One second time steps for 27 hour day
    - Trip gap and link gap convergence criteria
  - Generates zone-to-zone skims using 5 minute increments of link and turning movement delays
Processing Time

- **TRANSIMS (v4.0) Router – Microsimulator**
  - Typically run on the TRACC Linux cluster using parallel processing of single thread executables
    - 16 or more plan partitions for Router and Plan processing
    - Single CPU for PlanSum and Microsimulator
  - Each iteration takes ~3.5 hours
  - Network stabilizes in about 20 iterations – ~3 days
  - RSG gap criteria requires ~60 iterations – ~9 days
  - RSG does 4 global iterations – ~36 days
- Upgrade to TRANSIMS (v5.0) for MPI and multi-threaded software performance
TRACC Computer Cluster
Integrated Computations

- File input/output and data manipulation is a huge component of run times
  - If the computer has sufficient memory and CPUs, keep data and iterations in memory
- Simulator processing and convergence
  - Time sorted, geographic partitions
  - Vary level of computational resolution by iteration
    - Time-based flows-speeds to macro, meso, micro-simulation
- Integrate Router and Simulator
  - Build paths that start at each time increment
Software Performance Lessons

- **Isolate independent calculations**
  - Processing threads or partitioned applications

- **Preserve input/output order**
  - Processing threads write to an ordered queue that an output thread uses to write to the output file

- **Avoid file or data locks and input/output**
  - Write to shared memory if data records are fixed and the thread has unique record ownership
  - Use private thread-based memory to hold data until a data exchange is required
Modeling Principals

- Changing the computing configuration should not change the model results
  - Single CPU, multi-threaded or computer cluster
- Changing the data partitioning or re-running the model should not change the model results
  - Random impacts should be consistent and reproducible
- Balance run times with computer requirements
  - Advanced models require high performance computing \(\rightarrow\) application and staffing challenges