

TRANSIMS Training Course at TRACC

Transportation Research and Analysis Computing Center

Part 1

Introduction to the Methodologies and Implementation of TRANSIMS

Dr.-Ing. Hubert Ley

Transportation Research and Analysis Computing Center

Last Updated: December 9, 2009

1
Unit



TRACC - TRANSIMS Training Course

Contents

- Background of TRANSIMS
- Data sources and requirements
- The basic TRANSIMS methodology
- Trip based modeling versus activity based modeling
- Population Synthesizer
- Activity Generator
- Router
- Microsimulator
- Visualization examples
- TRANSIMS resources
- Summary



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:

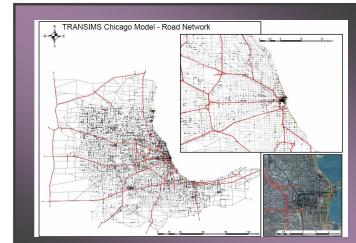
<http://www.transims-opensource.net>

- Latest Release: Version 4.06, released in November 2009

3

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 (>>30,000,000* 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.

4

Background

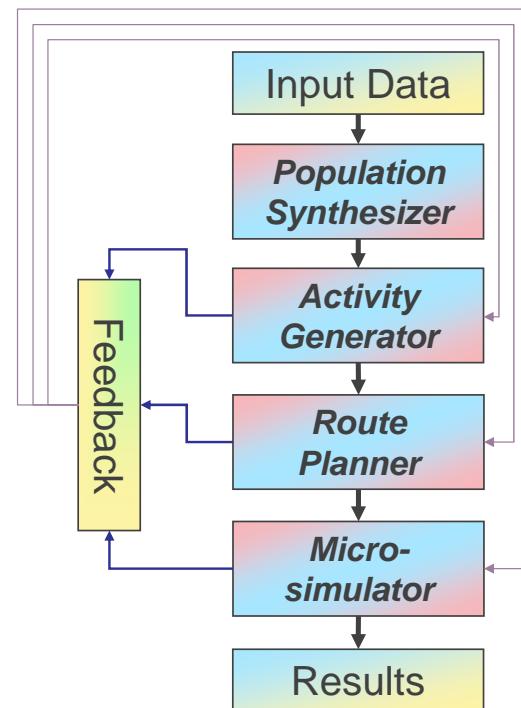
- TRANSIMS results
 - Detailed snapshot data: the location of each individual traveler, car, or transit vehicle is known for every second of the day
 - Statistics on traffic flow, congestion, queues at intersections, and much more
 - Time-dependent link delays for the entire road and transit network

- 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

5

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

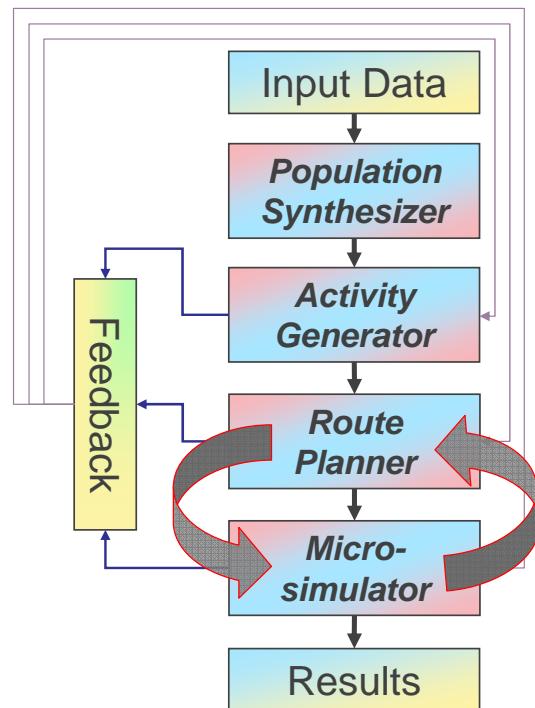


Generalized TRANSIMS Flow Chart

6

Basic TRANSIMS Methodology

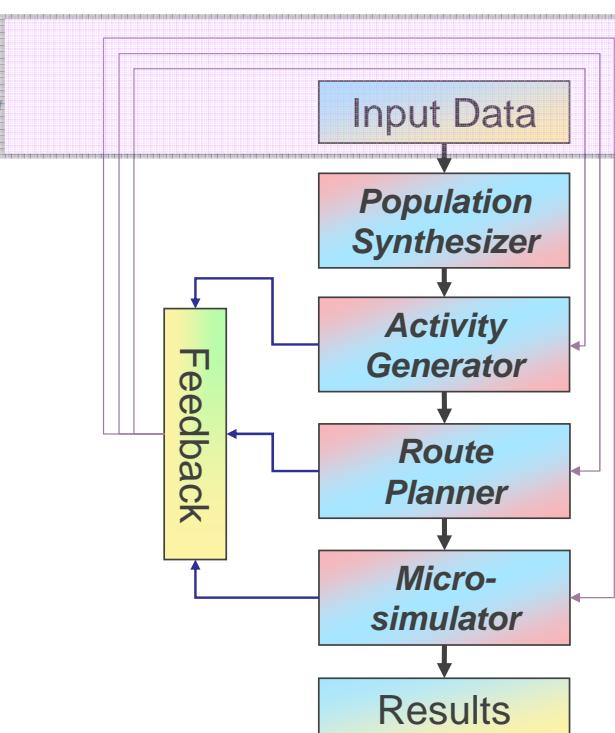
- The goal is to load traffic onto the network and iterating towards the Nash equilibrium
 - Travelers cannot achieve significantly better routes when trying to choose a shorter path, meaning that each traveler chooses the route that's best for the overall population
- Important constraint
 - Travelers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



7

TRANSIMS Step by Step

- Create a Road Network
- Create a Transit Network
- Obtain Transit Schedules

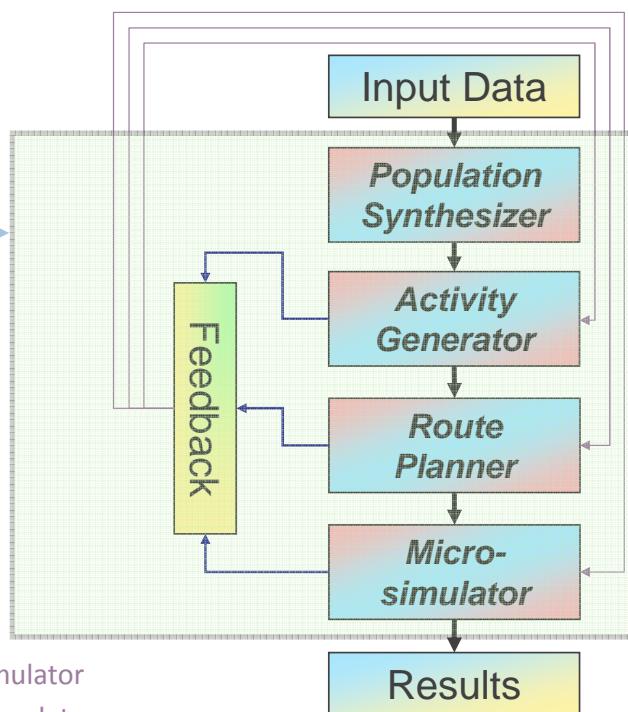


8

TRANSIMS Step by Step

- Create a Road Network
- Create a Transit Network
- Obtain Transit Schedules
- Methodology #1
 - Obtain Census Data
 - Obtain Activity Survey
 - Run Population Synthesizer
 - Run Activity Generator

-
- Create Travel Plans from Activities using the Router
 - Test the Travel Plans in the Microsimulator
 - Iterate Between Router and Microsimulator

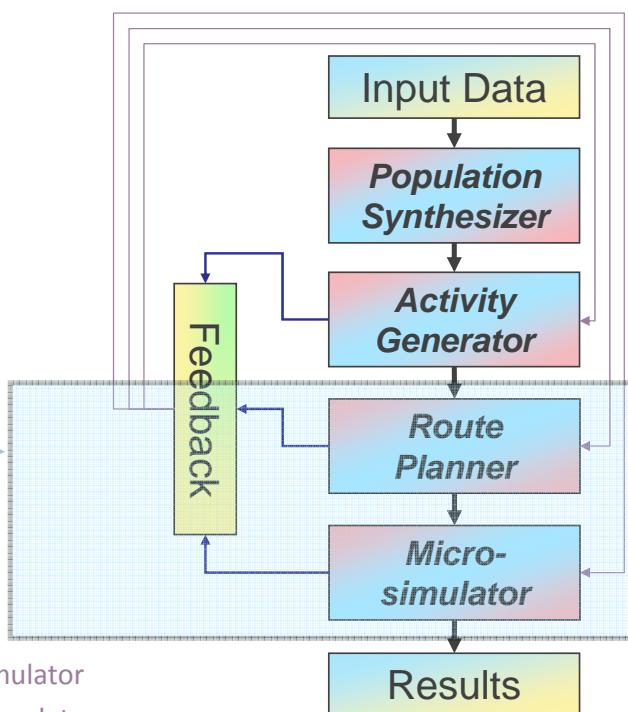


9

TRANSIMS Step by Step

- Create a Road Network
- Create a Transit Network
- Obtain Transit Schedules

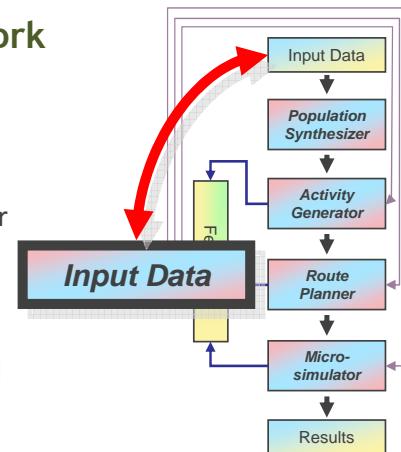
- ↓
- Methodology #2
 - Obtain Trip Tables
 - Obtain Diurnal Distributions
 - Run Trip Converter
 - Create Travel Plans from Trips using the Router
 - Test the Travel Plans in the Microsimulator
 - Iterate Between Router and Microsimulator



10

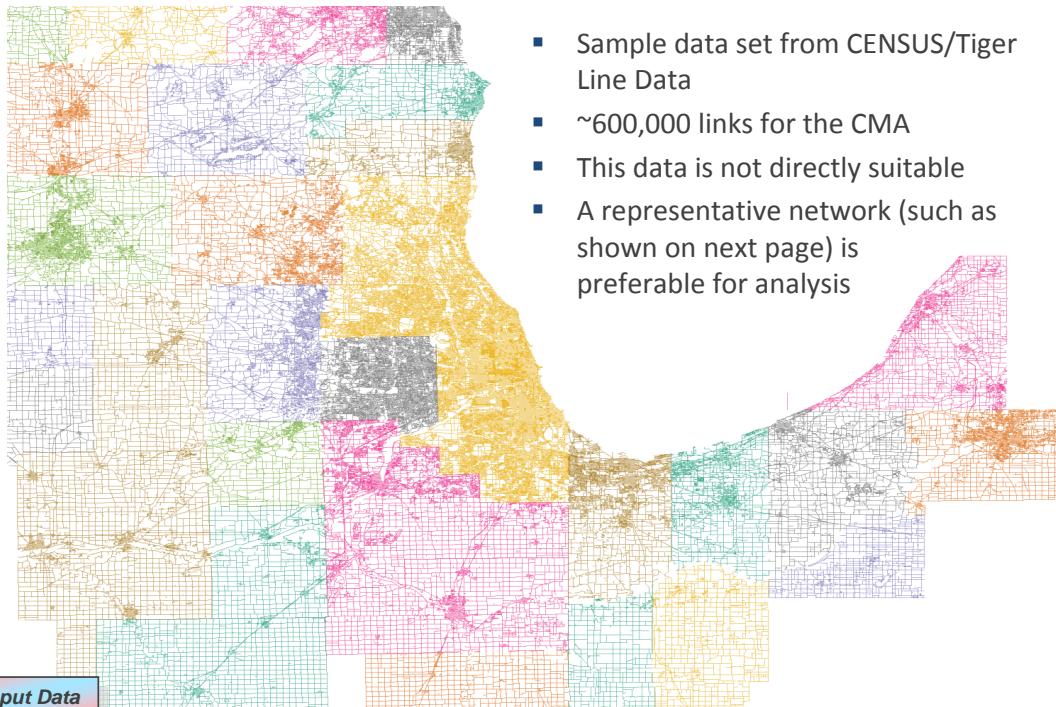
Input Data - The Road and Transit Network

- Typically, street and transit networks are available from metropolitan planning organizations
- Road and transit networks can be exported from other traffic analysis tools into a fairly simple tabular format
 - Nodes, Links, Zones, etc.
- TRANSIMS is able to make use of some common GIS tools and formats with regards to network editing and cutting
- TRANSIMS understands important geographic projection systems (state plane system, universal transverse mercator system, etc.)
- Tools are available to convert TRANSIMS network components into GIS shape files for effective visualization and editing
- Tools exist to single out a smaller area within the simulation and to extract it from the overall network based on complex polygons



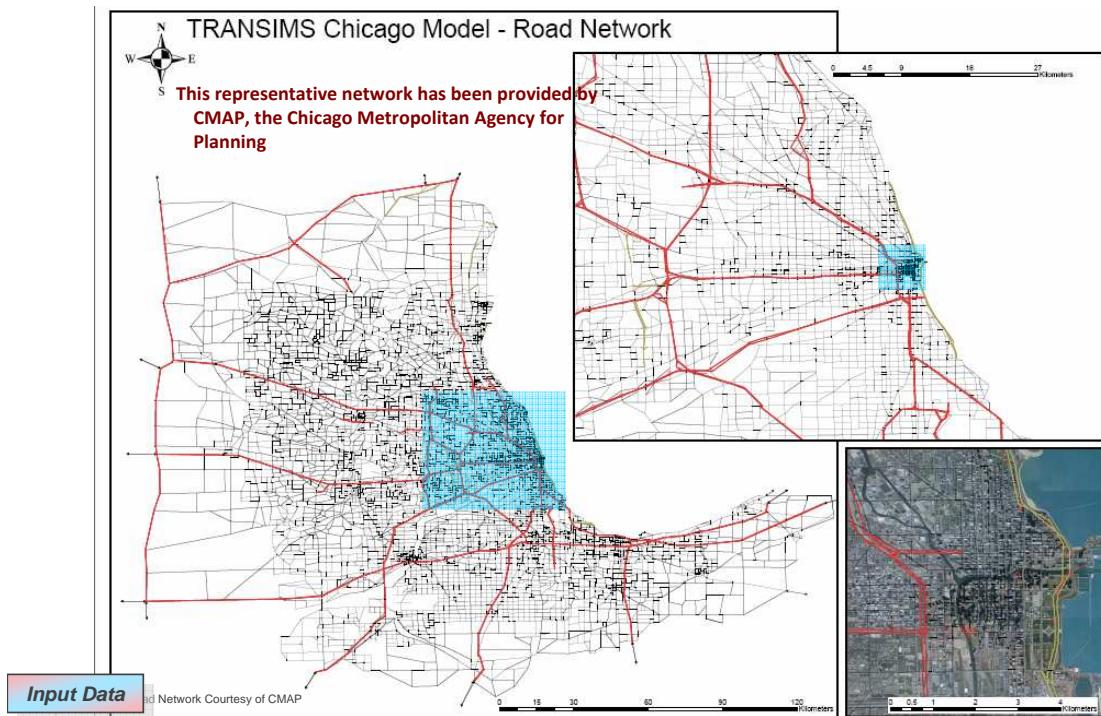
11

Example Metropolitan Network (Chicago, Source: TIGER)



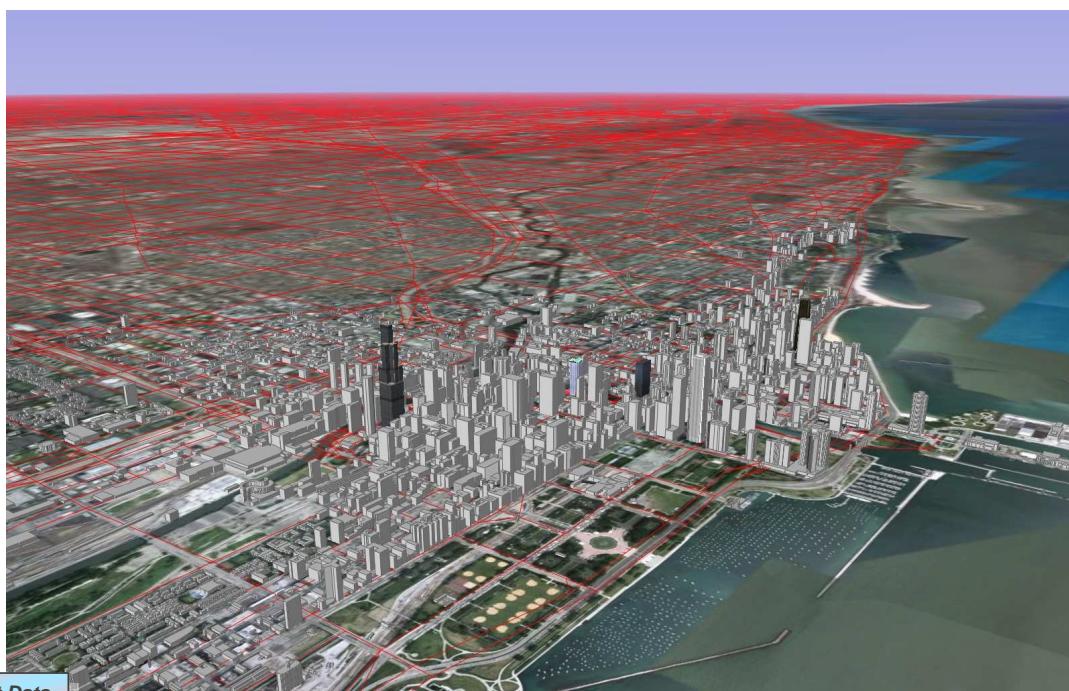
12

Example Metropolitan Network (Chicago, Source: CMAP)



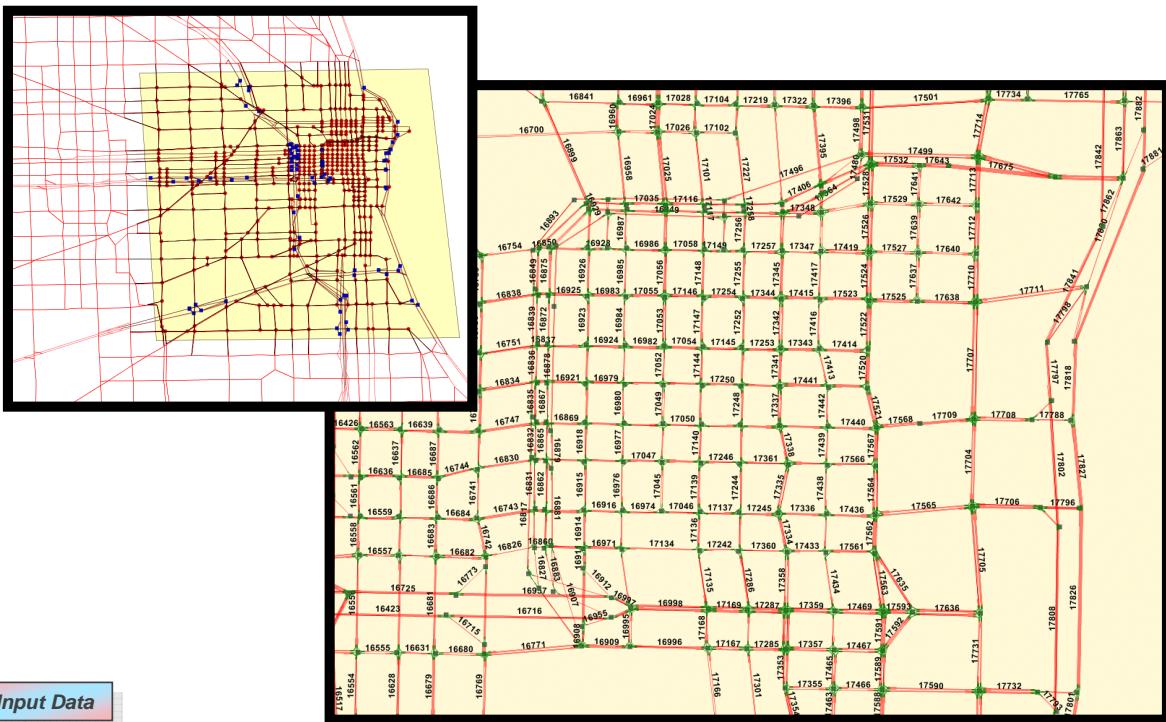
13

Example Metropolitan Network (Chicago, Source: CMAP)



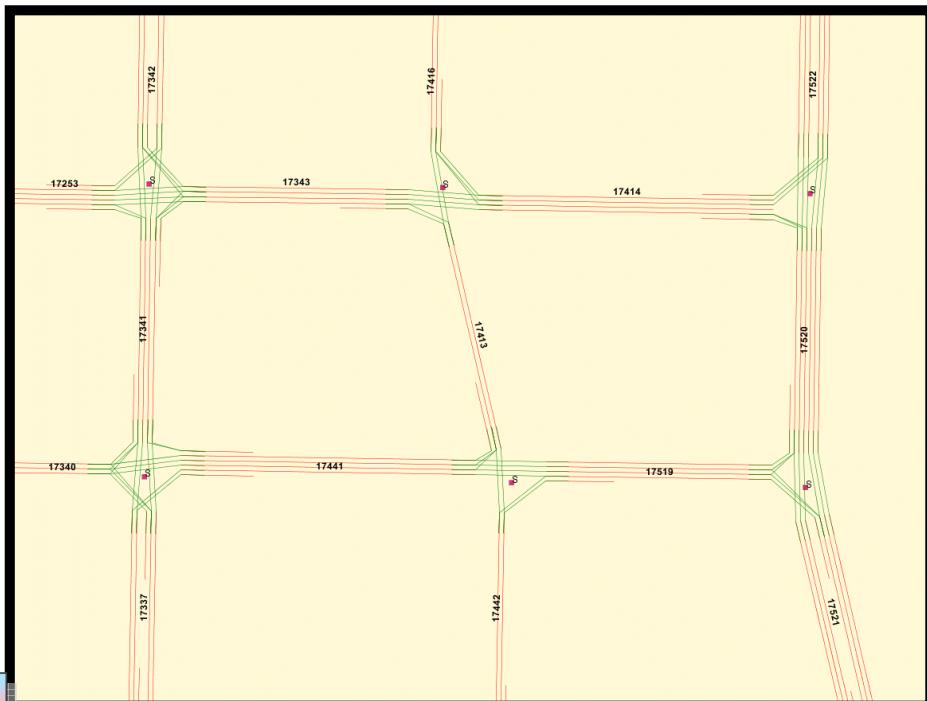
14

Example Metropolitan Network (Chicago, Source: CMAP)



15

Example Metropolitan Network (Chicago, Source: CMAP)



16

TRANSIMS Street and Transit Network Challenges

- Street Networks
 - Generally available data sources are public Census Tiger/Line, commercial NavTeq, and especially networks already prepared and maintained by metropolitan planning organizations
 - May be detailed (full) or representative (reduced)
 - Needs many details that are not typically provided by common data sources (traffic signals, turn lanes, and much more)
 - Must be topologically appropriate (connections between links must be consistent and representative)

- Transit Networks
 - Must be compatible with the street network layer
 - Data must be usually compiled from several independent sources
 - Buses are flowing with the traffic, therefore given bus schedules may conflict with microsimulator results

Input Data

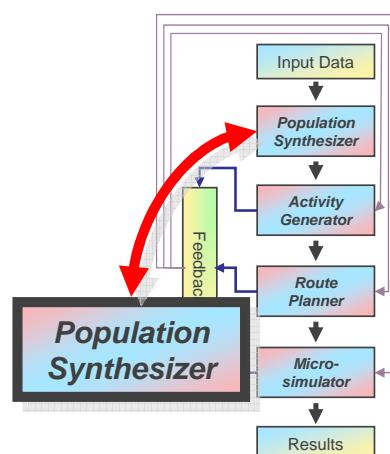


17

The TRANSIMS Population Synthesizer

- Mimics regional population (“synthetic population”)
 - Demographics closely match real population
 - Households distributed spatially to approximate regional population distribution
 - Household locations determine some of the travel origins and destinations

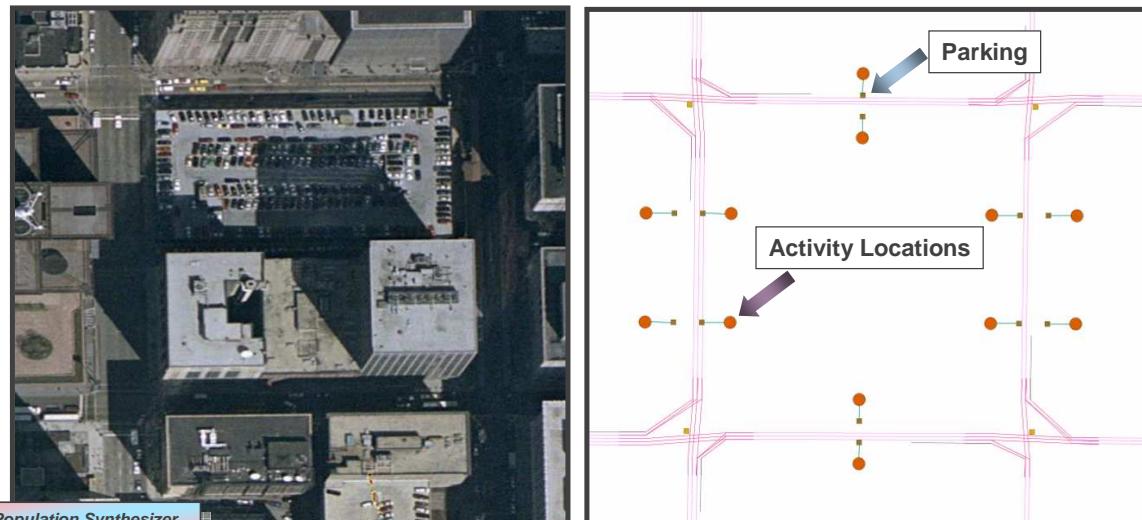
- Functions of the Population Synthesizer
 - Generation of synthetic households from census data at the block group level
 - Development of each household demographic characteristics (income, members, etc)
 - Placement of each synthetic household on a link in transportation network (activity locations)
 - Assignment of vehicles to each household (sharing vehicles and rides within a household)



18

The TRANSIMS Population Synthesizer

- Real population versus synthetic population
 - Activity locations
 - Generic parking



19

The TRANSIMS Population Synthesizer

- Synthetic populations are largely built from anonymous US CENSUS data
- www.census.gov**
- CENSUS data has been made anonymous
 - Data is freely available for the entire US from the CENSUS web site
 - Types of applicable data:
 - STF3 data is aggregate data describing relatively small regions named block groups (for about 4,000 households each)
 - PUMS data is a 5% sample of the actual questionnaire records, made anonymous but being representative for the area (for about 100,000 households)

<input checked="" type="checkbox"/>	?	?	?
<input checked="" type="checkbox"/>	?	?	?
	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>

STF3: Aggregate data only, but covering a small area in full

<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>

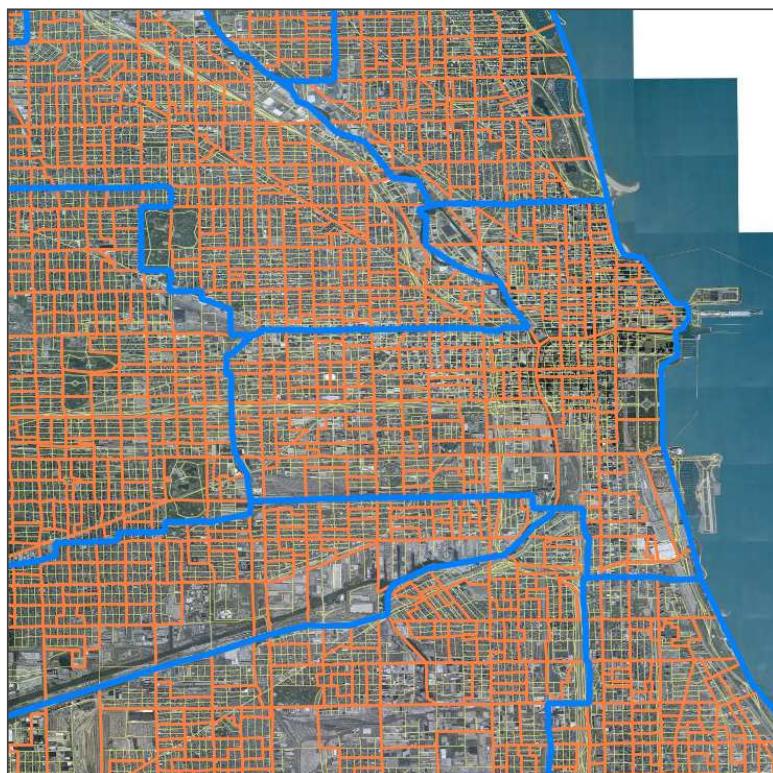
PUMS: Disaggregate data, but covering a much larger area and reduced to a 5% sample

Population Synthesizer

20

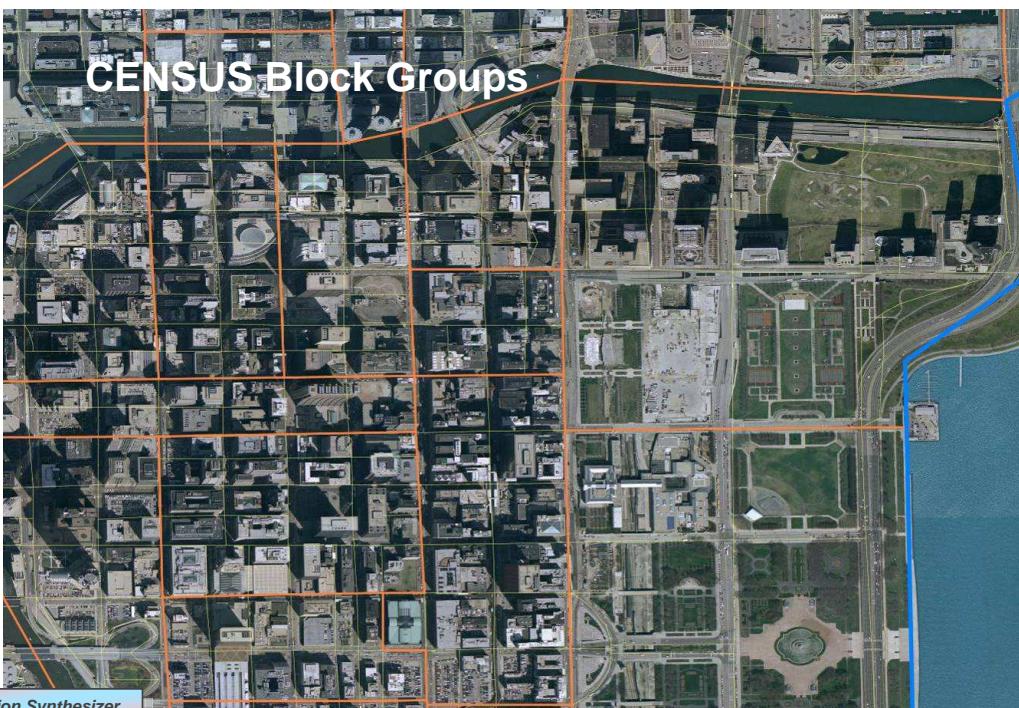
The TRANSIMS Population Synthesizer

- **BLUE**
PUMS 5% Sample Data
- **ORANGE**
Aggregate STF3 Data
- **YELLOW**
Street Network



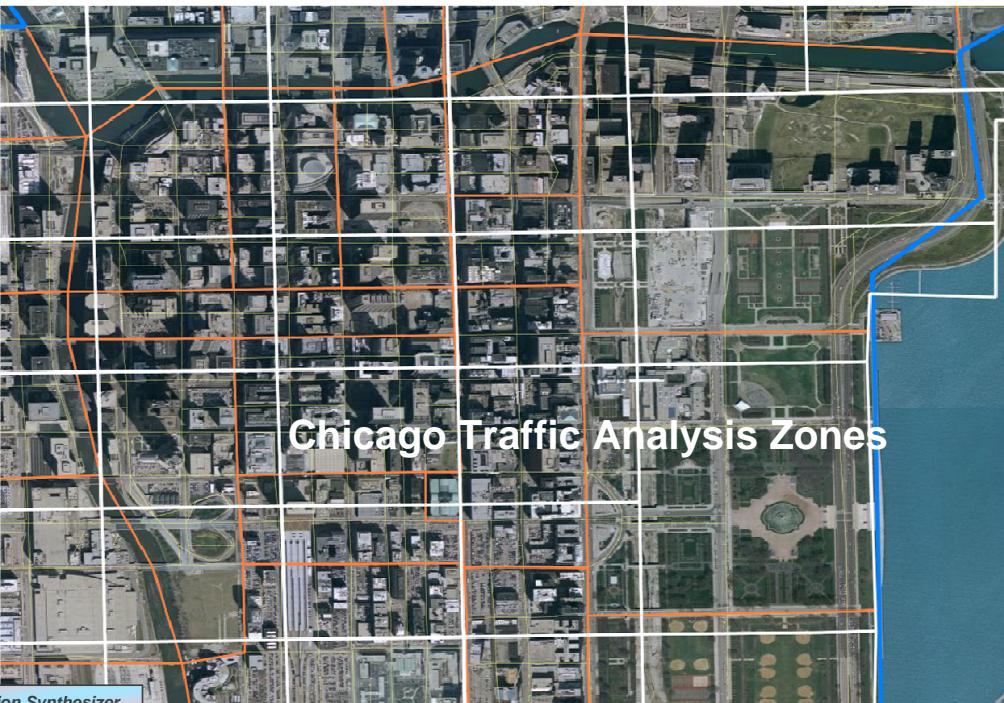
21

The TRANSIMS Population Synthesizer



22

The TRANSIMS Population Synthesizer



Population Synthesizer Challenges

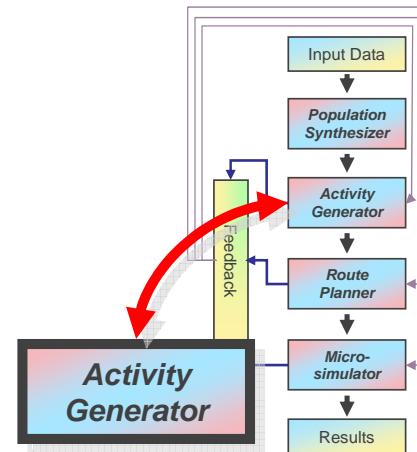
- Extrapolation of CENSUS data to the current point in time
 - CENSUS is only conducted every 10 years
 - Not all necessary data may be collected in the future
- Extrapolating the anonymous aggregate data and sample records to build a synthetic population
 - **Resolution:** TRANSIMS “activity locations” are distributed on a much finer grid than CENSUS data is provided for
 - **Zoning:** Additional land use data is necessary to allocate households appropriately to activity locations (home, work, schools, shopping)

Population Synthesizer



The TRANSIMS Activity Generator

- The activity generator is used to determine the “demand” for trips that will be loaded onto the road and transit network
- The activity generator uses the synthetic population generated in the previous step to assign transportation actions to all individual people in the given households
- Additional data is needed to assign individual activities to all simulated individuals
 - The main input data is a detailed activity survey that is representative for the simulated area
 - The data consists typically of a few thousand records derived from telephone surveys



- The records capture all activities of interviewed individuals throughout the day, e.g.
 - 7am to 8am breakfast
 - 8am to 9am drive to work
 - 9am to 1pm work
 - ...

25

The TRANSIMS Activity Generator

- Activities versus trips
 - Activities provide a higher level of “knowledge” and are highly disaggregate
 - Transportation is only the means to accomplish the primary goals of individuals, e.g. working, school, shopping
 - Trips are largely driven by non-transportation activities
 - Trips are therefore derived from activities and become tours
 - chaining individual trips together based on known individuals
 - Enables the modeler to track (synthetic) individuals at all times
 - therefore provides a platform for human behavior modeling
- Activity survey data
 - Difficult and expensive to obtain
 - Must be representative for the entire study area
 - Activities and travel behavior change quickly based on population growth and changing infrastructure, making surveys easily obsolete

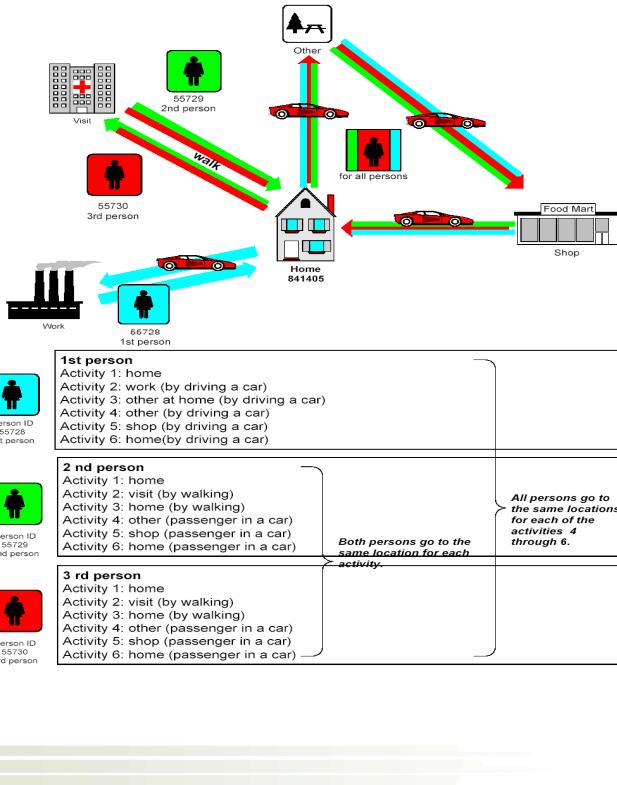
Activity Generator

26

Advantages of Activity-Based Simulation

- Activity-based modeling allows tracking of dependencies between individuals (within households at this time)
- For future extensions, activity-based modeling allows the implementation of reasoning and human behavior
 - This may be important for special cases such as the modeling of emergency scenarios and evacuation planning

Activity Generator



27

The TRANSIMS Activity Generator

- General activity assignment process
 - Surveys are sparse (providing at the most thousands of records)
 - Surveys contain socioeconomic data
 - Use the socioeconomic data to match synthetic households with corresponding survey households (using CART)
- Small random variations are applied to survey records to avoid exact duplications for the many different synthetic households they are assigned to

Activity Generator



28

The TRANSIMS Activity Generator

- Destination choice model
 - Home locations for all households have been previously assigned by the population synthesizer
 - Activities include work, school, shopping, recreation, and many more
 - Destinations are based on zoning information (embedded in activity locations)
 - First, a work location is chosen based on survey travel times and following a “gravitational” model
 - Other activities are assumed to be likely close to either work or home and are chosen as a secondary step
- Transportation mode
 - The mode of transportation (e.g. walk, drive, bus, rail) is determined by the survey records, and does not result from the route optimization

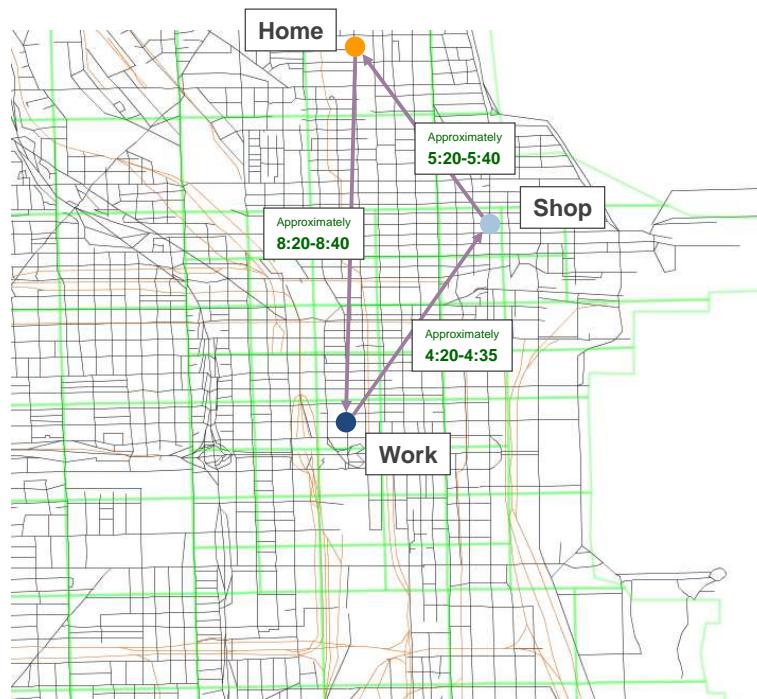


29

The TRANSIMS Activity Generator

Example:

- Based on the travel time to work and the “gravitational attraction” of possible employment locations, the individual is assigned a work location in the Sears tower
- The afternoon shopping trip (from the survey) causes the person to make a stop on Michigan Avenue



30

The TRANSIMS Activity Generator

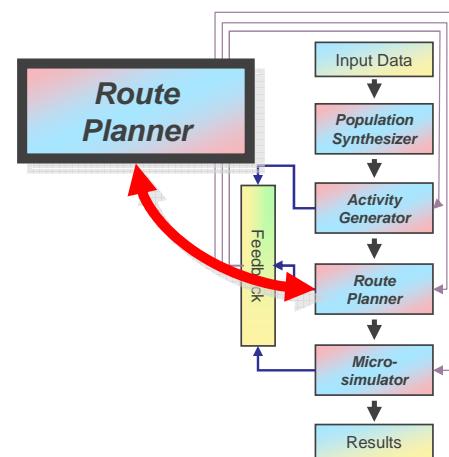
- The modification of activities may be part of the iterative solution
 - The activity generator's extrapolation of survey records may be too coarse
 - Assumptions on the availability of transit connections may be incorrect
 - Dependencies between the activities of all members of a household may be illogical or unfeasible
- Challenges for the TRANSIMS Activity Generator
 - Limited sample size in the survey may create a coarse activity distribution
 - Depends on the availability of a recent and up to date activity survey
 - Depends on detailed zoning information and requires manual adjustments
 - May lead to some illogical activity patterns for certain regions



31

The TRANSIMS Route Planner

- The TRANSIMS route planner reads the individual activities from the activity generator and determines the fastest route at that time of the day
- Households are routed in a coordinated fashion to allow for ride sharing, such as dropping children off at school.
- The algorithm considers a very detailed time-dependent network based on link delays for each link that vary during the course of the day
- The transportation mode is part of the activity record (or trip record); the router does not choose the transportation mode but finds the best route given the mode of transportation (e.g. choosing the best rail or bus stations for the traveler based on departure details)



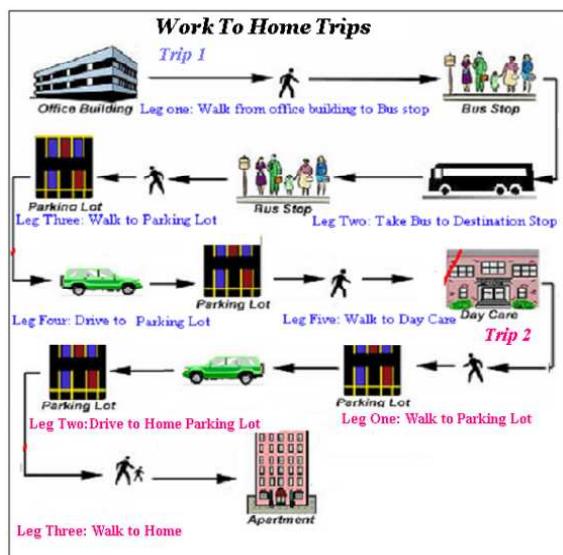
- The route planner is somewhat comparable with services such as MapQuest, but includes time-dependent optimization as well as transit, bicycling, walking, driving, and more



32

Route Planner: Tours, Trips, Legs, and Travel Modes

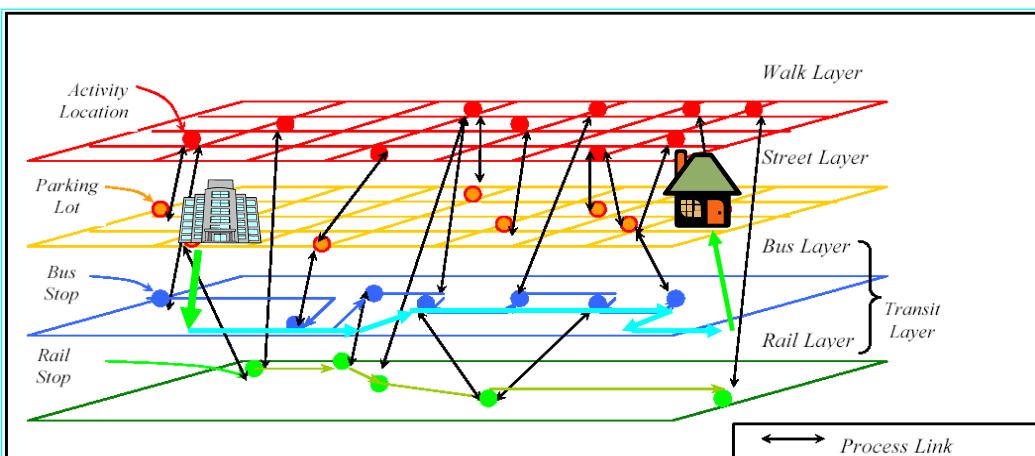
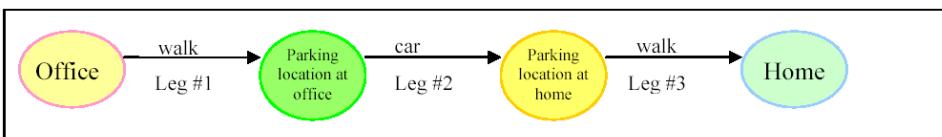
- The symbols represent different transportation modes:
 - w** = "walk," **c** = "car," **b** = "bus," **l** = "light rail"
- A series of symbols expresses a mode string:
 - wcw** = "walk, then drive a car, then walk"
 - wcwbw** = "walk, then drive to a transit stop, then take bus, then walk"
 - wbwlwbw** = "walk, ride bus, then transfer to light rail, then walk to a bus stop, then ride bus, then walk"
 - w** = "only walk"



Route Planner

33

Route Planner: Shortest Path Based on a Mode String

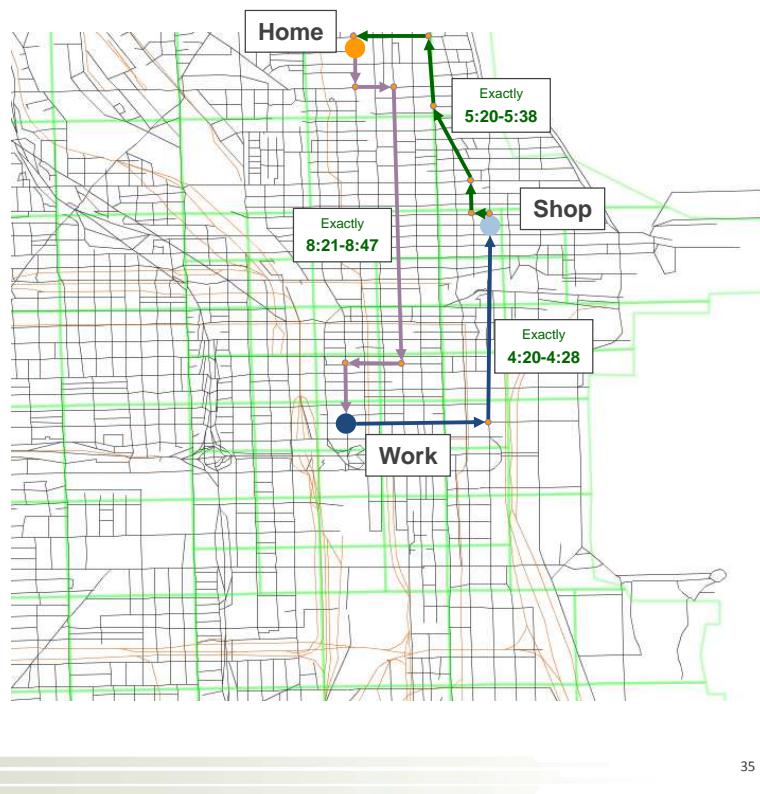


Route Planner

34

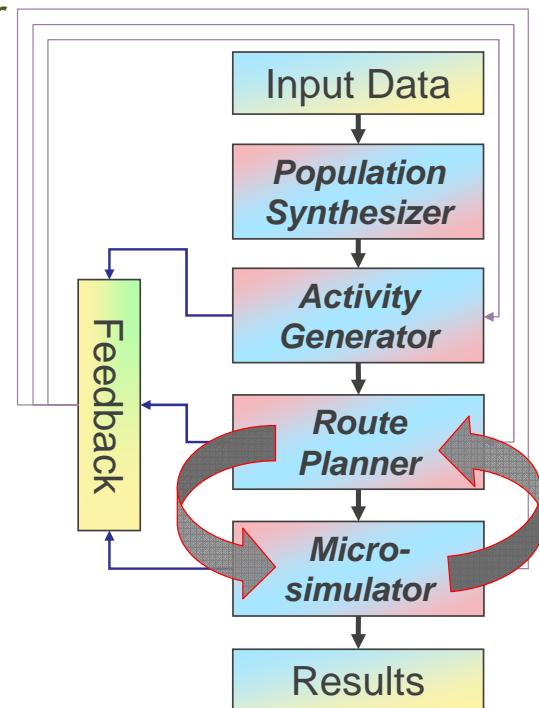
The TRANSIMS Route Planner

- The router is aware of current link delays at any time during the day (based on results from microsimulation)
 - An approximated trip assigned by the activity generator is now routed at precise times through specific links and nodes
 - The resulting plans contain the exact departure and arrival times based on the router's knowledge of the overall congestion pattern in the simulation area



Route Planner and Microsimulator

- The route planner and the microsimulator (see next chapter) work in an iterative loop to equilibrate the traffic assignments on the network
 - The router starts by using well-known traffic assignment functions (BPR+) to estimate link delays based on the number of trips routed through each link
 - The router determines the optimal route for each trip and creates precise travel plans
 - The microsimulator tests the interaction between the vehicles while following these travel plans and determines a new set of link delays replacing the ones used previously by the router
 - The router and microsimulator iterate until equilibrium is achieved



The TRANSIMS Route Planner

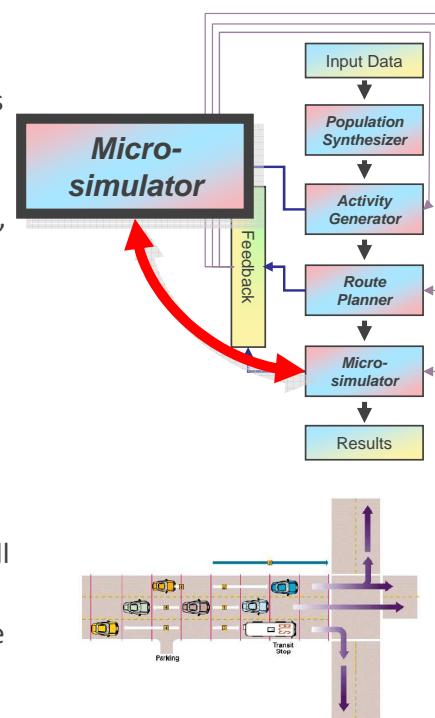
- Challenges
 - The quality of the underlying network (both for roads and transit) is very important
 - The file storage requirements are significant, e.g. 1.4GB of individual driving trip data (~25,500,000 daily trips) for the Chicago model turn into approximately 6.2GB of plan files
 - The routing process is complex and requires significant CPU time, especially considering that each traveler and trip in a metropolitan area must be routed repeatedly during iterations with the microsimulator (~24 hours of CPU time for 25,500,000 trips)
- Current development (Fall of 2009)
 - A parallel version of the router is currently under construction to make use of the implicit parallelism of routing. Prototype has been run on Chicago and Atlanta networks successfully.
 - The parallel version makes use of multi-core machines and high performance clusters to reduce computation time significantly



37

The TRANSIMS Microsimulator

- The Microsimulator executes all travel plans determined by the router on a second by second basis on a highly detailed network
- The Microsimulator uses cellular automata principles to analyze the interaction between individual vehicles, producing emergent behaviors such as traffic congestion
- The Microsimulator can be used to work on the entire metropolitan area or may be used on a smaller region only
 - Additional tools are provided to link the routing process for the metropolitan area properly with the microsimulation of a smaller region
- The Microsimulator produces individual locations of all travellers and vehicles at all times
- The Microsimulator calculates new link delays that are being used iteratively to selectively reroute some travellers in the equilibration loop

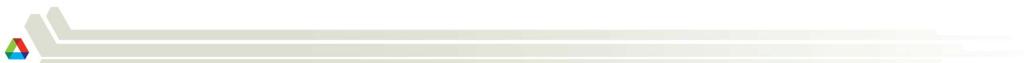


38

Simulation Details

- Walk Legs
 - Not explicitly simulated
 - Begins at the time specified at the point of origin for the leg
 - The traveler arrives at the destination point at time computed by adding the delay time to the start time for the walk leg
- Driving Legs
 - Starts and ends at parking location
 - Traveler associated with specific vehicle
 - Vehicle must be present or traveler waits for vehicle to arrive
 - Plans dictate movement on network by specifying route to follow
 - Plans also specify if there is a pick-up to be made
- Bus Legs
 - Considers delays for loading and unloading
 - Capacity and resource constraints observed
 - Traveler boards at bus stop then rides it until desired stop and exits
 - Itinerary of the bus determined by the bus schedule
 - Travelers plans require information on the acceptable bus routes

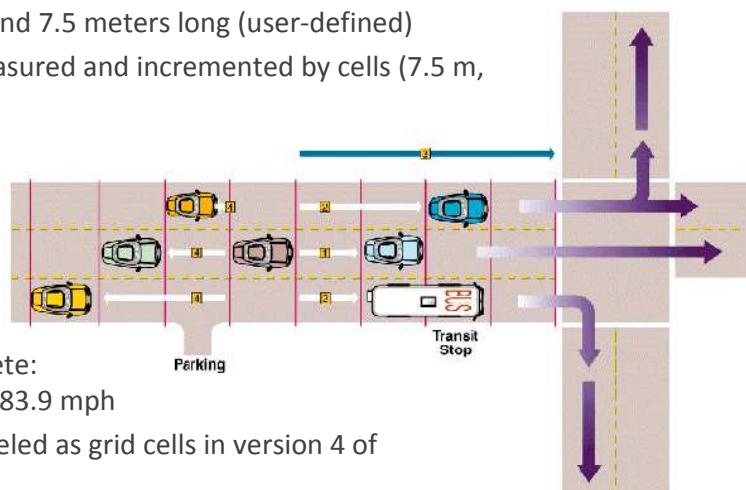
Microsimulator



39

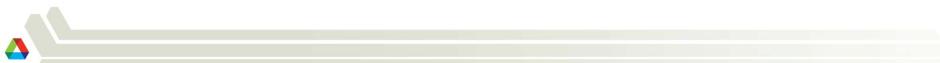
Microsimulator Principle: Cellular Automata

- Roadway sections are divided into grid cells
- Each cell is one lane wide and 7.5 meters long (user-defined)
- Position and speed are measured and incremented by cells (7.5 m, 7.5 m/s)



- Vehicle speed will be discrete:
16.8, 33.6, 50.3, 67.1, or 83.9 mph
- Intersections are fully modeled as grid cells in version 4 of TRANSIMS
- Car following model is being developed for version 4.2 of TRANSIMS

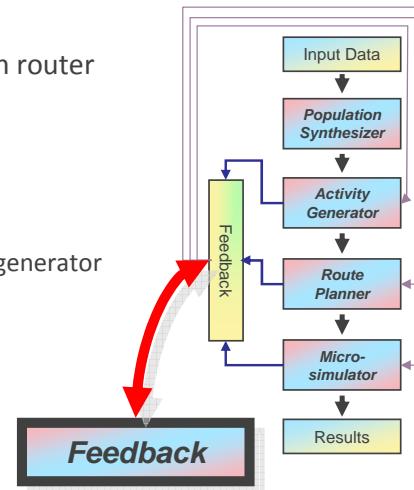
Microsimulator



40

Feedback

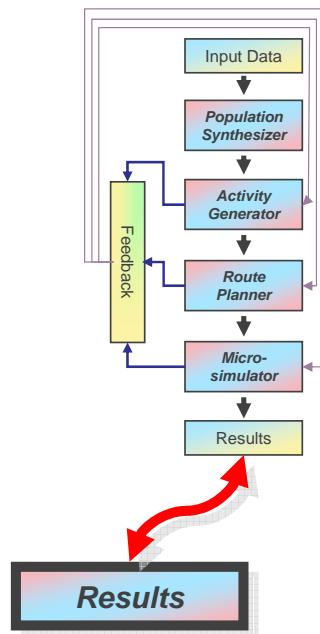
- The TRANSIMS equilibration process iterates between router and microsimulator
- Some routes are not feasible, e.g.
 - Significantly longer than dictated by the survey data
 - Not feasible based on the given transportation mode
 - These trips or activities are passed back to the activity generator to determine appropriate alternatives
- In the Microsimulator, vehicles can stall because they are unable to change lanes or make turns
 - Passing the households that own the vehicle back to the router for new routing suggestions may solve the problem
 - Some plans cannot be followed because of time-dependent road closures and other triggers
- Tools are available to select households for rerouting based on many criteria



41

TRANSIMS Results

- TRANSIMS can create aggregate results comparable to traditional tools
- The microsimulation leads also to highly detailed snapshot data, e.g. the exact location of every traveler at any given time
- The amount of data is difficult to comprehend, so effective visualization is essential
 - fourDscape and the Balfour visualizer
 - ArcGIS and similar GIS tools (uDig etc.)
 - The original TRANSIMS visualizer
 - Google Earth and NASA World Wind
 - Tools currently being developed at NCSA
 - Metropolis
 - Ray-tracing
 - Batch movie tools developed at Argonne
 - NEXTA, developed by the University of Utah

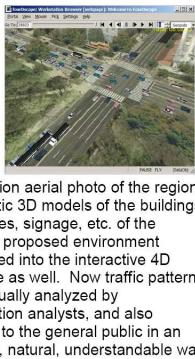


42

Example: fourDscape

- Three-dimensional visualization with additional time component
- Commercial application, by Balfour Technologies

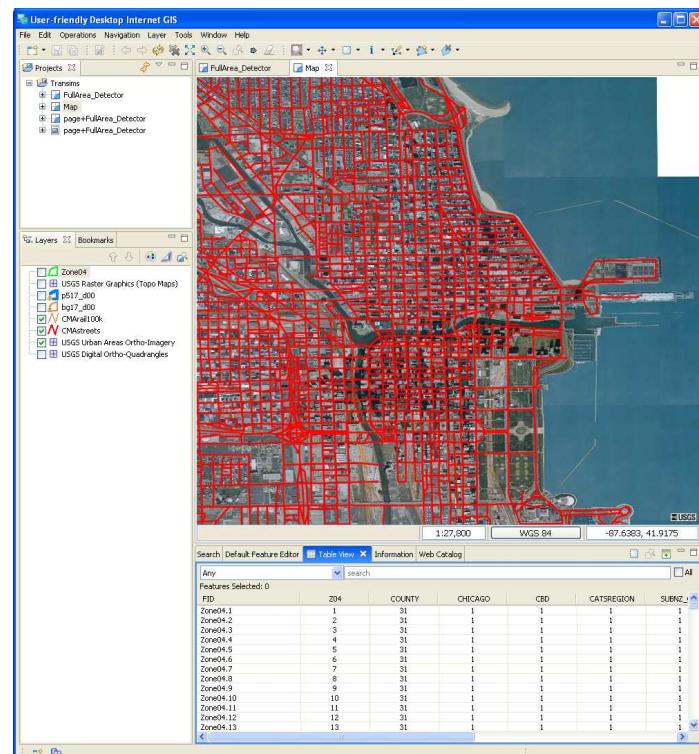
SOLUTION: A Virtual Transportation Visualization based on patented *fourDscape™* technology. *fourDscape™* creates a virtual, high-resolution four-dimensional (4D) Landscape represented in a single visual canvas that effectively provides an interactive, real-world representation of traffic patterns over time, generated from a variety of traffic simulation software packages including TRANSIMS, the Federal Highway Administration's newest regional Transportation Analysis Simulation System. In *fourDscape™*, traffic flow is geo-registered on the actual roadway lanes on a high-resolution aerial photo of the region, with realistic 3D models of the buildings and features, signage, etc. of the existing or proposed environment incorporated into the interactive 4D Landscape as well. Now traffic patterns can be visually analyzed by transportation analysts, and also presented to the general public in an interactive, natural, understandable way.




43

GIS Tools

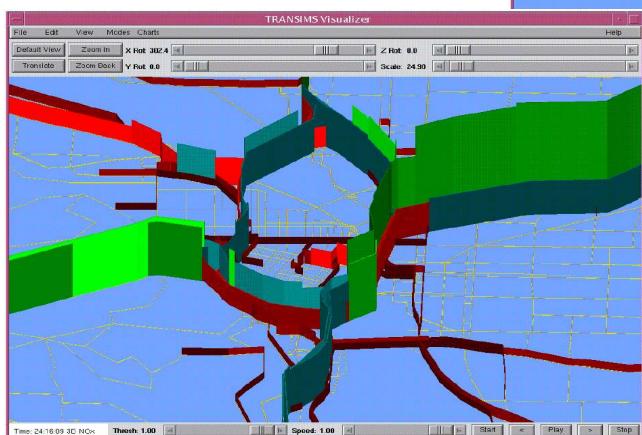
- Standardization
 - A wide variety of GIS tools exists to visualize results in maps
- Layer concept
 - Data from different sources and applications can be visualized in a single map
- Projections
 - Data formats are standardized to recognize projection systems of sources as well as destinations



44

Original TRANSIMS Visualizer

- Capacity is limited to small problem sizes
- Moving vehicles represented by triangles

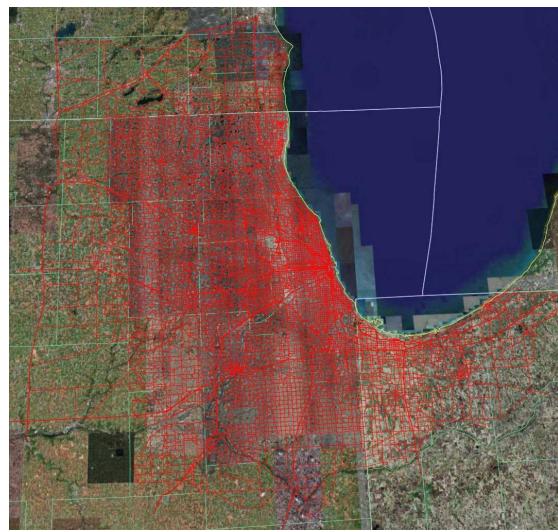
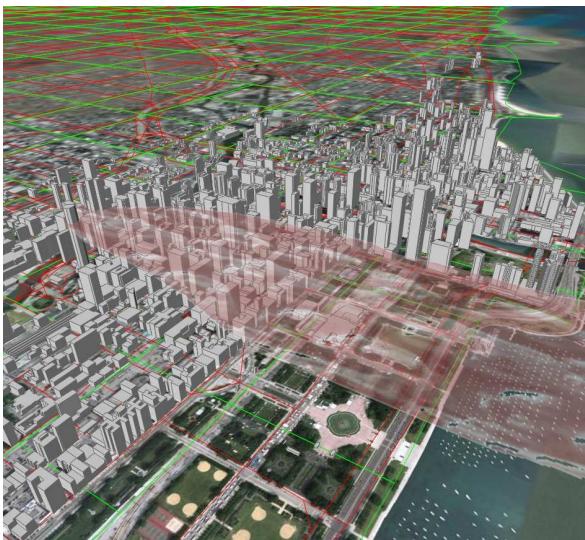


- Link delays and other aggregate information can be displayed in form of time-dependent bar graphs on top of network links

45

Google Earth

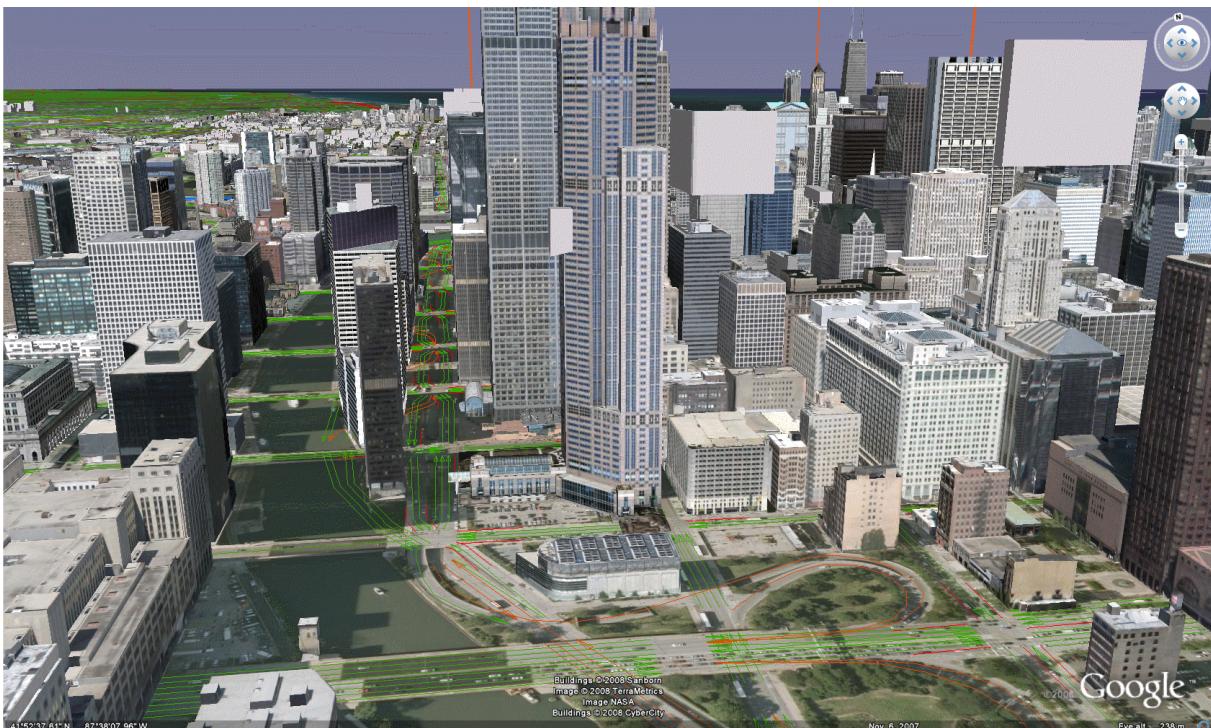
- Freely available and allows for the distribution of results in an easily distributable format (KML markup language)



- Web-based application, allowing integration with other data sources and online distribution of results
- Limited to static data representations

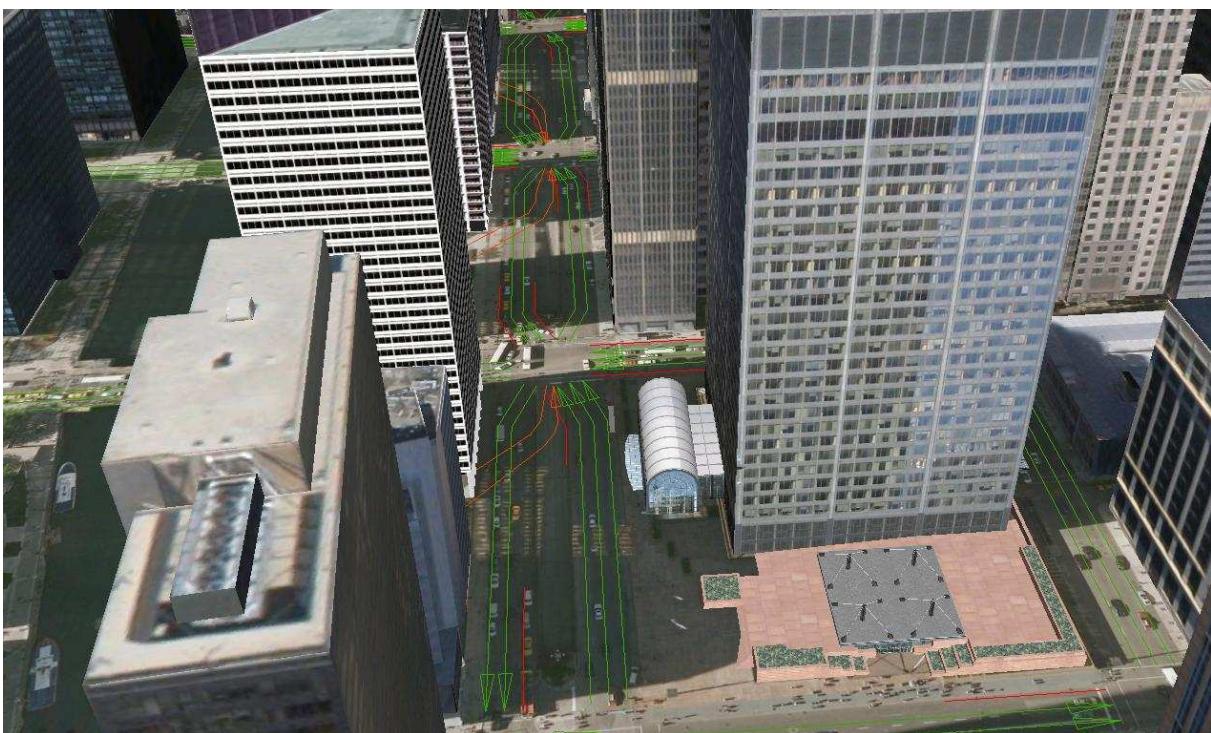
46

Google Earth Example for Static Data



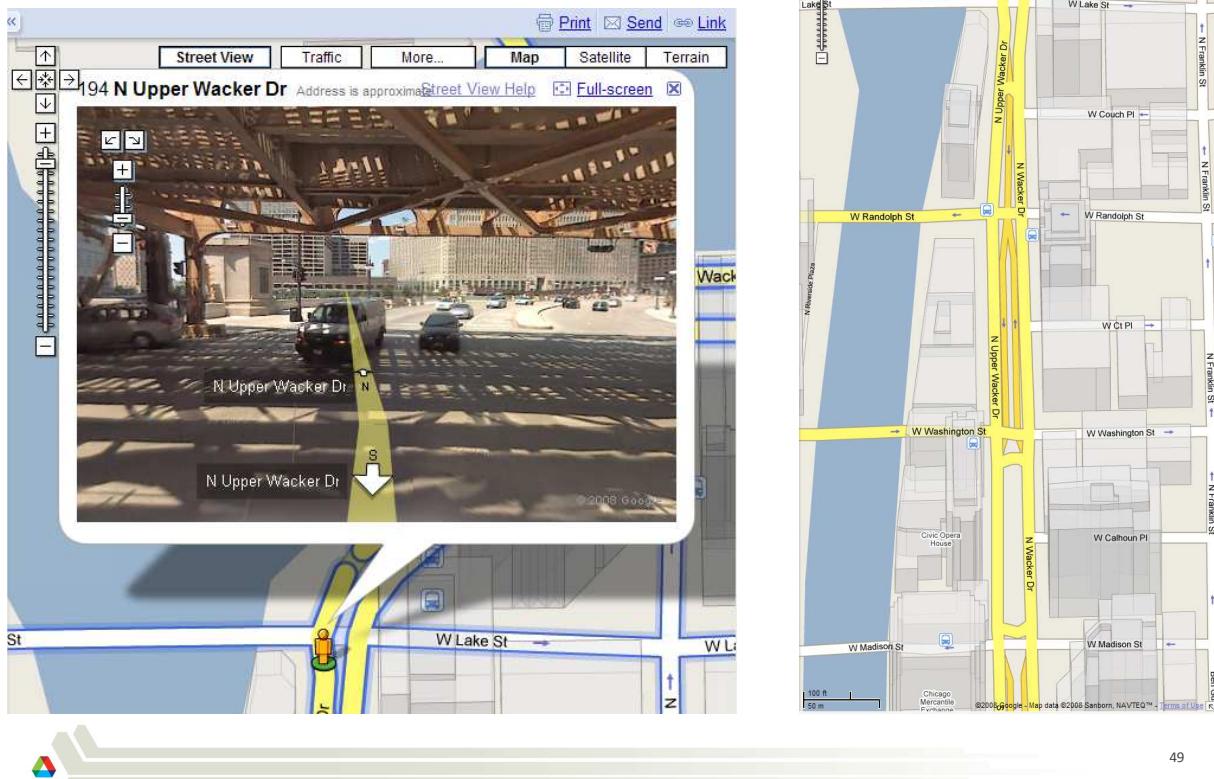
47

Google Earth Example for Static Data



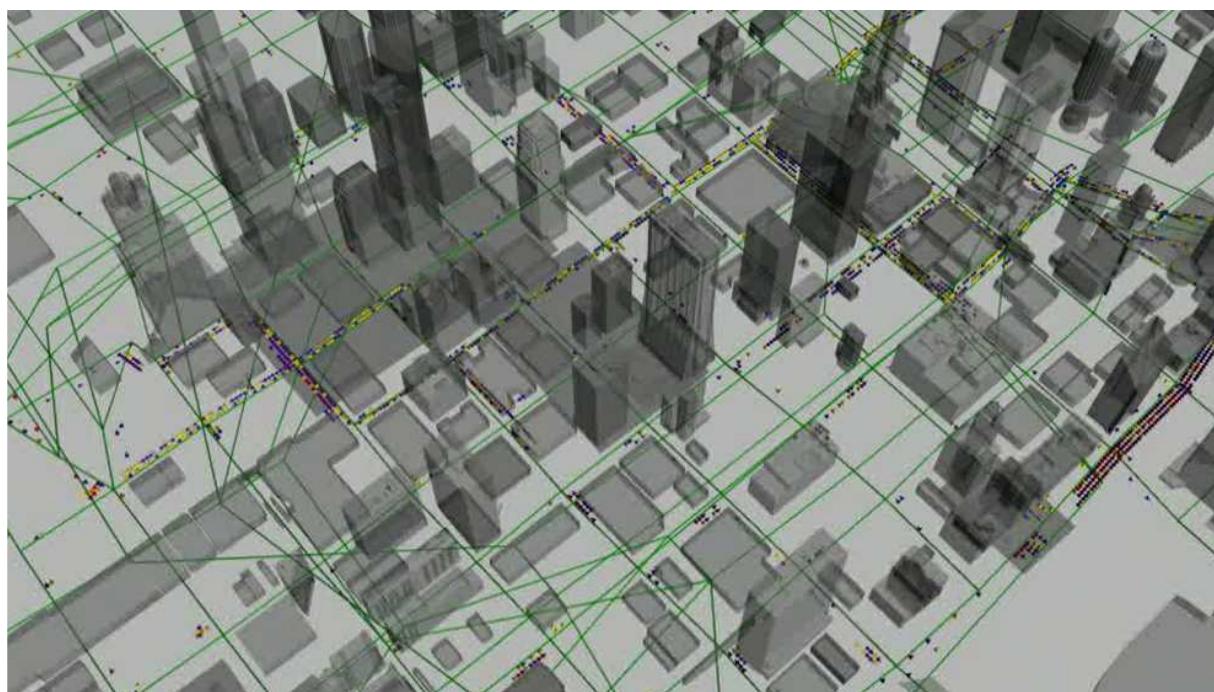
48

Google Maps and Street View

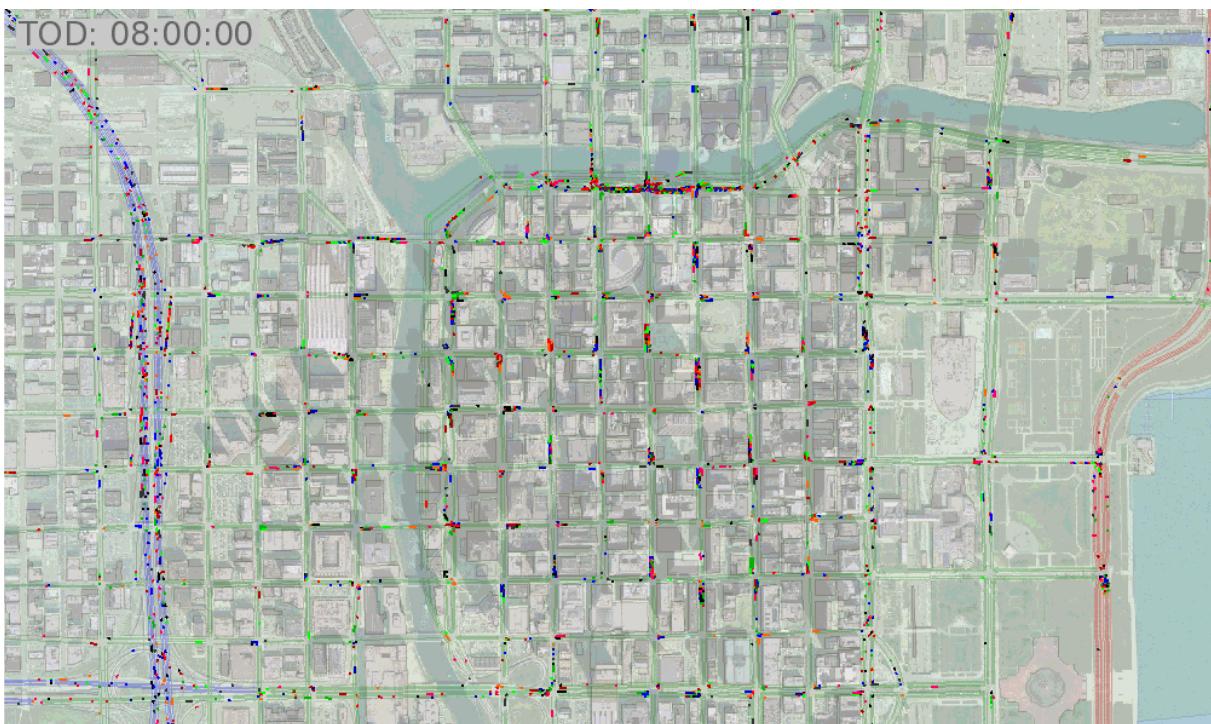


TRACC - TRANSIMS Training Course

Advanced Visualization (NCSA)



Argonne's Freely Available Visualization Methods



51

TRANSIMS Resources

- TRANSIMS is now an open source project publicly available under the NASA open source licensing terms
- There is a project web site operating at:
<http://www.transims-opensource.net>
- Several case studies are available for testing and tutorials
 - A sample case with data and scripts for the city of Alexandria is available. This case is meant for training and learning purposes, and is in its current form not a refined result of actual TRANSIMS modeling work. Argonne has used it to learn how to work on TRANSIMS on a limited size model.
- A forum is provided for user support and for public discussions
- The software is downloadable for Windows and Linux operating systems
- Collaborative code development is implemented as a SourceForge project using the SVN subversion repository
- Training workshops are being held several times a year
- A large workshop will be held in April 2010



52

The TRANSIMS Forum

TRANSIMS-OpenSource Site Forum Index

Forum	Topics	Posts	Last Post
General			
Announcements	3	3	26 Feb 2007 14:40 mvasudevan
Help!	7	19	30 Aug 2007 11:53 Doms
Community Structure and Governance	2	3	02 Jul 2007 13:45 mvasudevan
Test	1	0	No Posts
Lounge	1	1	24 Apr 2007 07:38 bhansharter
Toolbox			
Toolbox General	8	15	15 Aug 2007 06:21 roderic
Toolbox Help	20	48	11 Sep 2007 08:48 anilvoung
Toolbox Bug Reports	4	5	08 Aug 2007 11:57 roderic
Toolbox Development	18	51	10 Jul 2007 11:31 basant
Toolbox Feature Requests	0	0	No Posts
Studies			
Studies Discussion	2	2	19 Jul 2007 18:04 briangardner

All times are GMT - 6 Hours

53

TRANSIMS Open Source Licensing

NASA Open Source Agreement 1.3

NASA OPEN SOURCE AGREEMENT VERSION 1.3

(Language for Use in Distribution of TRANSIMS)
May 2005 Original
August 2007 Revised

THIS OPEN SOURCE AGREEMENT ("AGREEMENT") DEFINES THE RIGHTS OF USE, REPRODUCTION, DISTRIBUTION, MODIFICATION AND REDISTRIBUTION OF CERTAIN COMPUTER SOFTWARE ORIGINALLY RELEASED BY THE UNITED STATES GOVERNMENT REPRESENTED BY THE GOVERNMENT AGENCY LISTED BELOW ("GOVERNMENT AGENCY"). THE UNITED STATES GOVERNMENT, AS REPRESENTED BY GOVERNMENT AGENCY, IS AN INTENDED THIRD-PARTY BENEFICIARY OF ALL SUBSEQUENT DISTRIBUTIONS OR REDISTRIBUTIONS OF THE SUBJECT SOFTWARE. ANYONE WHO USES, REPRODUCES, DISTRIBUTES, MODIFIES OR REDISTRIBUTES THE SUBJECT SOFTWARE, AS DEFINED HEREIN, OR ANY PART THEREOF IS, BY THAT ACTION, ACCEPTING IN FULL THE RESPONSIBILITIES AND OBLIGATIONS CONTAINED IN THIS AGREEMENT.

Government Agency: U.S. Department of Transportation, Federal Highway Administration (FHWA)

Government Agency Original Software Designation: TRANSIMS

Government Agency Original Software Title: Transportation Analysis Simulation System (TRANSIMS)

User Registration Requested

Government Agency Point of Contact for Original Software: Brian Gardner

USER MENU

- My Resume
- Cluster (Workgroup)
- Add News
- User Information
- Find a Community Member
- Contributor Resources

54

TRANSIMS Development and Software Repository

The screenshot shows a Windows Internet Explorer window displaying the SourceForge.net Software Search results. The search term 'TRANSIMS' has been entered into the search bar. The results page shows one project, 'Transportation Analysis and Simulation', listed with a relevance score of 98.04% and a rank of 3,857. The project page includes a brief description, download links, and member statistics. A sidebar on the right features a green lizard icon and the text 'Your Linux is ready.'.

55

Credits and Acknowledgements

- GIS visualization materials were mostly developed at Argonne based on the TRANSIMS tools developed by AECOM for USDOT
- Chicago road and transit network data used in some of the examples was provided by the Chicago Metropolitan Agency for Planning
- USDOT provided the funding for the development of these training materials
- USDOT provided the funding for the TRACC computing center and the resources necessary to perform these training session
- Some figures have been developed for USDOT by Prof. Antoine Hobeika, Virginia Polytechnic Institute, Civil and Environmental Engineering
- The presentation is in part based on materials provided by USDOT at a training course in November 2006

56