POLARIS: Agent-Based Modeling Framework Development and Implementation for Integrated Travel Demand and Network and Operations Simulations

Joshua Auld, Michael Hope, Hubert Ley, Vadim Sokolov, Bo Xu, Kuilin Zhang
Transportation Research and Analysis Computing Center
Argonne National Laboratory
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POLARIS

(Planning and Operations Language for Agent-based Regional Integrated Simulation)

- Initially Designed to:
  1. Model Traffic Control Centers and other ITS Systems
  2. Enhance Interoperability among Existing Tools
  3. Build on model integration efforts in travel demand

- Core Goals and Philosophies of the POLARIS Effort:
  - Develop Transportation Modeling Standards and Protocols
  - Create an Open Source Model Development Environment
  - Connect Sub-Communities with a Common Modeling Framework
  - Offer Helpful Tools while Maintaining Flexibility and Modularity
  - Enable high-performance transportation simulations
What is POLARIS?

- Middleware for Developing Agent-based Models
  - Data Interchange
  - Visualization
  - Case Study Generation and Analysis
  - Discrete Event Simulation
  - Memory Management

- A Repository of Transportation Libraries
  - Common Algorithms
  - Extended by Researchers
  - Standardized Style and Structure

- Fully Developed Applications
  - Transportation Network Simulation
  - Integrated Activity Based Travel Demand Simulation

Low-level Capabilities
Agent-Based Modeling

- ABM is a well-established methodology for studying complex systems that has been shown to provide a structure useful for modeling a vast array of phenomena:
  - social processes
  - software systems
  - manufacturing systems
  - urban dynamics

- In agent-based modeling:
  - Agent encapsulate a set of behaviors that govern their interactions with other agents and with their environment
  - Autonomous and are capable to adopt or modify behaviors
  - Allows system to be modelled from the bottom up

- Increased computer power allows for analyzing large scale systems
  - Transportation is a large-scale complex system so ABM seems appropriate
Overview of the Agent-Based Transportation System Model

- Activity Generation
- Activity Scheduling
- Vehicle Choice
- Route Choice
- Activity Planning
- Housing Choice

- Congestion
- Safety / Incidents
- Energy Use
- Emissions

- Activity Engagement
- Traveler Movements

- ITS Infrastructure
- Intersections
- Links

- Transportation Network
-Sensor Networks

- Communications Infrastructure
- ITS Responses

- Traffic Management
Key POLARIS Activity-Based Model Components

- **Agent Initialization**
  - Population synthesis creates households / persons
  - Network / ITS agents read from system database

- **Demand components**
  - Generation, Planning and scheduling of activities to satisfy needs

- **Network assignment / simulation**
  - Agent-based, individualized route selection (multi-modal)
  - Simulation of travel on transportation network (auto only)

- **ITS infrastructure and management simulation**
  - Simulate ITS infrastructure operation
  - Management strategies (directly input or automated)

- **Visualization and agent-interaction**
  - View model through POLARIS GUI
  - Modify agent / infrastructure states
Agent Demand Based Largely on the ADAPTS ABM

- ADAPTS activity-based model:
  - Simulation of how activities are planned and scheduled
  - Extends concept of “planning horizon” to activity attributes
    - Time-of-day, location, mode, duration, party composition
  - Dynamic generation and scheduling of activities

- Core concepts:
  - Set of activity planning / scheduling processes represented by heuristics and/or models
  - Outcomes constrained by local context
  - Dynamic state dependence in decision making
  - Generation, Planning/ Replanning and Scheduling occur continuously in conjunction with traveling
Demand Components Implemented as Agent Behaviors

- Activity Generation: Create new activity episodes throughout the day
- Planning Order Model: Assign intrinsic episode characteristics
  - When are decisions about attributes made? How flexible are those decisions?
  - Allows for planning constraint in choice models to reduce set sizes
- Attribute planning models: Choice models determine attributes
  - Departure, destination, mode choice, routing – constrained by existing schedule
- Scheduling model: resolve conflicts and add activities to schedule
  - Use individual routed travel time when scheduling to reduce inconsistency
- En-route replanning
  - Bounded rationality model, triggered by information or excessive delay
  - Account for scheduling information when doing route switching
  - Replan due to unexpected events (i.e. weather, emergencies)
Simulation Flow in the Travel Demand Model

Preprocessing
- Input / Scenario Data
- Population Synthesis
- School and Work Activity Planning

Each Planning Time-step (5-min intervals)
- Activity Generation
- Activity Scheduling
- Pre-trip Re-planning
- Schedule Departures
- Activity Plan

In continuous time
- Planning order model
- Activity Attribute Planning Models
- Activity Plan
- Get Route
- Depart Location

Integration point with network supply model
Simulation-Based Dynamic Traffic Assignment Model

- **Mesoscopic Traffic Simulation Model**
  - LWR-based traffic flow model (Newell’s discretization scheme)
  - Traffic Control Model simulates turn movements and signal operations

- **Multi-modal routing**
  - Individual, prevailing/historical conditions A*
  - Can use GTFS inputs for transit

- **Integration of traffic flow and system management components**
  - Drivers “see” VMS messages when drive by
  - Drivers get radio messages when tuned in
  - Many other models of agent information (navigation device, look ahead, etc.)
  - Can trigger en-route route switching
Simulation-Based Dynamic Traffic Assignment Process

Routing Agent
- Network Topology
- Traveler Characteristics
  - Activity Plan
  - Person Planner
- Route Generation Model
  - Routes
  - Route Decisions
- Router
  - Network / ITS Information
  - Route Decisions
- Person Mover
  - En-route switching Model
  - Traffic Operations and Control Model

Person Agent

Link Agent
- Link Simulation Model
  - ITS model
  - Traffic Events
  - Arrival States
  - Departure States
  - Network Performance

Intersection Agent
- Intersection Simulation Model
  - Signal State
  - Network Performance
Key Features Enabled by Disaggregate Integration: En-route Switching

- Planned route for vehicle
- Accident closes link
- Vehicle looks ahead one link and sees stopped travel – does rerouting
Key Features Enabled by Disaggregate Integration: En-route Switching

- Vehicle traveling on new route
- VMS signs and HAR can inform vehicles further downstream to enable better decisions
Key Features Enables by Disaggregate Integration: Activity Replanning due to Information
Next steps

- Enhance router to incorporate historical time-dependent information
  - Time-dependent shortest path A* routes
  - Incorporate information on prevailing conditions
  - More realistic information model for individual drivers (instead of perfect knowledge of prevailing conditions)

- Using individualized routing in activity planning decisions
  - Multimodal routed travel times for mode choice
  - Replacing skim matrices with individualized routing for destination decisions
  - Helped by reduction in complexity due to planning constraints

- Incorporating individual history and experiences in network
  - Currently routing individualized only in cost functions
    - all agents have same representation of network conditions
  - How to operationalize storage of individual experience for use in A* router
    - Very challenging and memory intensive

- Microsimulation of driver behavior
Conclusion

- Agent-based integrated model design allows for unique capabilities
  - Enroute route-switching and activity replanning
  - Individual reactions to unexpected events
  - Maintenance of consistency between demand and network models
  - Heterogeneity in agent responses in routing / traffic simulation

- Potentially more useful for certain applications
  - Operational simulations (ITS analysis, CAV fleets, ...)
  - Agents responding to unexpected events
  - Emergency planning

- Challenges
  - Computationally intensive to move to fully agent-based behaviors
  - Incorporating agent history in decision making
  - Theoretical underpinnings to solution (i.e. equilibrium)
  - Data availability
Thank You!

*For more information go to:*

https://github.com/anl-tracc/polaris

or

http://tfresource.org/Polaris