Activity/Travel Demand Modelling: Moving Research into Practice

Imperial College London, February 25, 2020

Eric J. Miller, Ph.D.

Prof., Dept. of Civil & Mineral Engineering

Director, UTTRI

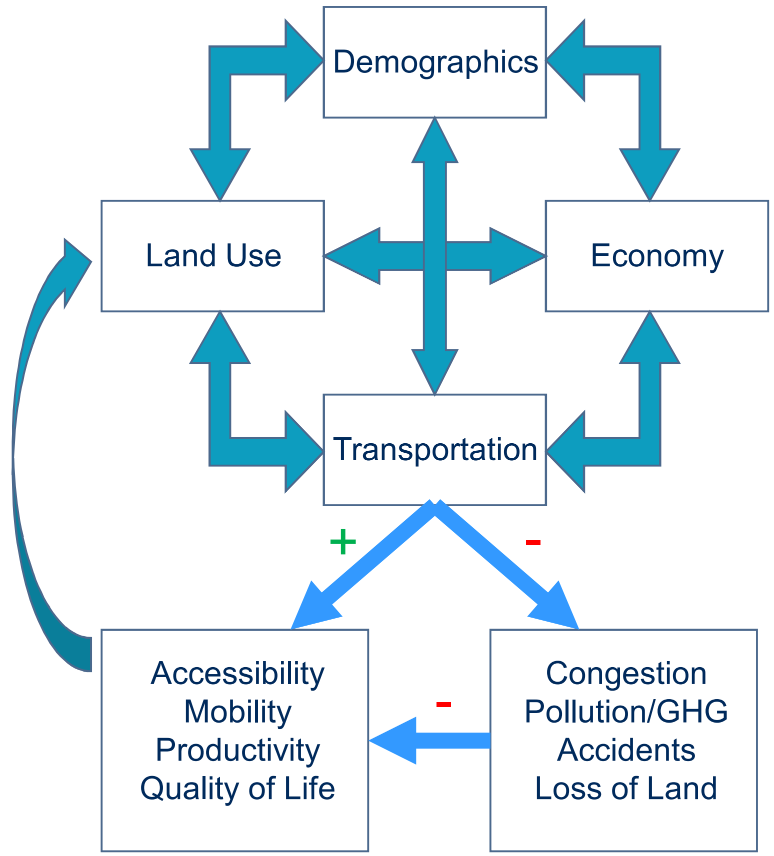
University of Toronto

UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE & ENGINEERING
Transportation Research Institute

UTTRI

Presentation Outline

- Preliminary comments re. modelling.
- Travel demand modelling research at UTTRI.
- TASHA & GTAModel V4.
- Travel demand modelling for:
  - Transit planning.
  - Emissions & energy modelling
- Current research.

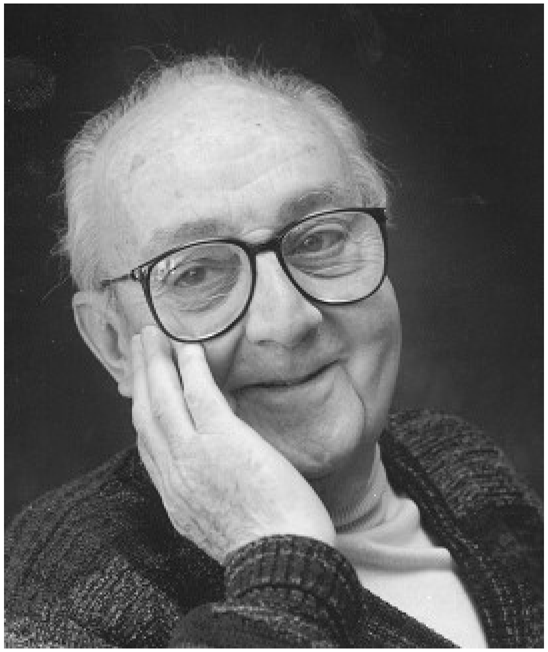


What is a model?

- A model is a simplification and an abstraction of reality (of a process, a system, ...).
- Many types of models exist:
  - Conceptual / verbal.
  - Physical.
  - Analog.
  - Mathematical (analytical-based).
  - Digital (computer/algorithm-based).
    - Simulation.

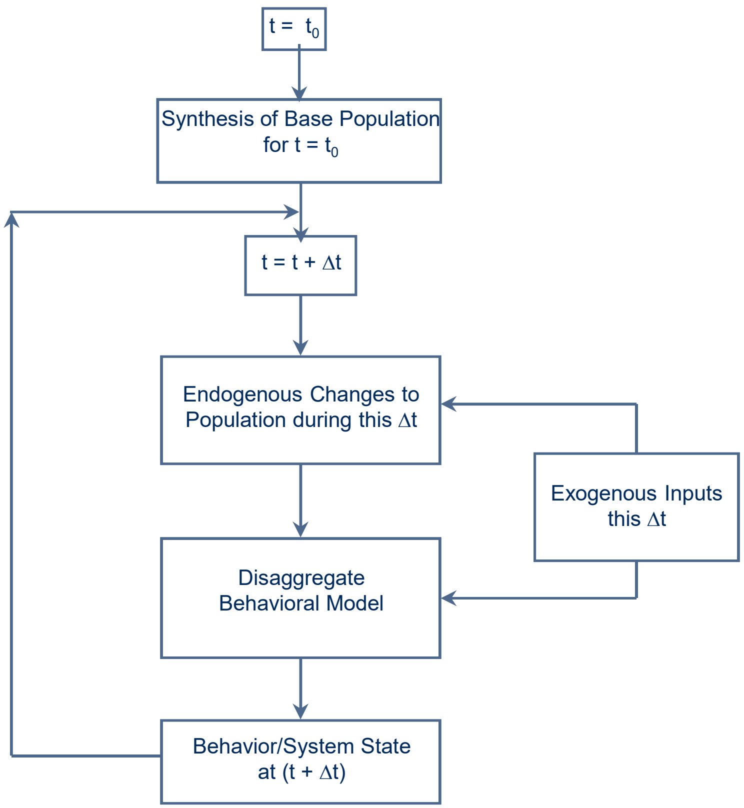
Why Model?

- To capture our understanding of how a system works.
- To explain to others how a system works.
- To learn/explore how a system works.
- To experiment with the system:
  - Explore "what-if" questions.
  - Policy analysis.
  - Alternatives testing & evaluation.
  - Forecasting.



"All models are wrong; some are useful."
- George Box

Simulation Modelling



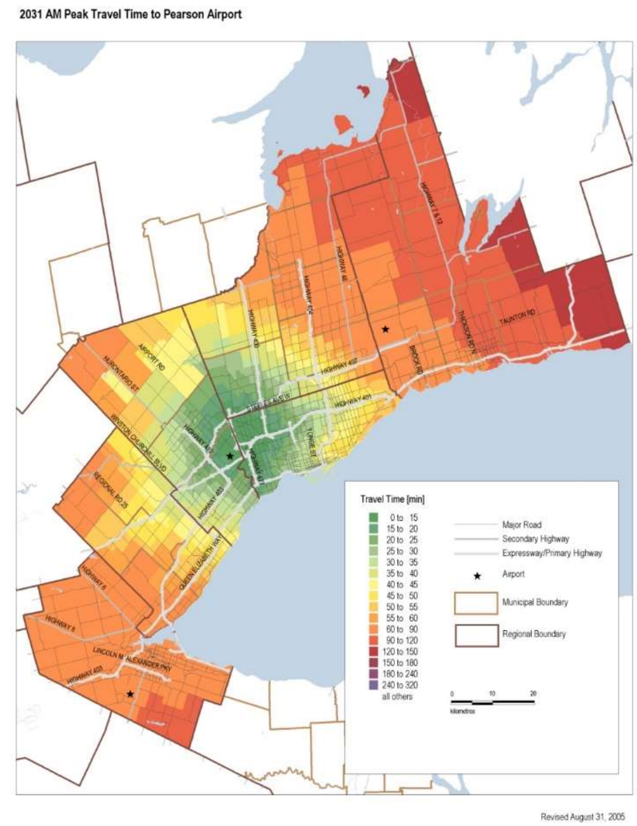
"Simulation is a numerical technique for conducting experiments with certain types of mathematical models which describe the behaviour of a complex system."

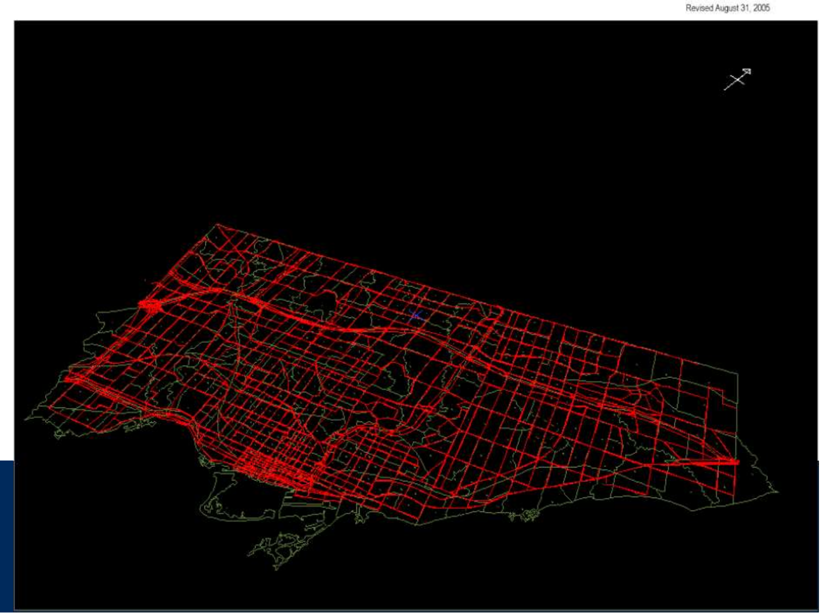
Simulation is a procedure for evolving a "system state" over time as a function of both exogenous and endogenous factors.

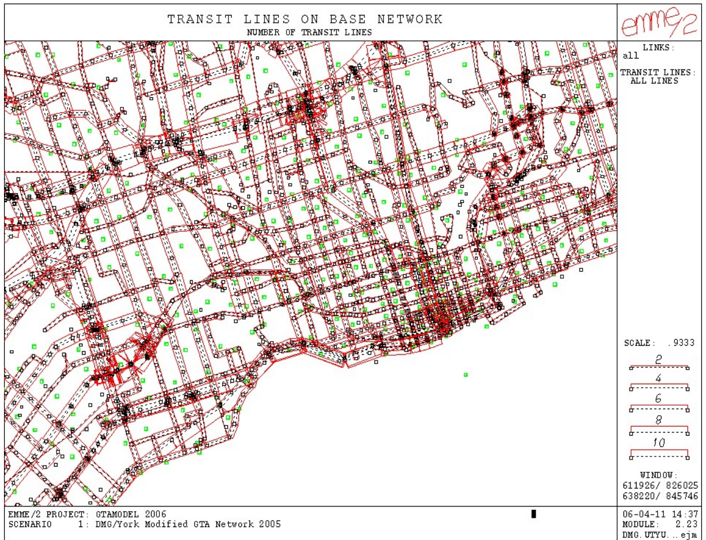
- The computer as laboratory.
- Simulation is a tool for experimental investigation of system behaviour.

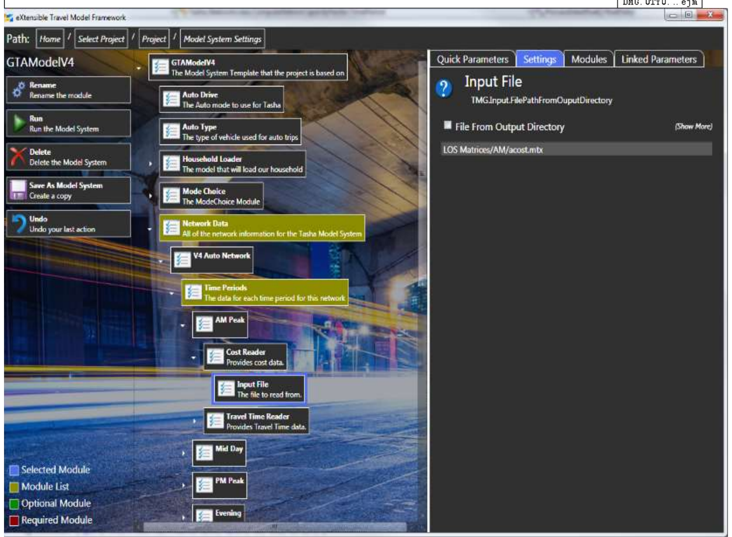
Travel Demand Models

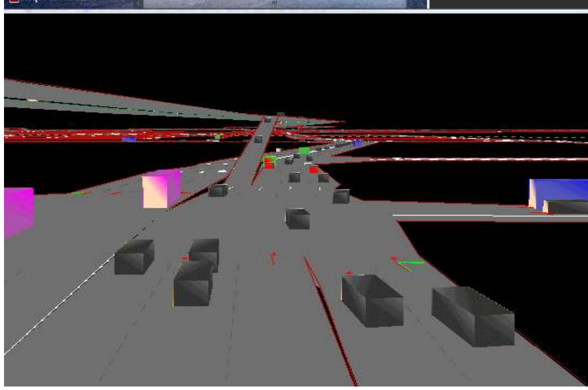
- Travel demand models are large computer simulation models that predict detailed typical daily travel patterns for a forecast year.
- They are used in urban regions worldwide to analyze transportation investment & other policy options.
- They allow us to ask "what if" questions about alternative investments & other policies (fares, land development, road pricing, etc.).
  - We can assess the likely benefits & costs of billion dollar investments in the virtual world of the computer before committing to these major investments in reality.
  - (Among other uses.)











Travel Demand Modelling at the University of Toronto

- UofT has been working with the Province of Ontario & Toronto region municipalities for over 30 years to develop improved travel demand modelling methods.
- This has resulted in state-of-the-art models being developed by University researchers that are operationally used by planning agencies.
- This strong, consistent, university-government interaction is relatively unique.

datamanagementgroup

UTTRI

travel modelling group

tmg

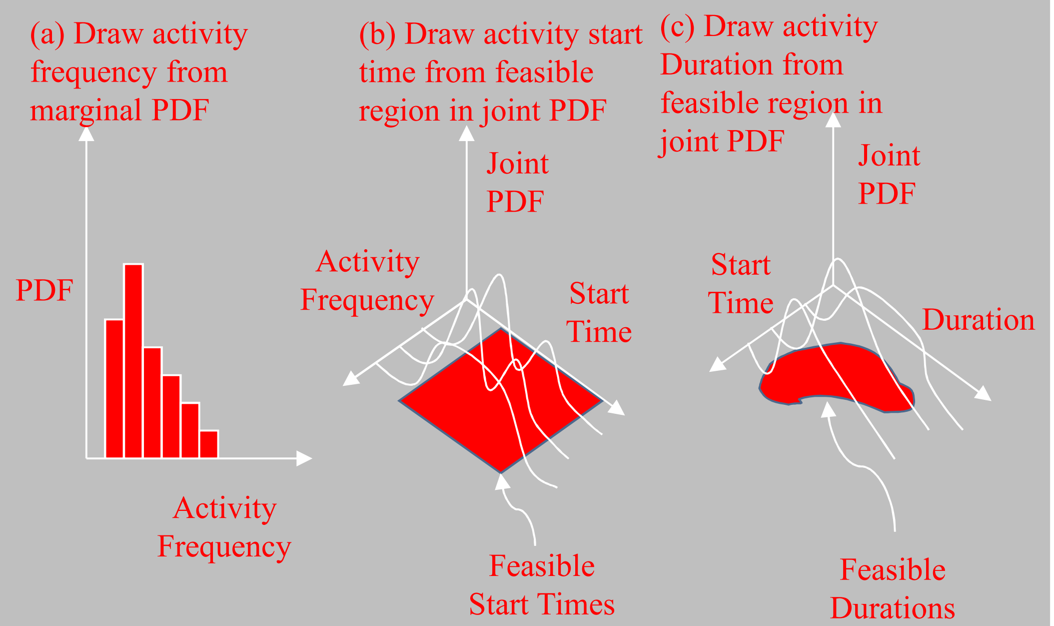
TASHA: Travel/Activity Scheduler for Household Agents

- TASHA is an activity-based travel demand forecasting model developed at the University of Toronto for the Greater Toronto-Hamilton Area (GTHA).

Key TASHA Features (1)

- Activity-based (a true activity scheduling model).
  - Travel is a "derived demand".
  - If we are to predict travel behaviour, we need to understand **why** people are travelling.
  - **What** are the activities in which they need to participate, **where**, **when**.

Activity Episode Frequency, Start Time and Duration Generation

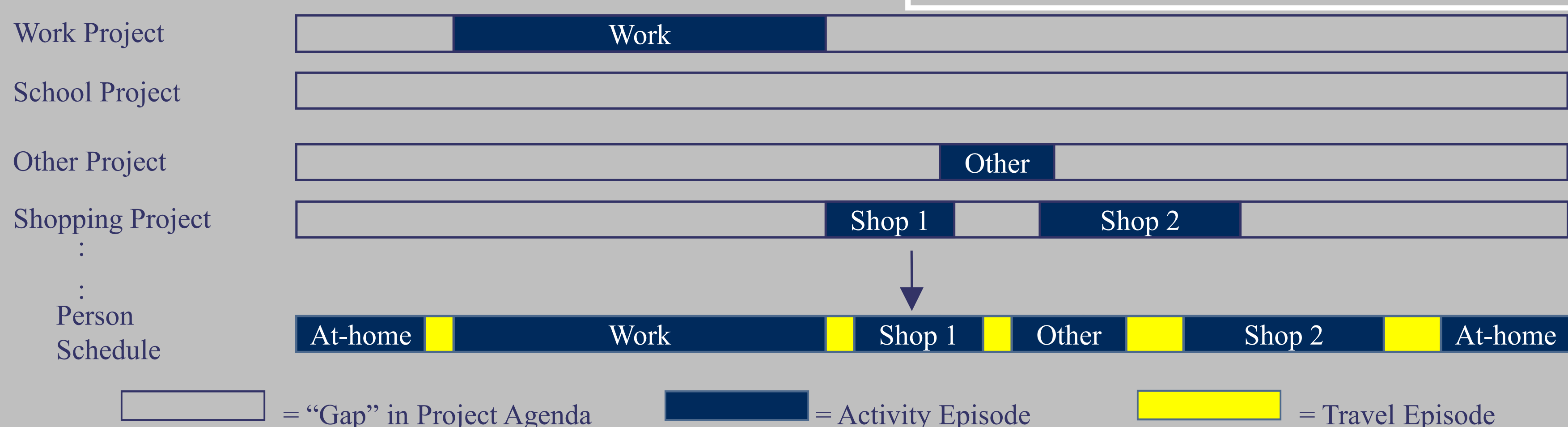


TASHA generates the number of activity episodes from a set of "projects" that a person (or household) might engage in during a typical weekday. It also generates the desired start time and duration of each episode.

It then builds each person's daily schedule, adjusting start times and durations to ensure feasibility.

Travel episodes are inserted as part of the scheduling process.

Scheduling Activity Episodes into a Daily Schedule

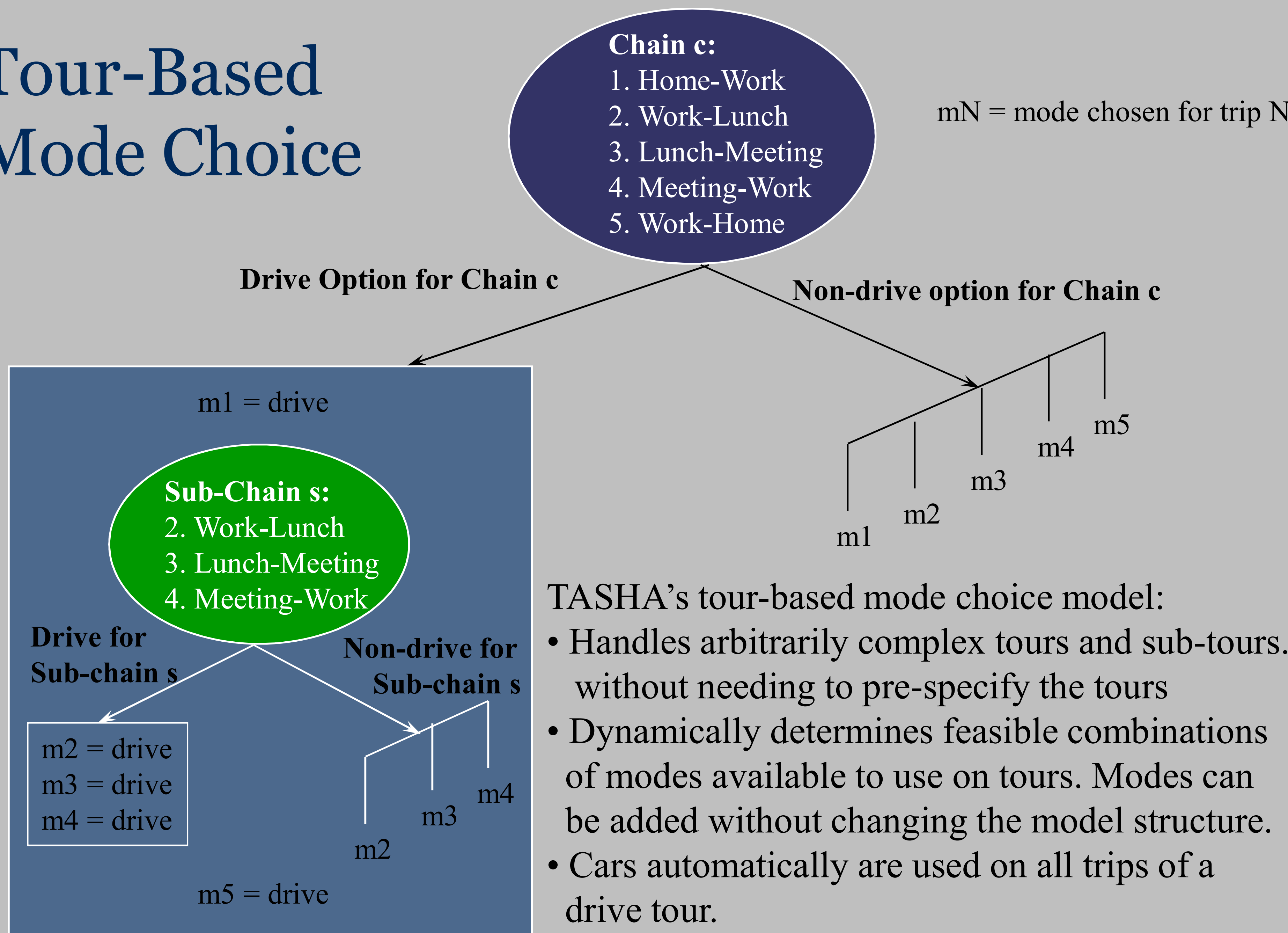


UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE & ENGINEERING
Transportation Research Institute

Key TASHA Features (2)

- Tour-based.
  - We organize our day around the pattern of activities in which we need to engage.
  - This results in (reasonably) well-organized trip-chains or tours
  - Within-tour constraints need to be recognized.
  - In TASHA, arbitrarily complex tours can be parsimoniously & efficiently modelled.

Tour-Based Mode Choice



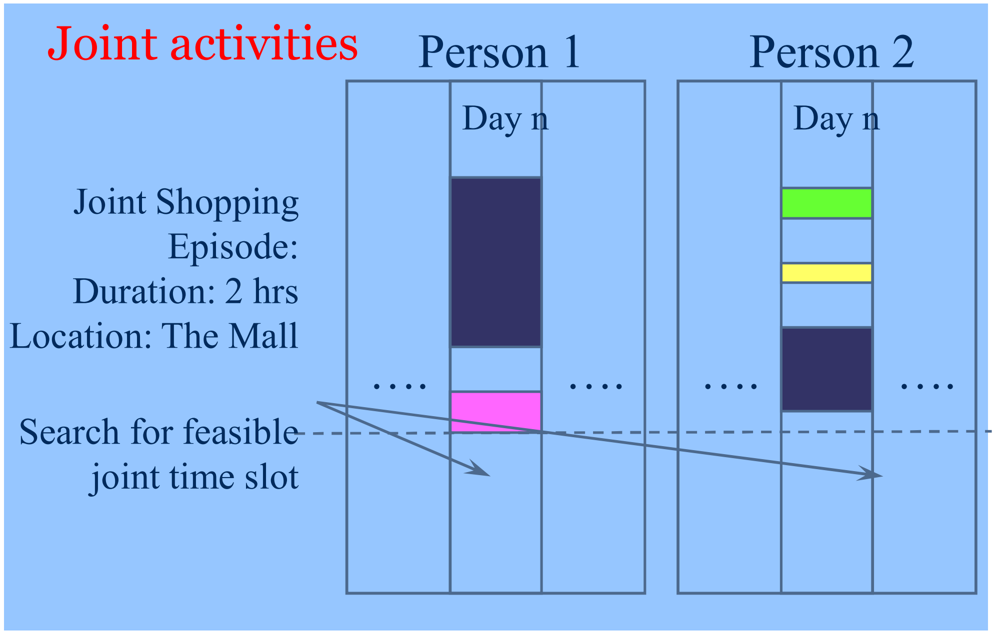
TASHA's tour-based mode choice model:

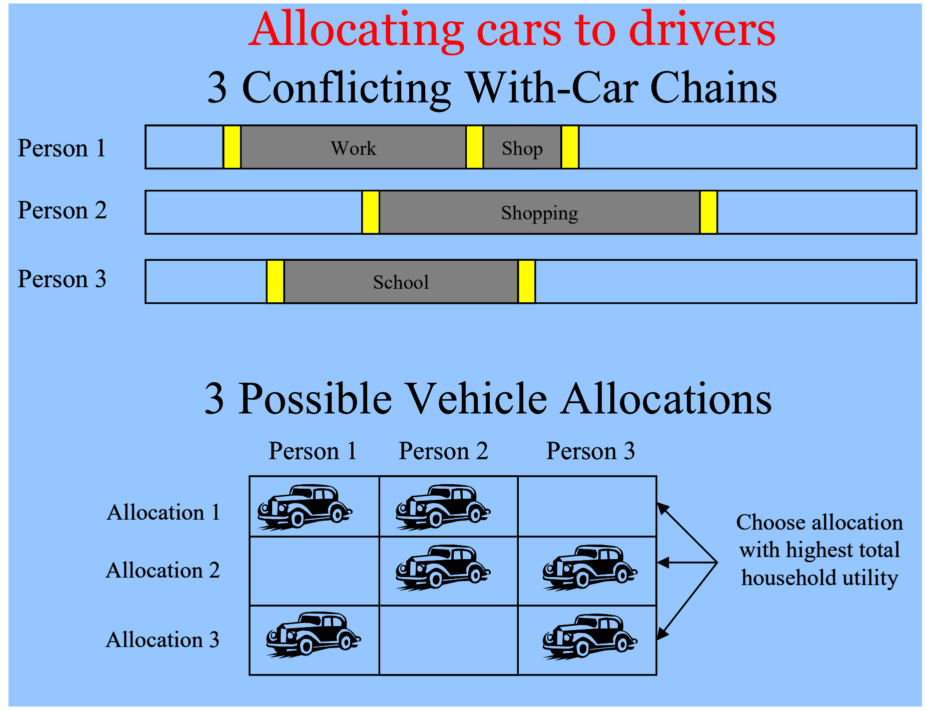
- Handles arbitrarily complex tours and sub-tours. without needing to pre-specify the tours
- Dynamically determines feasible combinations of modes available to use on tours. Modes can be added without changing the model structure.
- Cars automatically are used on all trips of a drive tour.

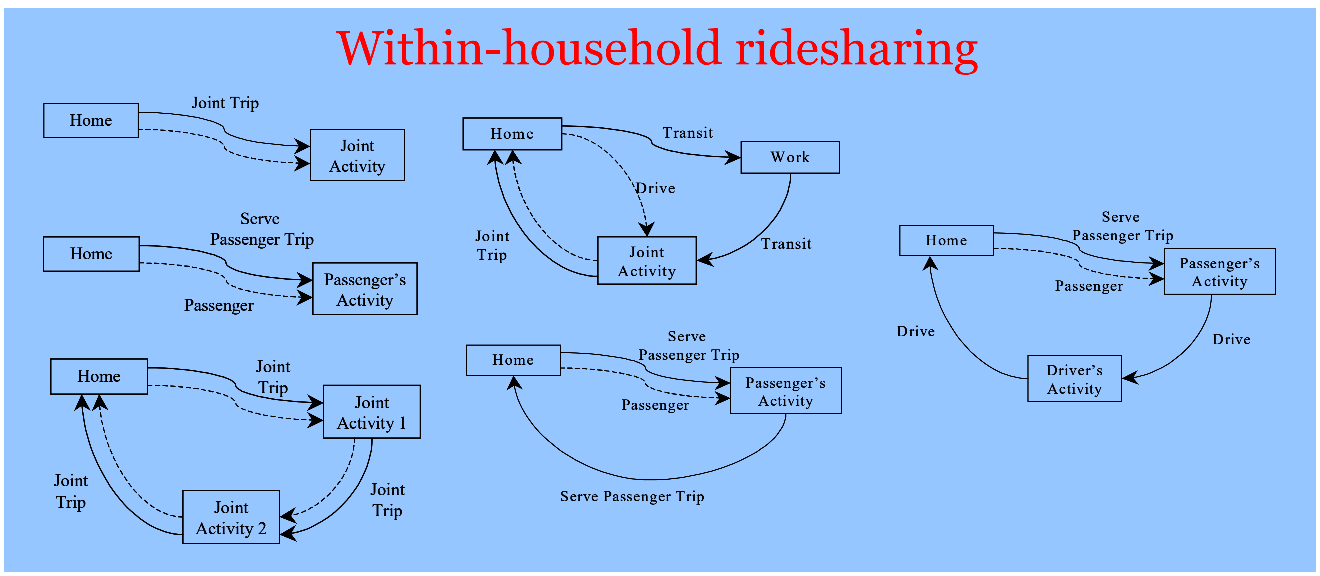
Key TASHA Features (3)

- Household-based.
  - Household constraints & interactions are critical in determining individual persons' travel.
  - TASHA was the first operational fully household-based model (and still the only one in Canada).

Household Level Interactions







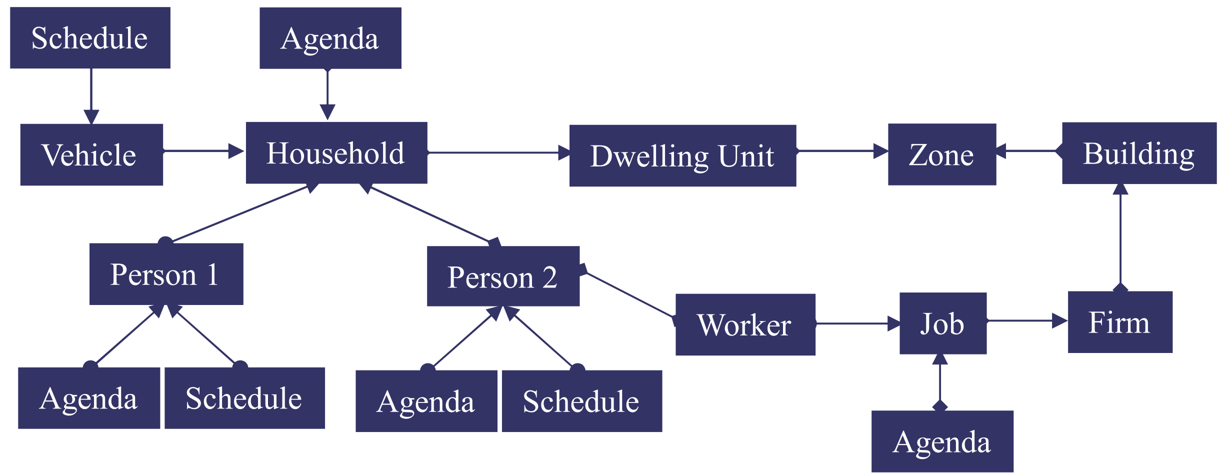
Key TASHA Features (4)

- Fully agent-based microsimulation.
  - Travel demand is the result of each person deciding how best to organize their day.
  - In TASHA, every person & household in the region is individually modelled.

Agent-Based Modelling (ABM)

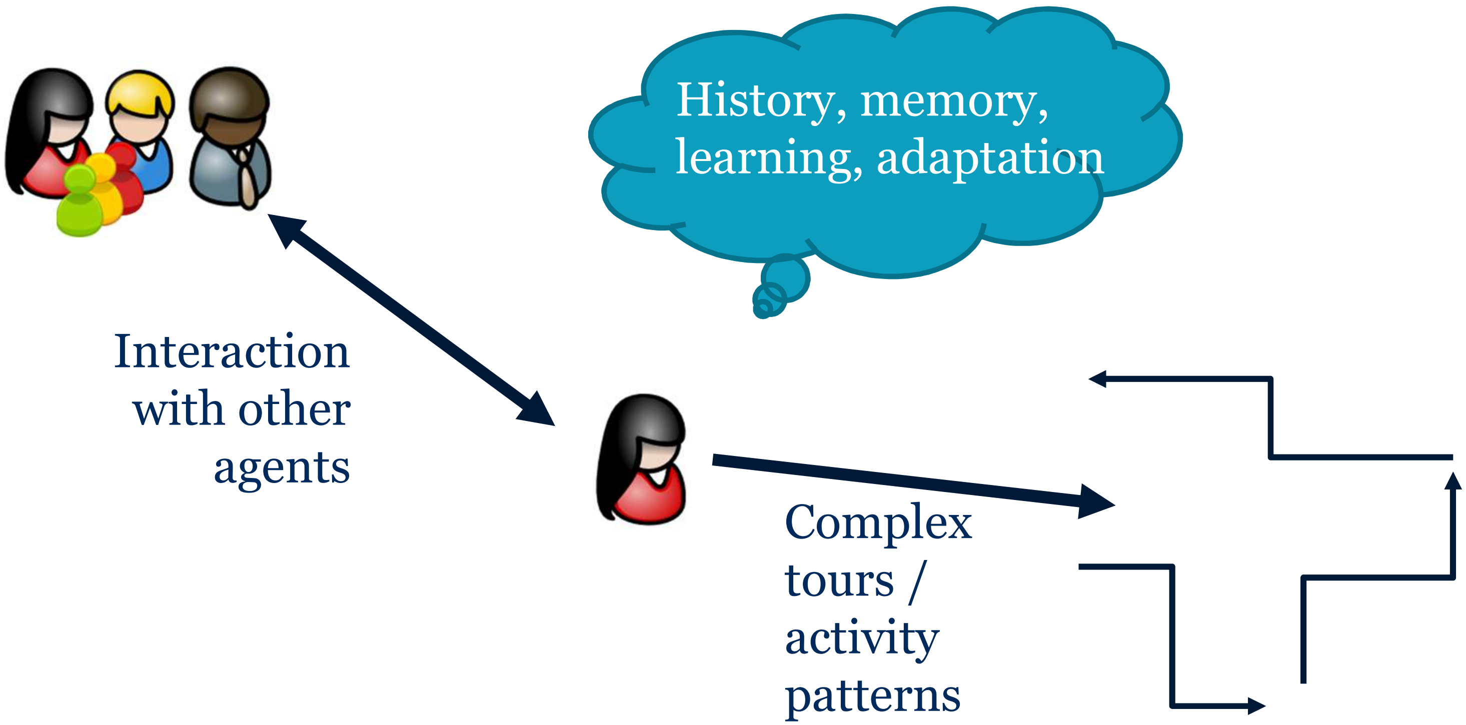
An intelligent object is an *agent* ("an object with attitude" – Paul Waddell).

Agents:
- perceive the world around them
- make autonomous decisions
- act into the world



Agents provide an efficient, highly extensible, behaviourally-sound framework for modelling human socio-economic activity.

Advantages of Agent-Based Modelling

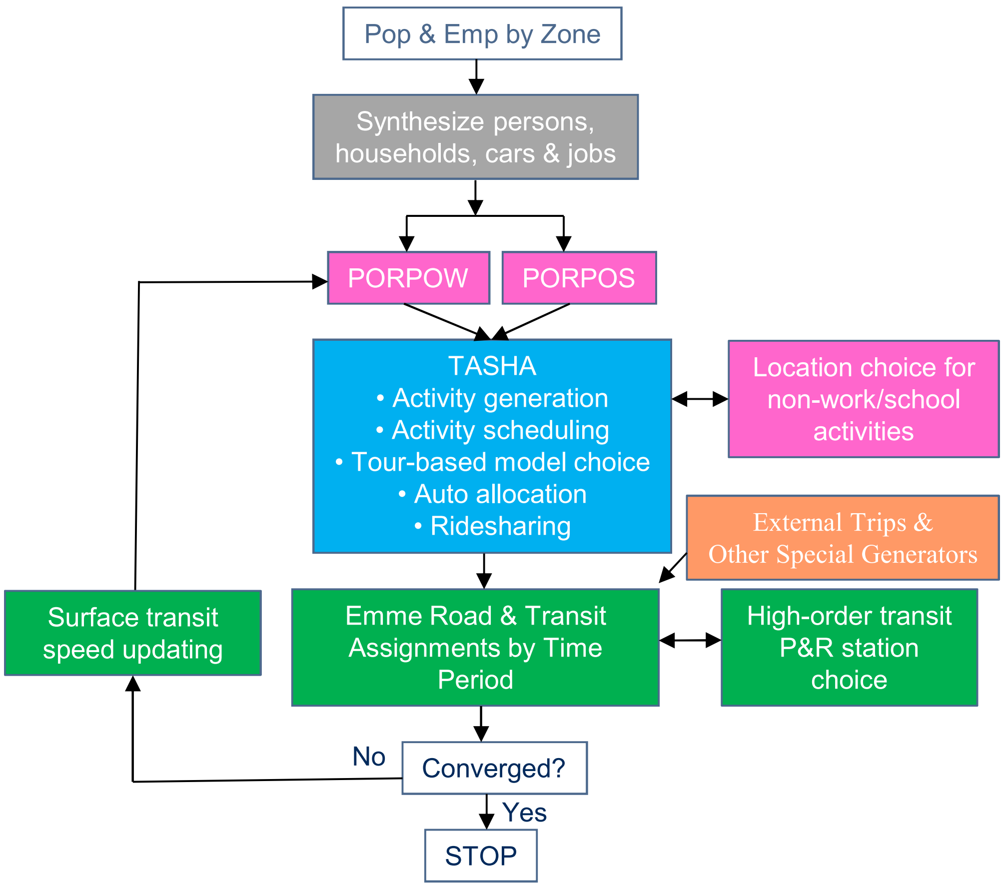


Key TASHA Features (5, 6, 7)

- Continuous time (over a typical 24-hour weekday).
  - All trips modelled, by time of day.
  - Peaking & peak-spreading emerge naturally within the model.
- Developed from conventional travel survey data.
  - A very practical consideration!
  - Built using conventional travel survey data.
  - Special surveys not needed.
- Computationally efficient.
  - Also very practical! A model run only takes 1-3 hours (depending on the computer).
  - Rapid turnaround means <u>many</u> scenarios, alternatives, "permutations on a theme" can be explored.

First we take Toronto …

"First we take Manhattan, then we take Berlin …"
-- Leonard Cohen (1988)



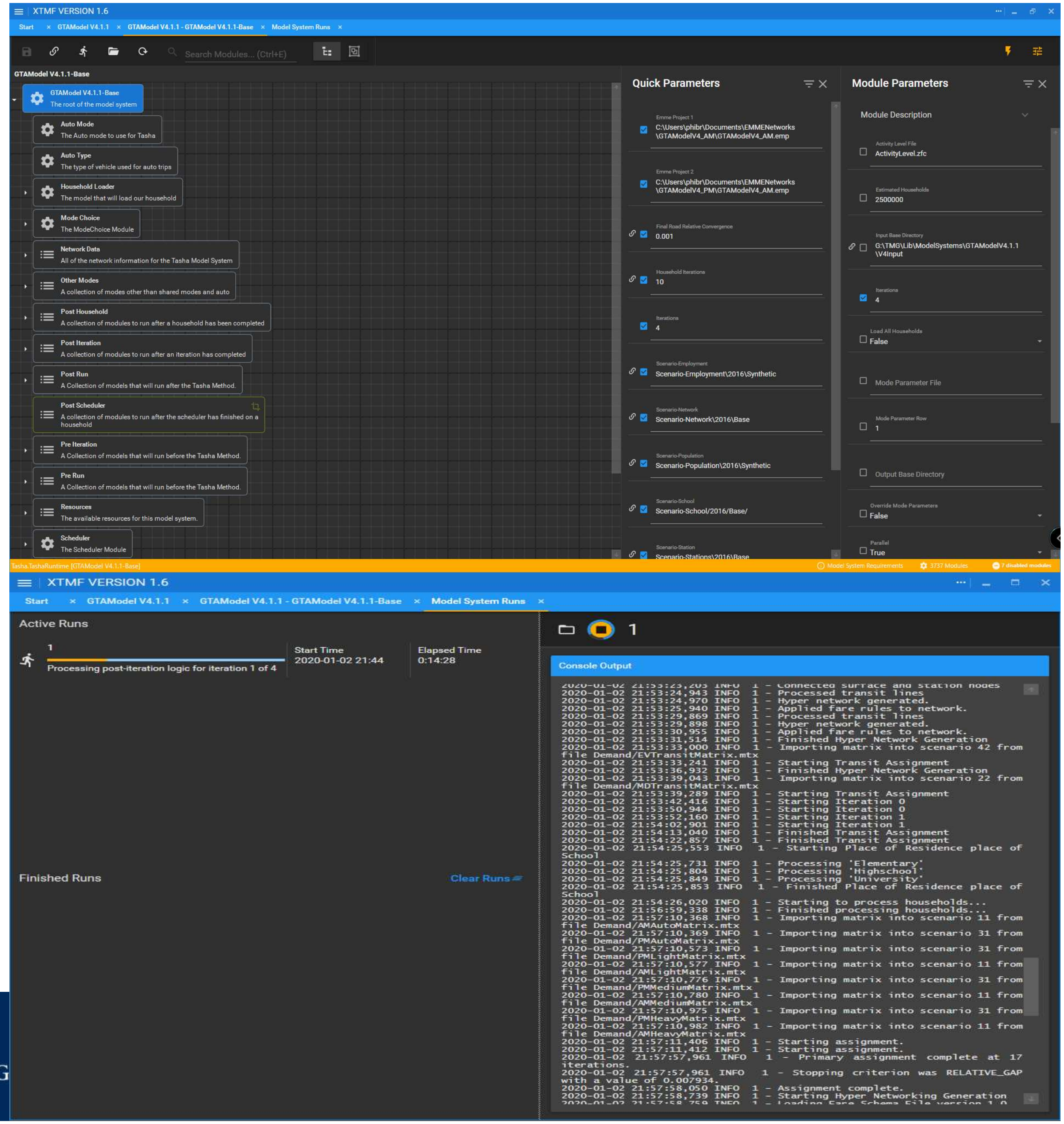
TASHA has been operationally implemented within the GTAModel V4 model system, in use by the City of Toronto since early 2016. Most GTHA municipalities have since adopted it.

Elsewhere being applied (for research purposes) in:

- Asunción, Paraguay
- Cape Town, South Africa
- Changzhou, China
- Helsinki, Finland
- Melbourne, Australia
- Regina, Canada
- Temuco, Chile

eXtensible Travel Modelling Framework (XTMF)

TASHA & GTAModel are implemented in XTMF, custom software developed at TMG to support rapid, flexible, extensible development of model systems.



UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE & ENG
Transportation Research Institute

XTMF, cont'd

- XTMF is written in C# under .net.
- It currently consists of 680+ modules to support:
  - Model system construction.
  - Model parameter estimation.
  - Model and model system validation.
  - Input data preparation.
  - Output results analysis & visualization.
- XTMF supports a full interface with Emme through the TMG Emme Toolbox.
- Both XTMF & the Toolbox are open source (GPLv3) & available on GitHub.

Computational Efficiency

- XTMF, V4.0 and TASHA have all been "optimized" as far as possible to generate quick run times.
- Model design:
  - Parsimonious model design.
  - "Keep it simple" (as much as possible).
  - Exploit the ABM approach to simplify whenever possible.
- Computer code:
  - Parallization whenever possible.
  - GPU usage where possible.
  - Take computation time seriously.

Computational Efficiency, cont'd

- Currently doing 100% population runs for the Greater Toronto-Hamilton Area (GTHA), containing approximately:
  - 7.0 million persons (10 million by year 2041)
  - 3.0 million households
  - 2300 traffic zones
- Runs on a compute server:
  - 64 hardware threads at 4.1GHz, 64GB of ram
  - **1-hour run time!**
    - **Vast majority of this is consumed by road & transit assignments.**

Network Assignment Modelling

- We often focus on mode choice as the critical policy component in travel demand models.
- But road & transit assignment models are also critical to effective, credible policy analysis.
  - Majority of run time is taken up by the assignment models.
  - "Point of entry" for most policies.
  - Public/politicians relate to networks.
  - Mode choice depends critically on quality of the assignment model outputs.
- We have spent much more time fine-tuning our networks and our assignment models than any other part of the model system.

GTAModel & Network Modelling

- We are still using Emme V4 for our network modelling since it is the standard network modelling package in the region.
- We have research implementations using MATSim in Helsinki, Melbourne & Cape Town.
- We are also currently developing an Aimsun implementation within the GTHA to exploit their new maco-meso road network modelling capability.

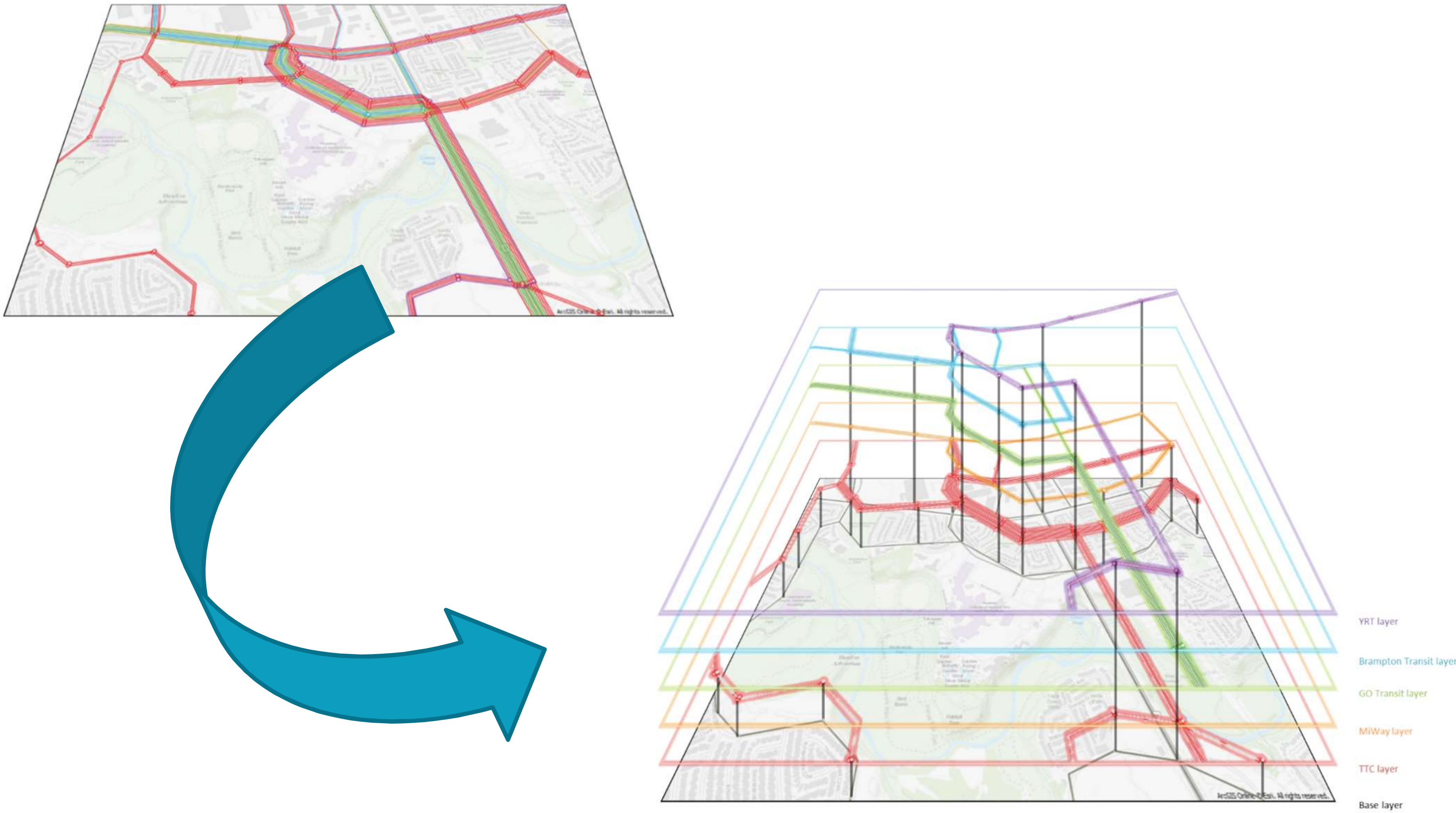
Transit Assignment

- Given the transit policy focus in Toronto, the transit assignment model is critical to policy analysis.
- Our current Emme-based transit assignment model includes:
  - Stochastic path choice.
  - Fare-based assignment (fares are converted into time equivalents).
  - "Congestion" (on-board crowding) penalties.
  - Surface transit speed updating to capture roadway congestion effects.

Transit Assignment
("A mode by any other name")

- Probably the biggest innovation is the adoption of an "integrated", "technology neutral" representation of the transit network.
- Transit "sub-modes" (commuter rail, subway, LRT, buses, etc.) are all treated as alternative paths through the network, NOT as separate modes.

Integrated Transit Hyper-network



Integrated Transit Network, cont'd

- Advantages of the integrated approach:
  - <u>Much</u> simplified mode choice model.
  - New modes/services can be readily introduced.
  - Forces the modeller to capture as many factors as possible in systematic components of the utility function.
- Disadvantage: does it adequately deal with qualitative elements?
- Experience to date: So far so good (we think!).

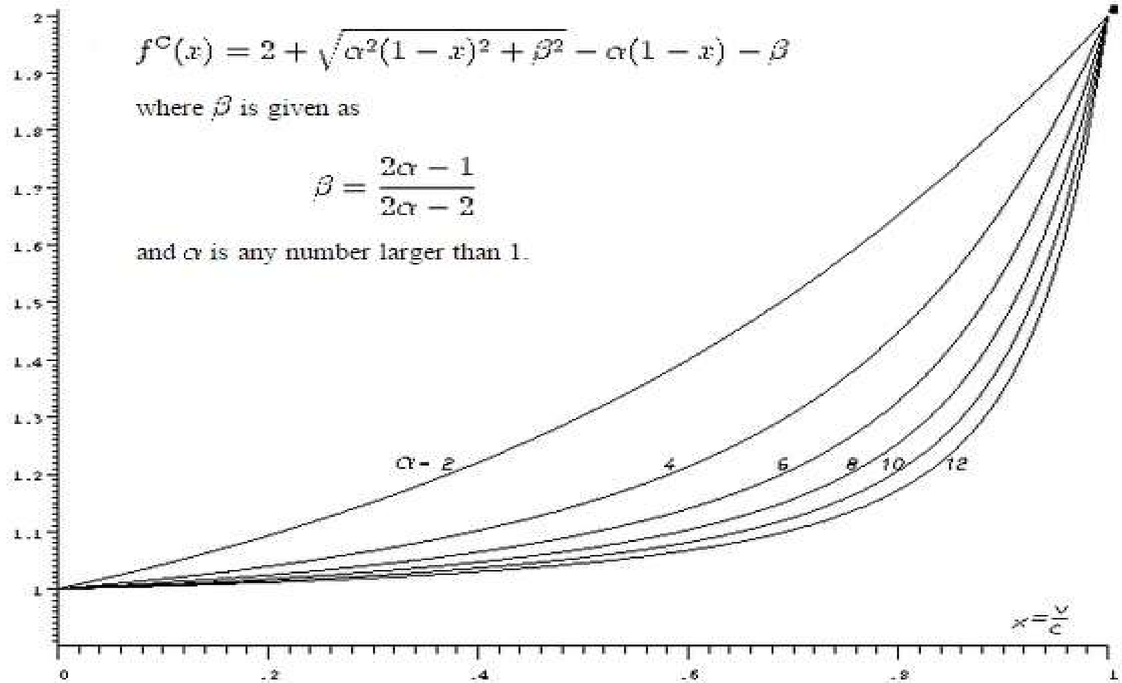
Fare-Based Transit Assignment

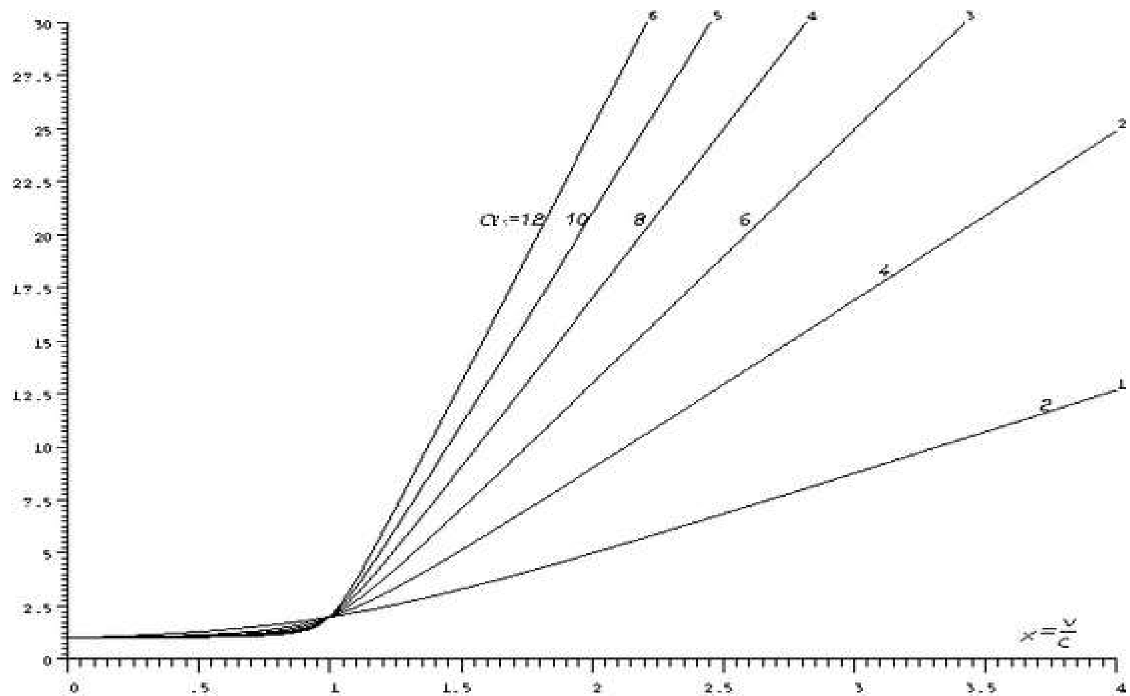
- The hyper-network coding allows us to code initial and transfer fares into the network and accumulate fares along the O-D paths.
- Fares are converted into IVTT time equivalents and path choice is based on the "generalized cost" or "disutility" of competing path times + costs.
- Can handle:
  - Flat fares
  - Distance-based fares
  - Zone-based fares

Dealing with London's fare system would be a challenge!

Modelling “On-Board” Congestion/Crowding

- To account for transit vehicle/line capacity constraints & associated crowding effects, the Emme “congested transit assignment” procedure is used.
- The conical volume-delay function is used.
- Calibrating this function is challenging!

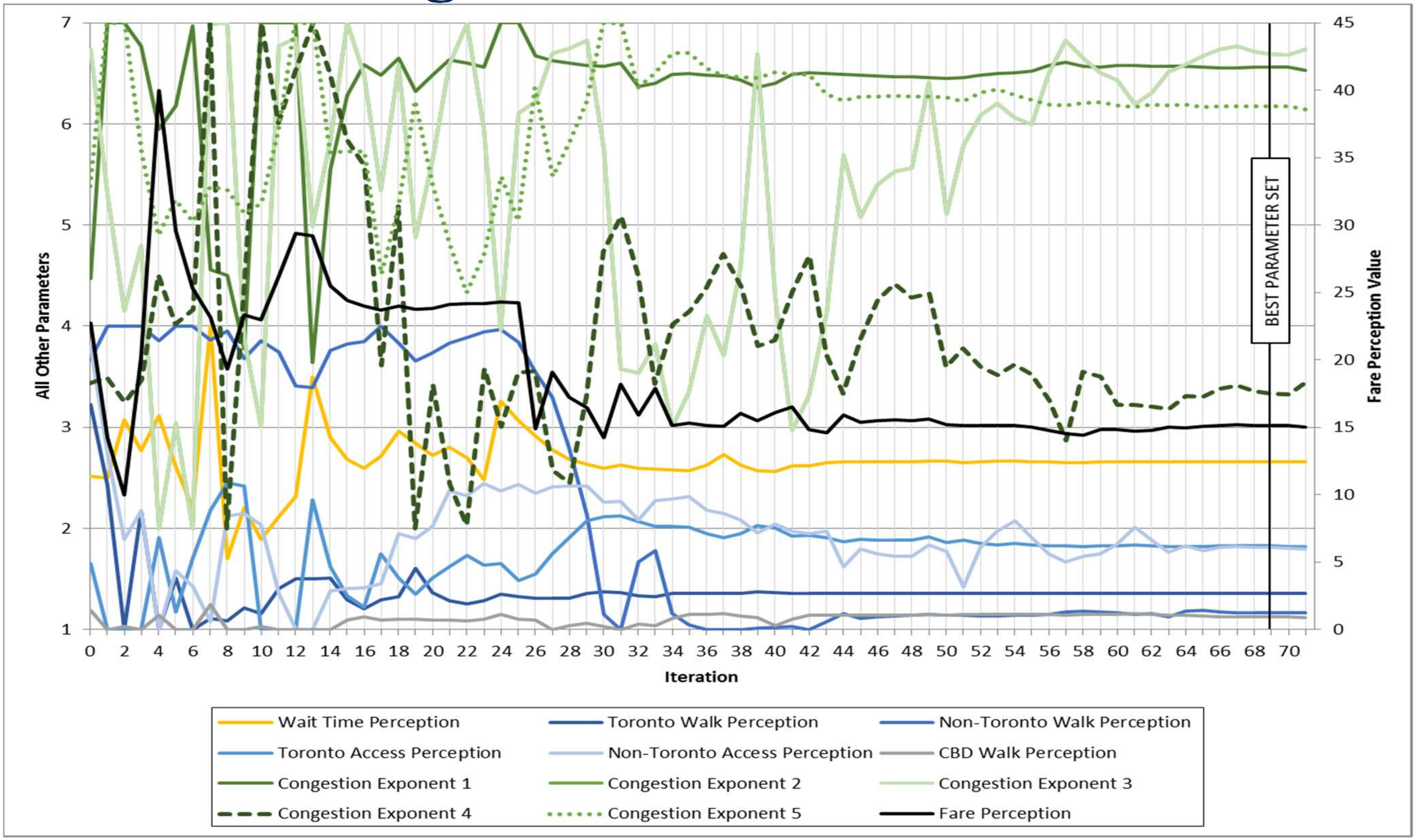




Parameter Estimation Methods

- A Particle-Swarm Optimization (PSO) procedure is used to estimate both the transit assignment and tour-based mode choice models.
- PSO is a general-purpose iterative optimization algorithm.
  - Selects initial points in parameter space and velocity vectors randomly.
  - Each of these points is referred to as a particle, which maintains a history of the best point in parameter space that it has explored.
  - For each iteration the parameters are moved by a combination of their momentum, an attraction to the globally optimal point, the previous generation's best point, and a repulsion from their best observed point (Hassam et al, 2005).
- This algorithm was chosen due to the reduced computation times required for good convergence compared to more traditional estimation methods such as genetic algorithms (Hassam, et al., 2005) or gradient descent.
  - With 23 parameters, a gradient descent algorithm would need to test 47 points to approximate the derivatives for each iteration, two points for each dimension plus the origin point. In comparison the PSO only requires to 12 points per iteration

Transit Assignment Model Estimation



Mode Choice Model

- The TASHA tour-based mode choice model is a multinomial probit random utility choice model.
- The tour utility = the sum of the trip utilities:

$$\tilde{U}_{ik} = \sum_{t=1}^{T} U_{im(t|k)t} = \sum_{t=1}^{T} V_{im(t|k)t} + \sum_{t=1}^{T} \varepsilon_{im(t|k)t}$$

Modes

- Auto drive
- Transit with walk access
- Transit with auto access/egress
- Walk all-way
- Bicycle
- School bus (elementary & secondary student only)
- Auto passenger modes:
  - Household passenger
  - Household rideshare
  - Inter-household carpool
  - Taxi/ridehailing (Uber)

Modes

- Auto drive
- Transit with walk access
- Transit with auto access/egress
- Walk all-way
- Bicycle
- School bus (elementary & secondary student only)
- Auto passenger modes:
  - Household passenger
  - Household rideshare
  - Inter-household carpool
  - Taxi/ridehailing (Uber)

We have developed a generalized tour-based access/egress station choice model

Modes

- Auto drive
- Transit with walk access
- Transit with auto access/egress
- Walk all-way
- Bicycle

Modelled as a "tour-mode" in the same way as auto drive.

- School bus (elementary & secondary student only)
- Auto passenger modes:
  - Household passenger
  - Household rideshare
  - Inter-household carpool
    Taxi/ridehailing (Uber)
  - Taxi/ridehailing (Uber)

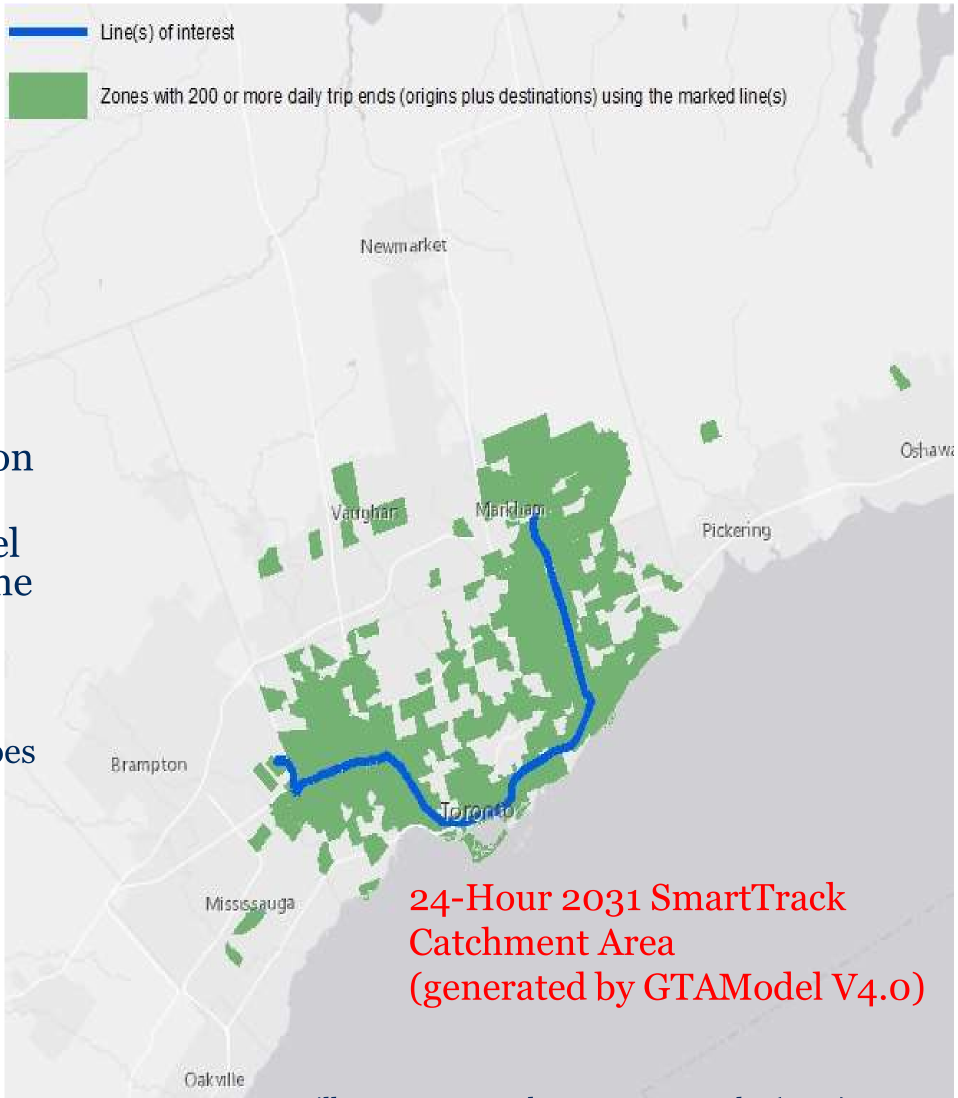
Modes

- Auto drive
- Transit with walk access
- Transit with auto access/egress
- Walk all-way
- Bicycle
- School bus (elementary & secondary student only)
- Auto passenger modes:
  - Household passenger
  - Household rideshare
  - Inter-household carpool
  - Taxi/ridehailing (Uber)

Endogenous within the household tour-based mode choice model

Model Outputs

- GTAModel generates a wealth of data concerning travel, such as:
  - Origin-to-destination (O-D) trips by mode, purpose & time of day.
  - O-D travel times & costs by mode & time of day.
  - Roadway volumes, travel times and congestion levels for every road link in the region.
  - Transit ridership, boardings, alightings, travel times and crowding levels for every transit line segment for every transit line in the region.
  - Trips, travel times experienced, etc. by each person in the region:
    - Benefits and costs experienced by different types of persons can be identified.
  - Accessibilities to work, school, shopping, etc.
  - Pollution & GHG emissions.
  - Transit system revenues.
  - Toll revenues.
  - Transit line catchment areas (who uses what lines).
  - …

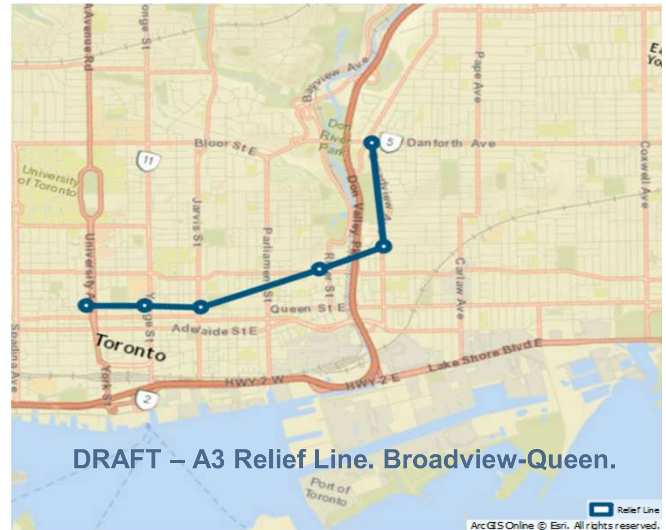


24-Hour 2031 SmartTrack Catchment Area
(generated by GTAModel V4.0)

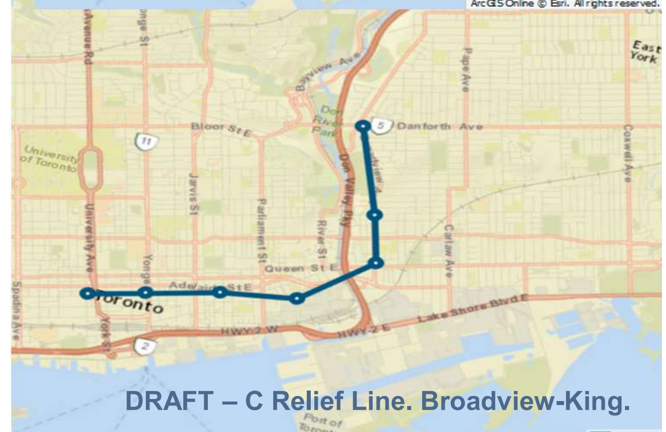
Source: Miller, E.J., J. Vaughan & M. Nasterska (2016) SmartTrack Ridership Analysis, Project Final Report, report to the City Manager, City of Toronto, Toronto: UTTRI.

SmartTrack Example

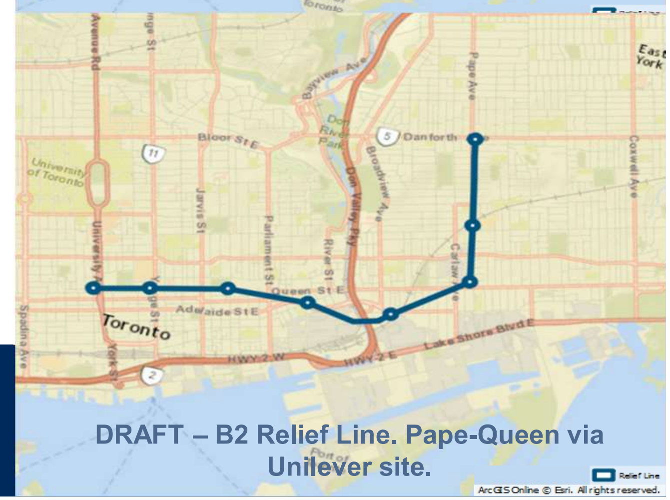
- The first major application of GTAModel V4.0 was to analyze major rail investment options for the City of Toronto.
- Hundreds of runs explored permutations and combinations of:
  - Route alignments.
  - Stations (number & location).
  - Fares.
  - Frequencies.
  - Combinations of lines.
  - Population & employment distributions.



DRAFT – A3 Relief Line. Broadview-Queen.



DRAFT – C Relief Line. Broadview-King.

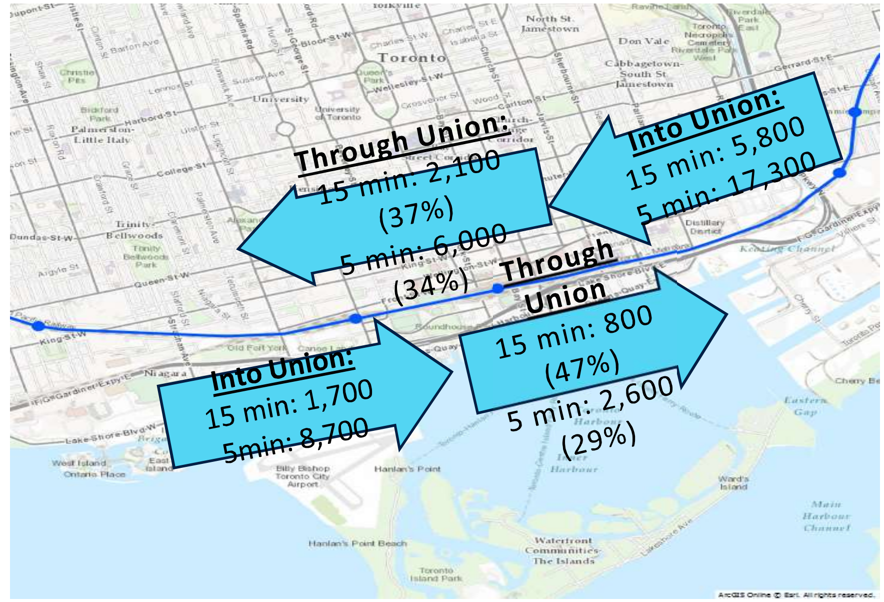


DRAFT – B2 Relief Line. Pape-Queen via Unilever site.

SmartTrack Headway	2031 TTC Fare Scenario	2031 GO Fare Scenario
15 min	74,000	34,400
10 min	151,700	57,100
5 min	307,900	102,400

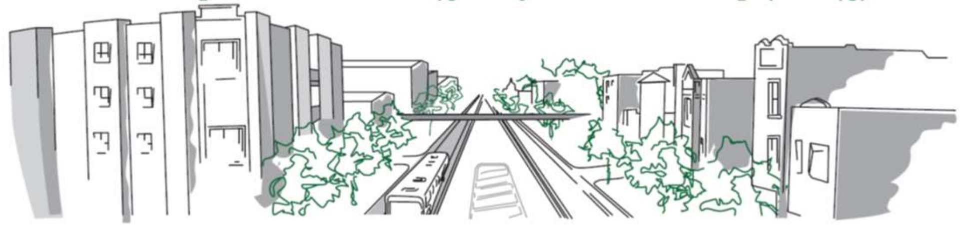
SmartTrack Headway	2031 TTC Fare Scenario	2031 GO Fare Scenario
	Compared to RER Base Case	Compared to RER Base Case
15 min	22,000	14,500
10 min	32,900	17,200
5 min	52,400	20,800

Land Use Scenario	SmartTrack Headway	All Day Boardings on SmartTrack	New Net System Riders**
Low Pop / Low Emp	15	59,100	9,200
	10	124,000	17,700
	5	266,100	33,700
Low Pop / Med Emp without ST Influence	15	61,800	8,900
	10	129,400	17,400
	5	276,600	33,500
Low Pop / Med Emp with ST Influence	15	74,000	22,000
	10	151,700	32,900
	5	307,900	52,400
High Pop / High Emp	15	75,500	*** No Base Exists
	10	154,200	*** No Base Exists
	5	314,000	*** No Base Exists
Additional Regional Growth	15	76,700	*** No Base Exists
	10	156,300	*** No Base Exists
	5	314,300	*** No Base Exists



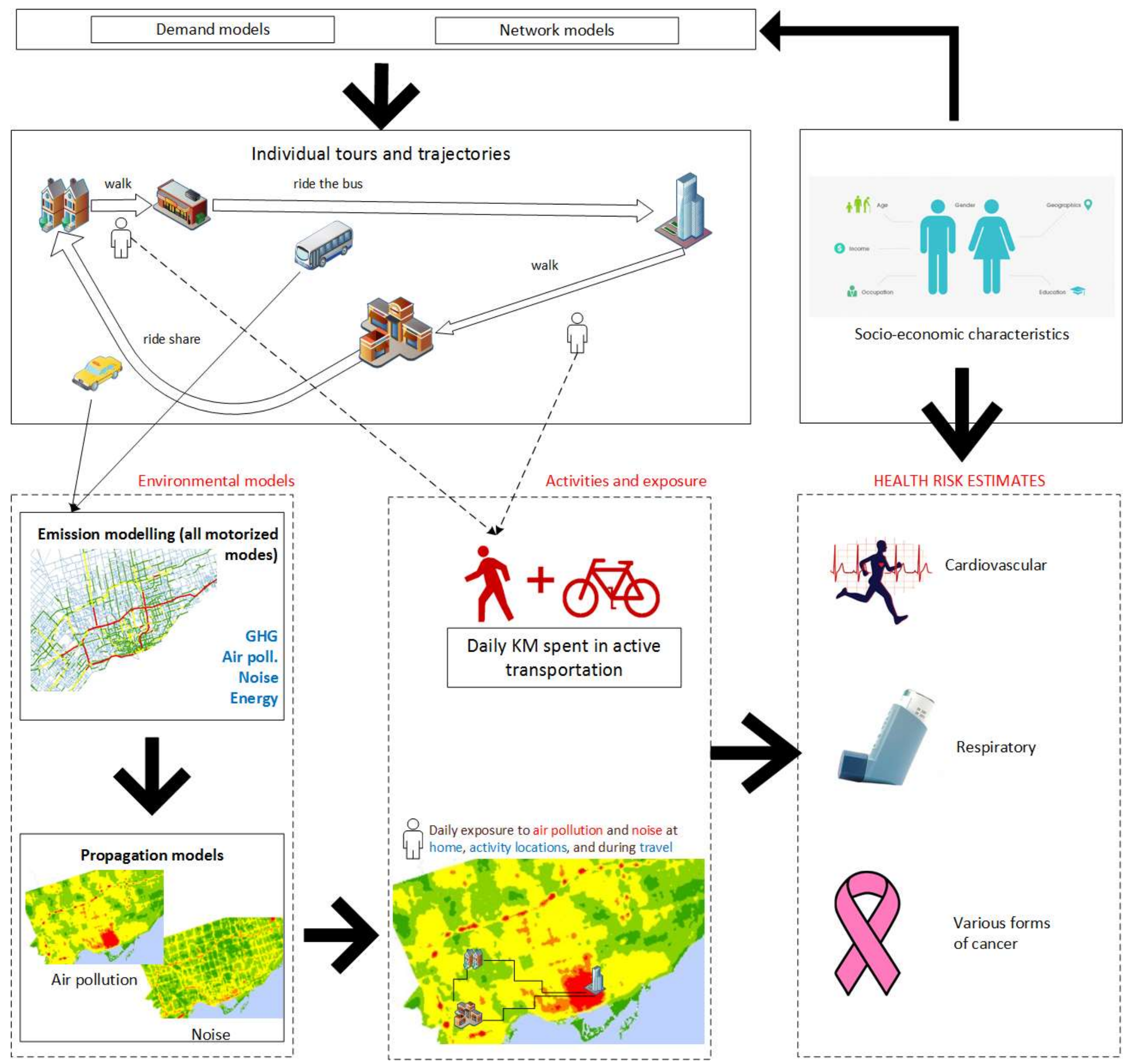
- Impacts examined included:
  - Transit ridership (including new riders).
  - Mode shares.
  - Roadway congestion.
  - GHGs.
  - Catchment areas.
  - Network synergy effects.

University of Toronto
Transportation and Air Quality Research Group (TRAQ)

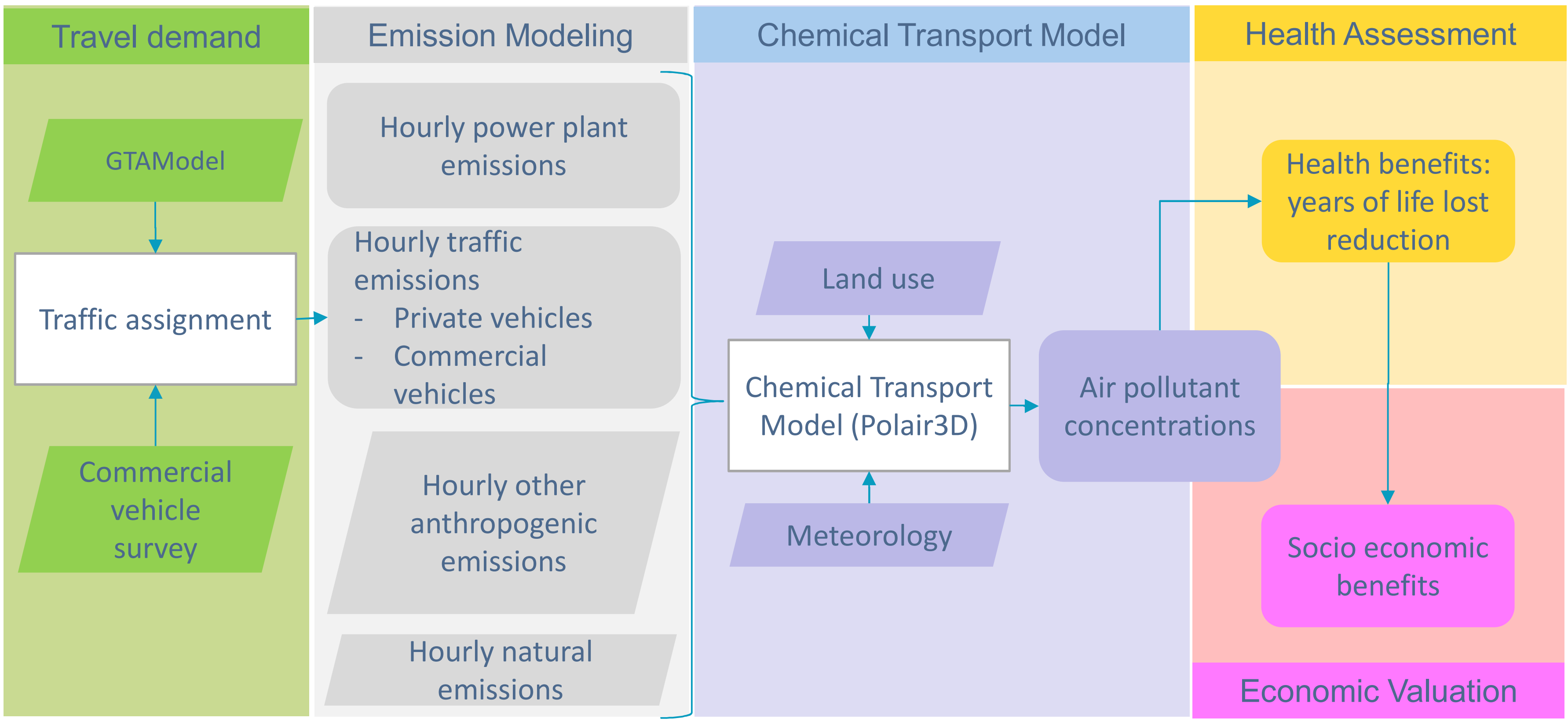


Modelling Air Pollution & GHG Emissions

Prof. Marianne Hatzopoulou

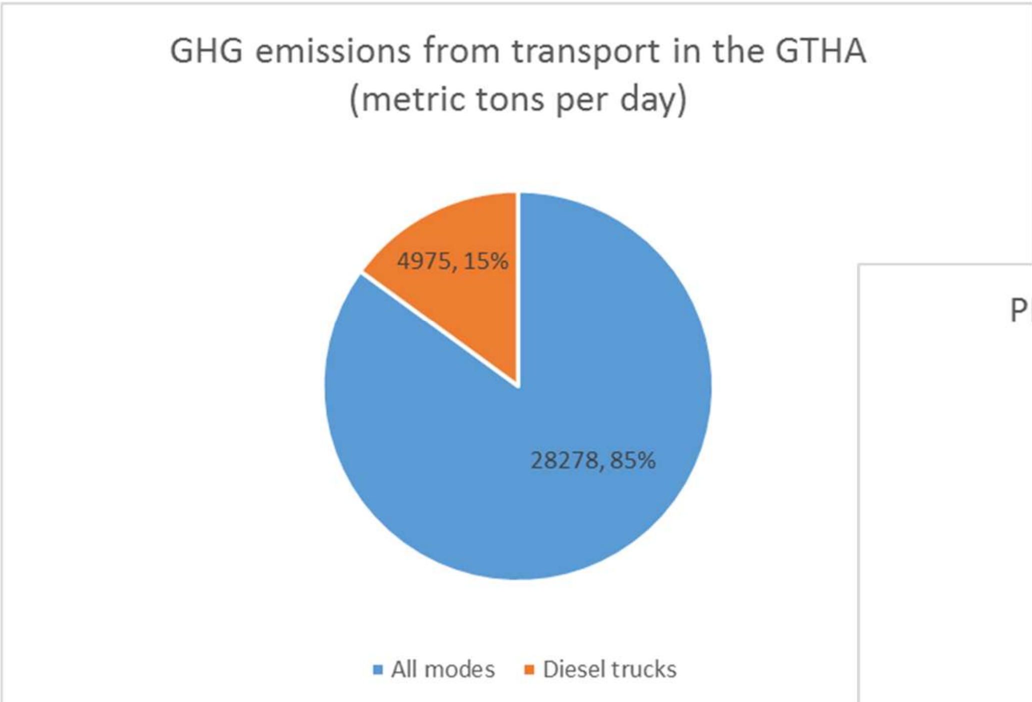


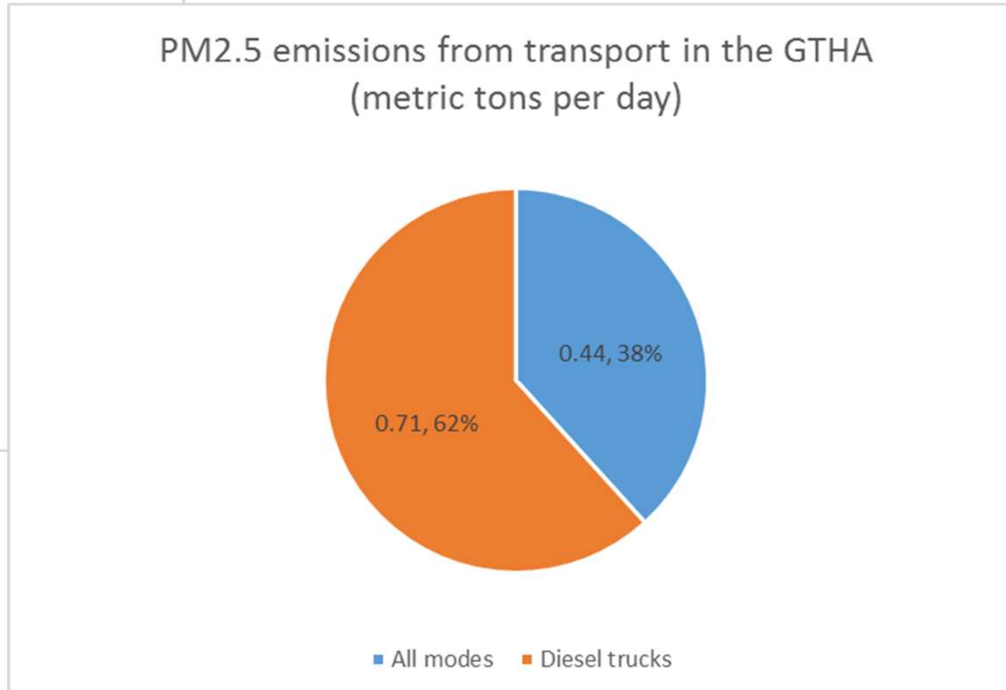
Overview of the Modeling Framework



UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE & ENGINEERING
Transportation Research Institute

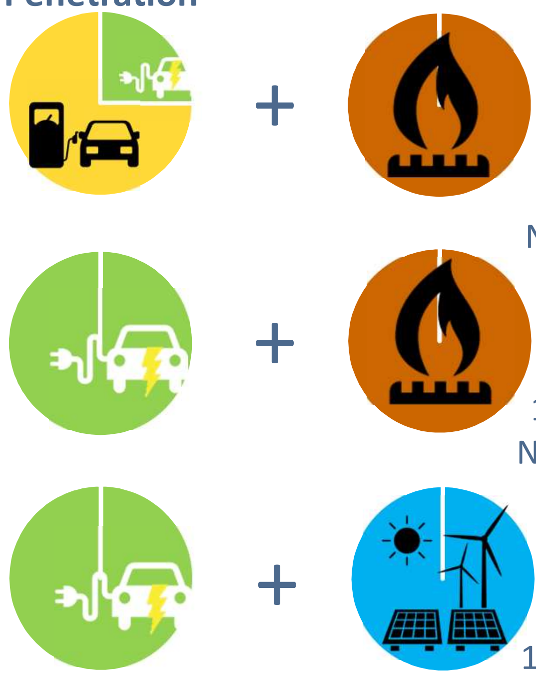
University of Toronto
Transportation and Air Quality Research Group (TRAQ)

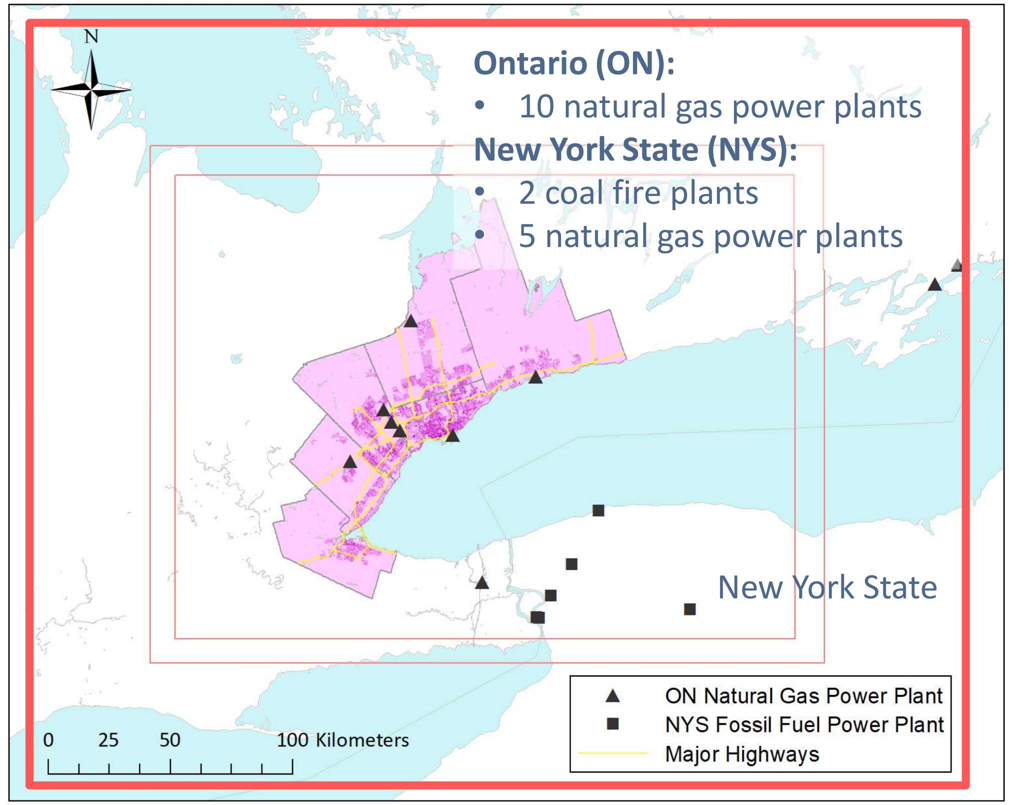

GHG emissions from transport in the GTHA
(metric tons per day)
4975, 15%
28278, 85%
All modes
Diesel trucks


PM2.5 emissions from transport in the GTHA
(metric tons per day)
0.44, 38%
0.71, 62%
All modes
Diesel trucks

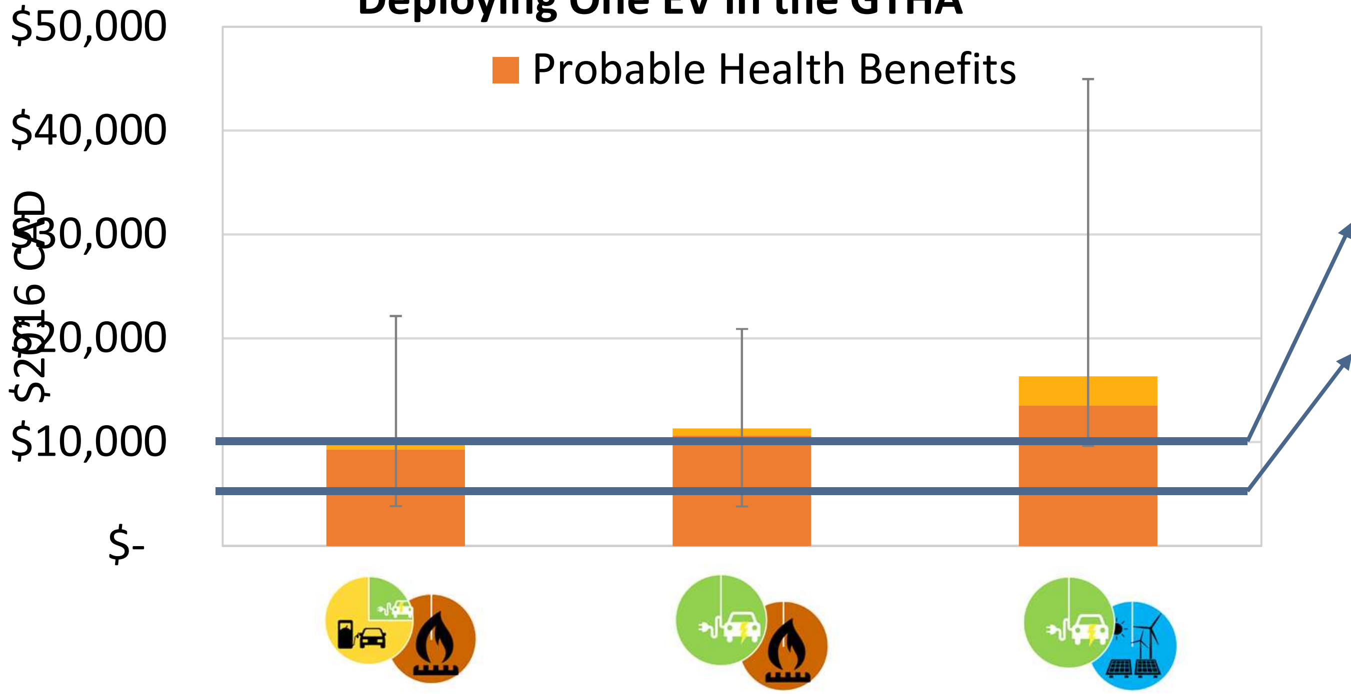
Electricity Generation Mix – Bounding scenarios

	EV Penetration		Energy source for EV charging	
1)		+		100% Natural gas
2)		+		100% Natural gas
3)		+		100% Renewable





Present Value of the Climate and Health Benefits of Deploying One EV in the GTHA



EV Incentives ($CAD):

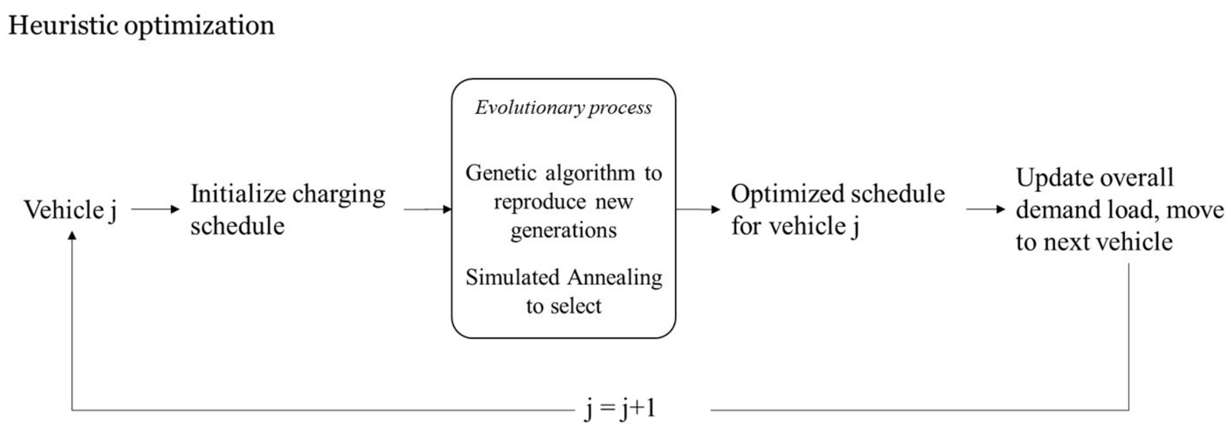
- Cancelled Ontario Incentive: ~ $10,000
- Canada federal incentive: $5,000

Optimizing EV charging to reduce GHG emissions

The GHG emission intensity of EV charging varies during the day due to the electricity mix (more natural gas during peak periods)

We developed a model that calculates marginal GHG emission factors

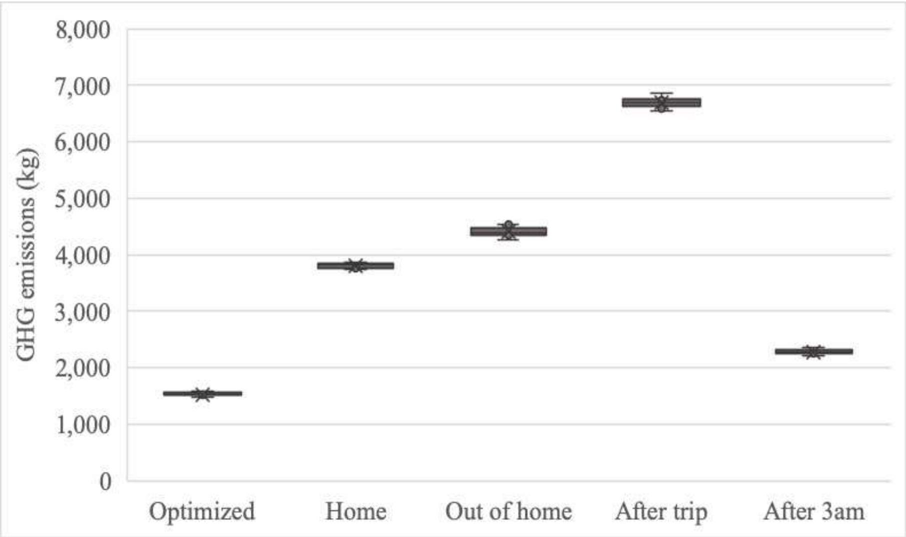
Based on travel survey data (TTS), we developed an optimization to identify, for each trip, the time and location of charging that would lead to the lowest system-wide GHG emissions



Optimizing EV charging to reduce GHG emissions

Compared to scenarios where everyone charges at home or at work/shopping, the optimized charging scheme achieves the lowest system-wide GHG emissions

The optimal charging scheme performs better than the scenario where everyone charges at night.

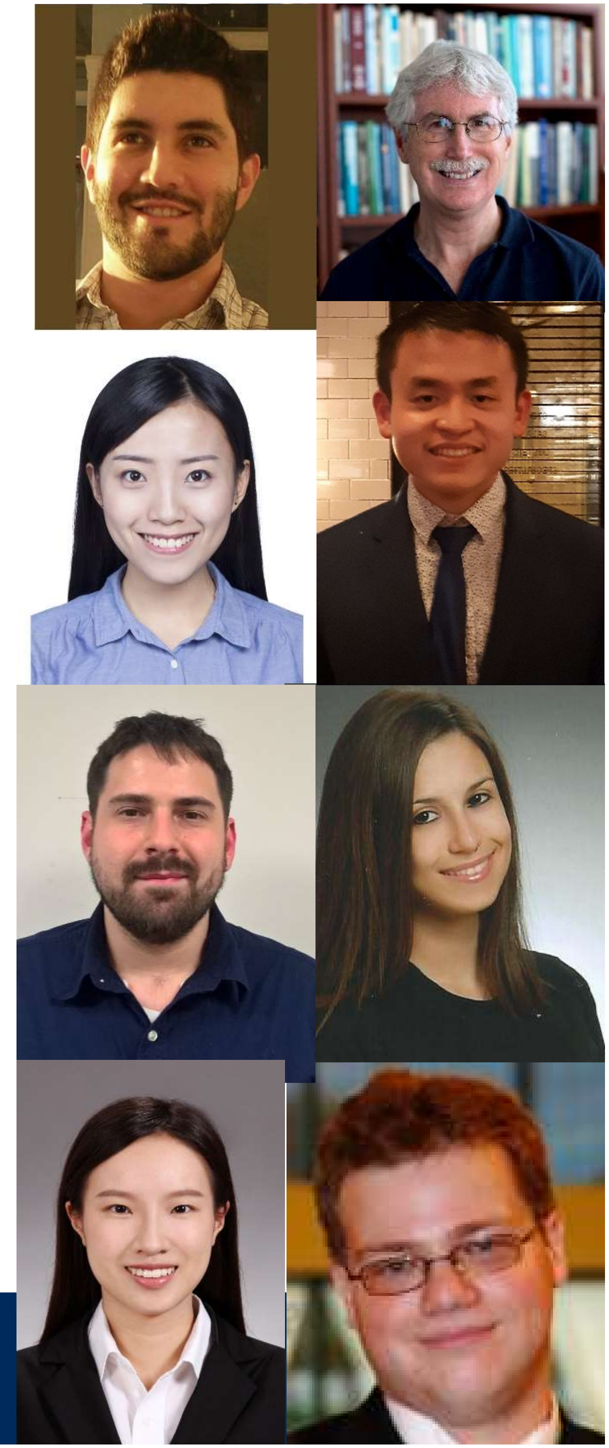


Current Research

- Modelling mobility services.
- Temporal stability of activity/travel generation.
- Accessibility measures & accessibility-based planning.
- Tighter integration with emissions models.
- Improved population synthesis & demographic updating.
- Land use modelling.
- TASHA/2 – GTAModel V5 – XTMF 2.0.

THANK YOU

QUESTIONS?



The UTTRI Travel Modelling Group team:
Building tomorrow's models today !