A Deep Dive into an Operational Activity/Travel Demand Model System

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Workshop Agenda

Will break for lunch around noon. ☺

https://tmg.utoronto.ca/doc/1.6/gtamodel/index.html

https://tmg.utoronto.ca/doc/1.6/xtmf/index.html

Introduction to Activity-Based Models

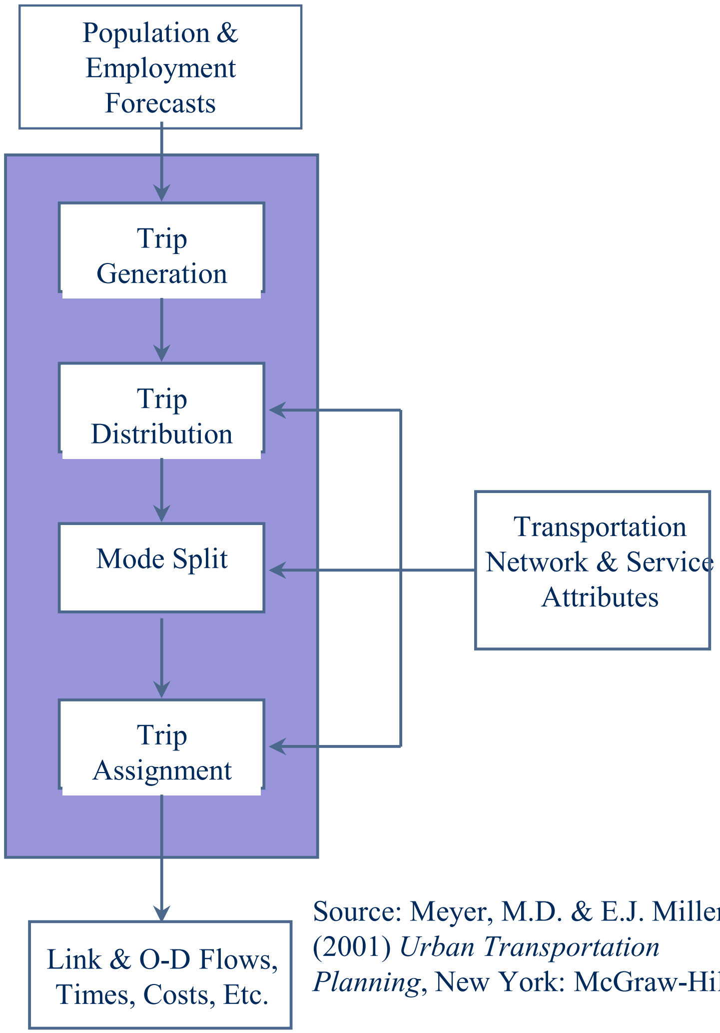
- What is an activity-based travel model?
- Why adopt an activity-based approach?
- A generic framework for activity-based modelling.
- Tour-based vs. activity-scheduling models.
- Implementing ABM: Agent-based microsimulation.

Why activity-based modelling (ABM)?

- It has long been understood that travel is a derived demand: we generally do not travel for the sake of travel per se, but in order to participate in out-of-home activities.
- Thus, the motivation and utility of travel derives largely from activity participation, as does the frequency, timing and location of trip-making.
- And so, to understand and model travel, we really need to approach the problem from an activity-based perspective.

Trip-Based Demand Modelling

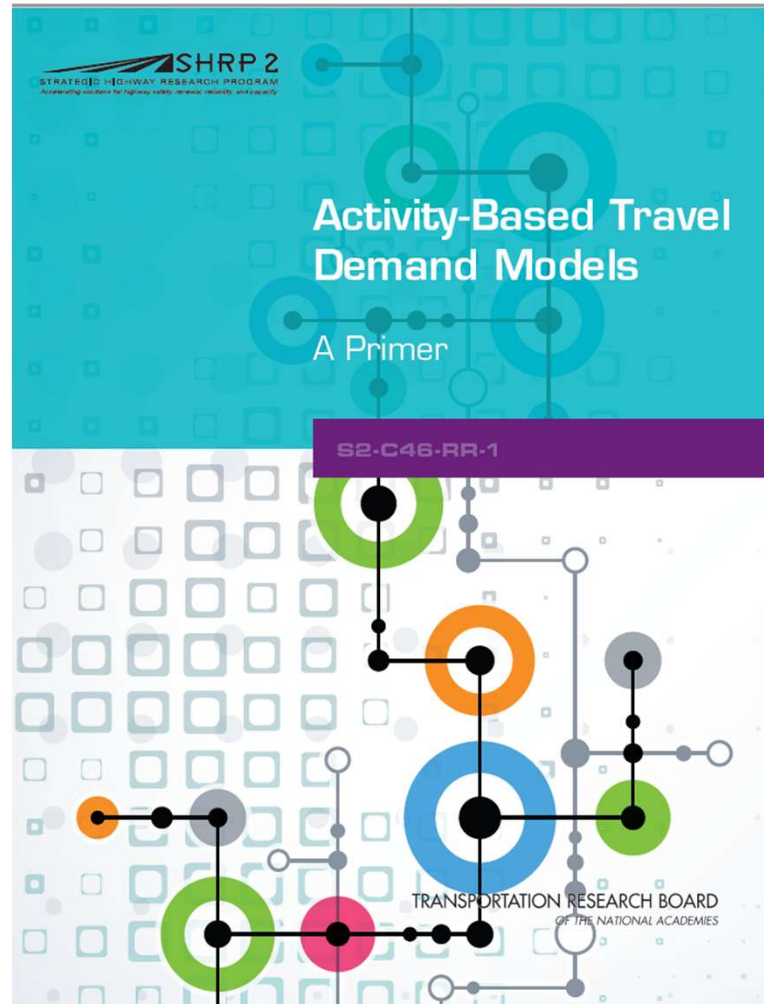
- Trip-based demand models are at best a "first-order approximation" to activity-based modelling.
- Can get away with this if only interested in peak-period commuting & willing to ignore a host of factors affecting actual travel decisions.
- But such models are inadequate to address a wide range of current & emerging issues:
  - GHG emissions.
  - Equity concerns.
  - Household interactions.
  - Tour interactions.
  - Road pricing & transit fare policies.
  - Land use interactions.
  - Off-peak (let alone weekend) travel.
  - In-home & online activities & their impact on travel.
  - …



Source: Meyer, M.D. & E.J. Miller (2001) *Urban Transportation Planning*, New York: McGraw-Hill

What is an activity-based model?

- An activity-based model is one in which out-of-home activity participation is explicitly modelled, with trips being the emergent outcome of the need to travel to these out-of-home locations (and to eventually return home again).
- Activity-based modelling recognizes that:
  - A fundamental part of decision-making is not just where to travel but the "why", "when" and "how long" of out-of-home activities.
  - Travel needs to be understood within the context of daily activity patterns and the tours (trip-chains) used to engage in these activities, not just isolated, unconnected trips.
  - Activity & travel are constrained in a variety of ways: time, space, personal capabilities & resources, etc.



Activity vs. tour-based models

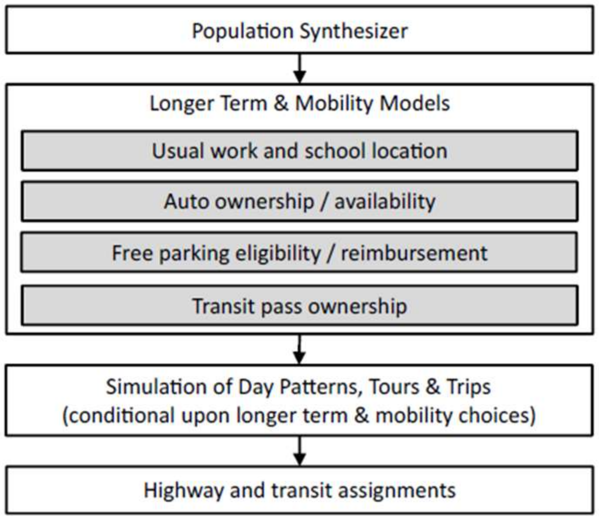


Figure 3.20. *Longer-term and mobility choice models in an activity-based model.*

- Most operational models, however, are <u>not</u> activity-based (despite being labelled as such); they are tour-based.
- This may be OK up to a point, since adopting a tour-based viewpoint for modelling travel is very important
- But many issues/problems exist with these models ….

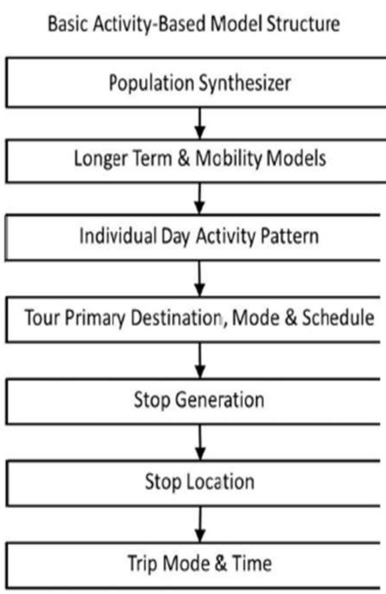


Figure 3.21. *Typical activity-based model structures.*

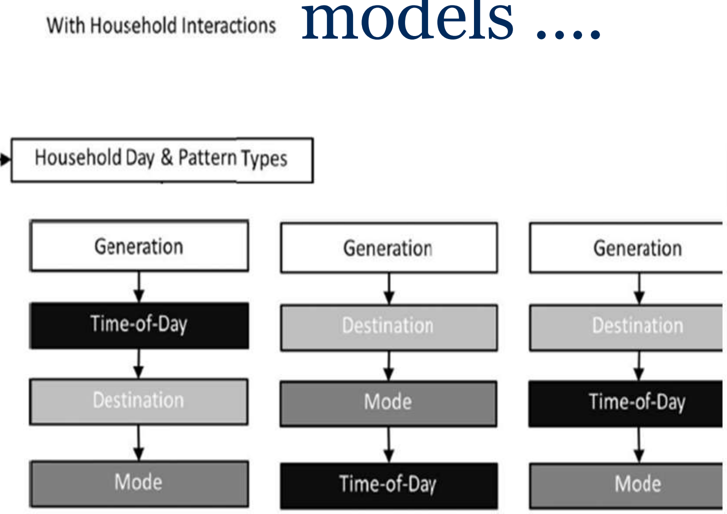


Figure 3.22. *Tour-level model hierarchies found in practice in the United States.*

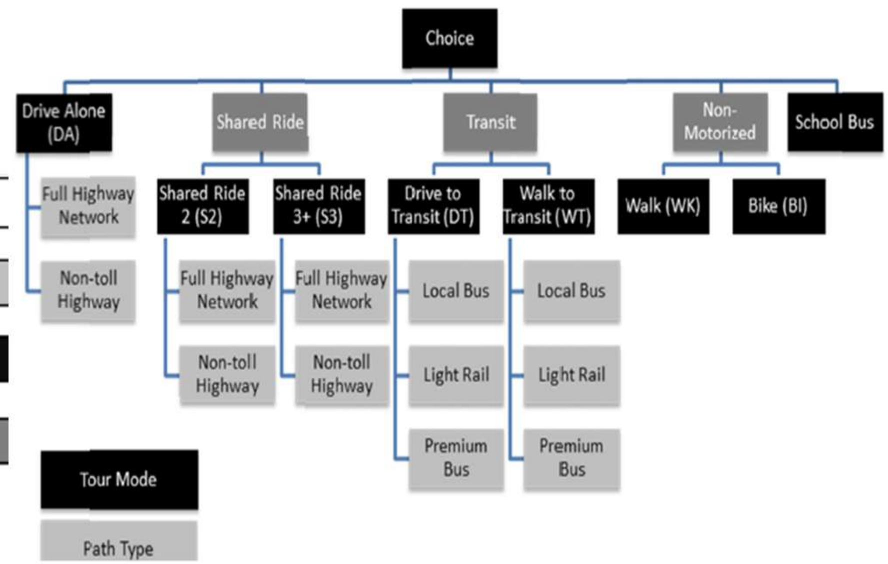


Figure 3.26. *Typical mode choice alternatives and nesting structure.*

Why is this important?

- Typical existing tour-based models have many weaknesses:
  - The methodology is "ancient" (Bowman & Ben-Akiva, 1996).
  - The model conceptual framework is very inflexible, not very "behavioural" and usually internally inconsistent (!).
    - Tour complexity is limited; excludes many possibilities.
    - Treatment of mode choice is excessively complicated.
    - Trip/tour generation very simplistic & generally inelastic.
    - Decision structure is "hard-wired" and not easily extensible.
  - The software is computationally inefficient, very complicated & not generally extensible.
    - Too much is "hard-wired" into the code.
    - Challenging to estimate & calibrate.
    - Very "black-boxy".
- As a result, many agencies are understandably reluctant to adopt such models.

Modelling Tours

- This is a typical structure for building tours in most models.
- This is <u>not</u> how people plan their days.
- Overly rigid – restricts the potential for complex tours.
- Tour structures limited & hard-wired.
- Ignores issues of activity durations.
- Does not deal well with household interactions (if at all).

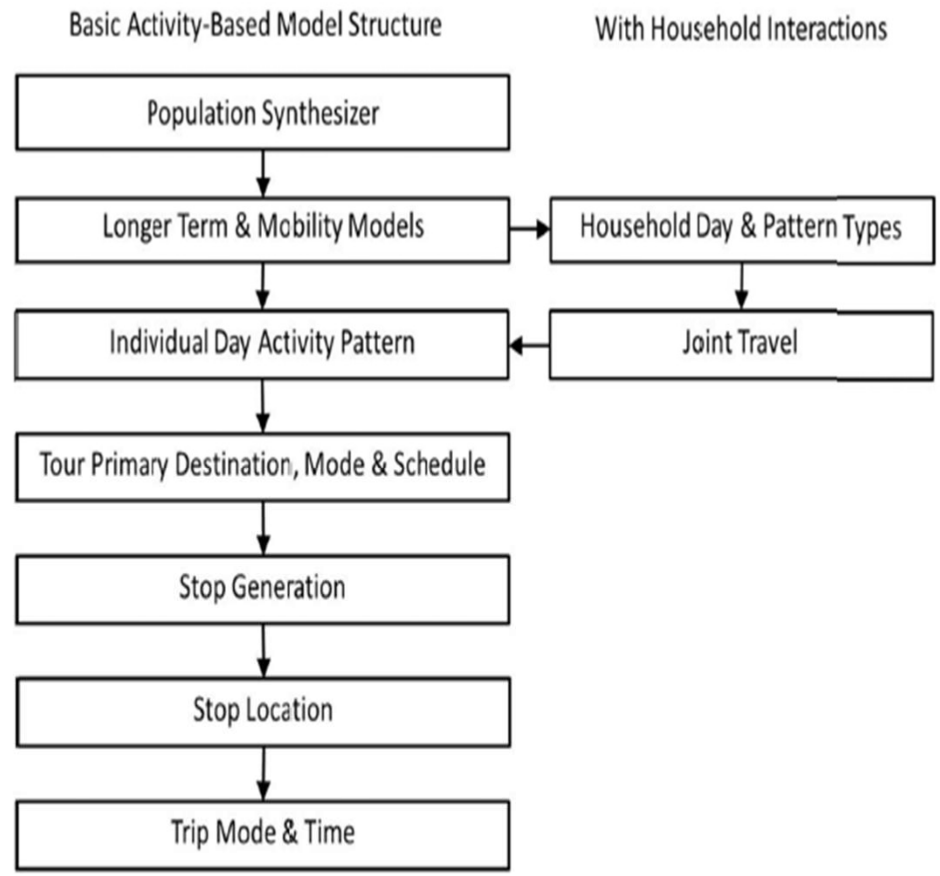


Figure 3.21. *Typical activity-based model structures.*

Mode Choice

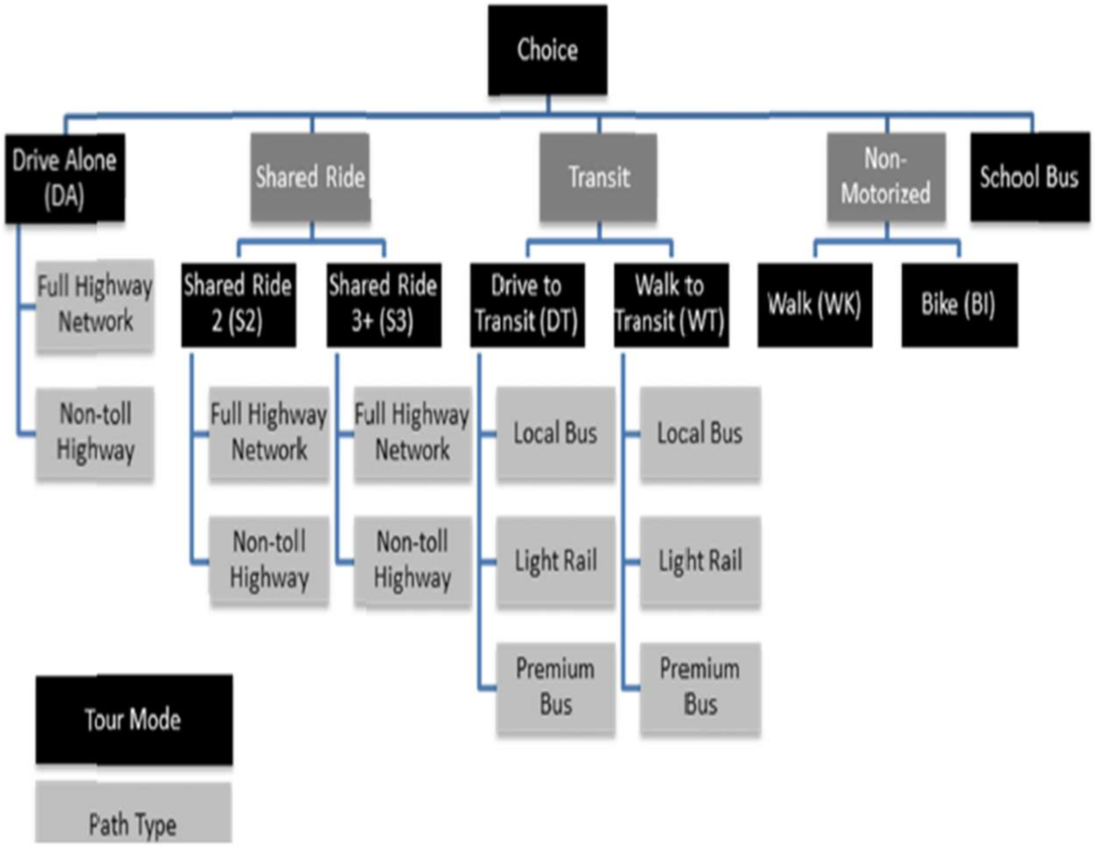


Figure 3.26. *Typical mode choice alternatives and nesting structure.*

- Overly complicated.
- “Trip” vs. “tour” mode: ad hoc & behaviourally unsound.
- Rigid decision structure.
- Does not support complex tour mode choices.
- Cannot effectively introduce new modes.
- Often internally inconsistent in allocation of cars to drivers.
- Computationally very burdensome.

What is the alternative? (1)

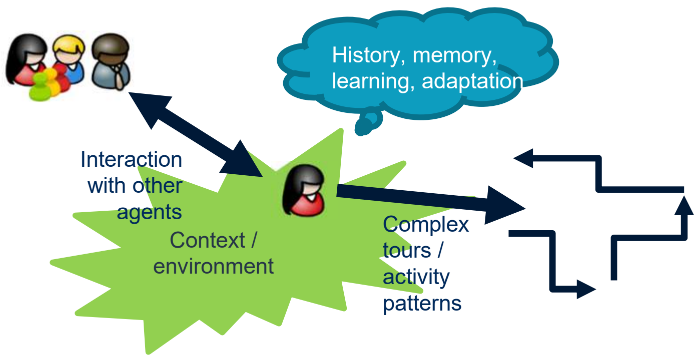
- Actually model activity participation!
- I like to label such models *activity-scheduling* models.
- Many examples exist, but most are in the academic literature and have not been implemented.
- Examples include:
  - ALBATROSS (FEATHERS); CEMDAP; ADAPTS/POLARIS; …
  - TASHA

What is the alternative? (2)

1. Start with policy analysis needs that determine model requirements.
2. Design a conceptual framework that is:
   a. Behaviourally sound.
   b. Addresses the model requirements as best as possible.
   c. Parsimonious: is only as complicated as necessary.
   d. Is feasible to implement given available/obtainable data.
   e. Supports efficient software design.
3. Implement the framework in well-designed, efficient, flexible & extensible software.

What is the alternative? (3)

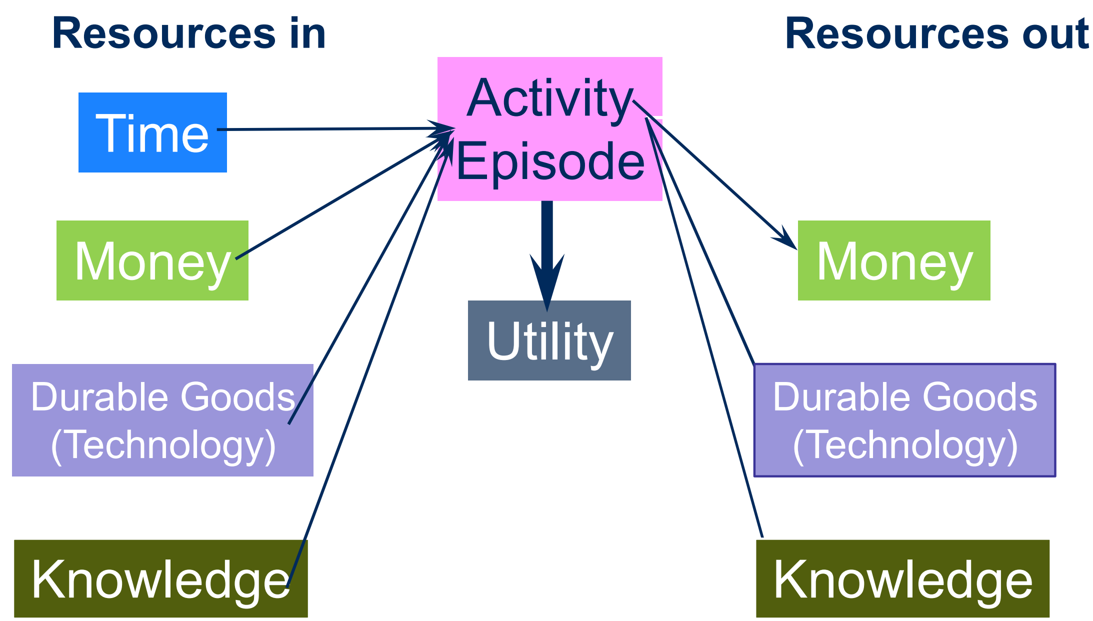
- Agent-based microsimulation! (another ABM)
- Current models are some form of microsimulation, but they rarely take "human agency" seriously, and are rarely, if ever, truly agent-based.
- But A^{gent}BM is by far the best way to implement A^{ctivity}BM, both theoretically and practically.
- Implementing an activity-scheduling framework within an A^{gent}BM software system can address many/most of the criticisms of current tour-based models. They can be:
  - Behaviourally sound.
  - Computationally efficient.
  - Generate complex behaviour without being overly complicated.
  - Much more transparent to both analysts & decision-makers.

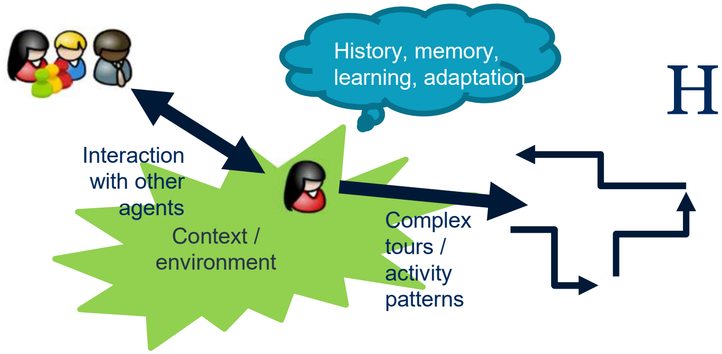


Human Agency (1): What do persons & households "do"?

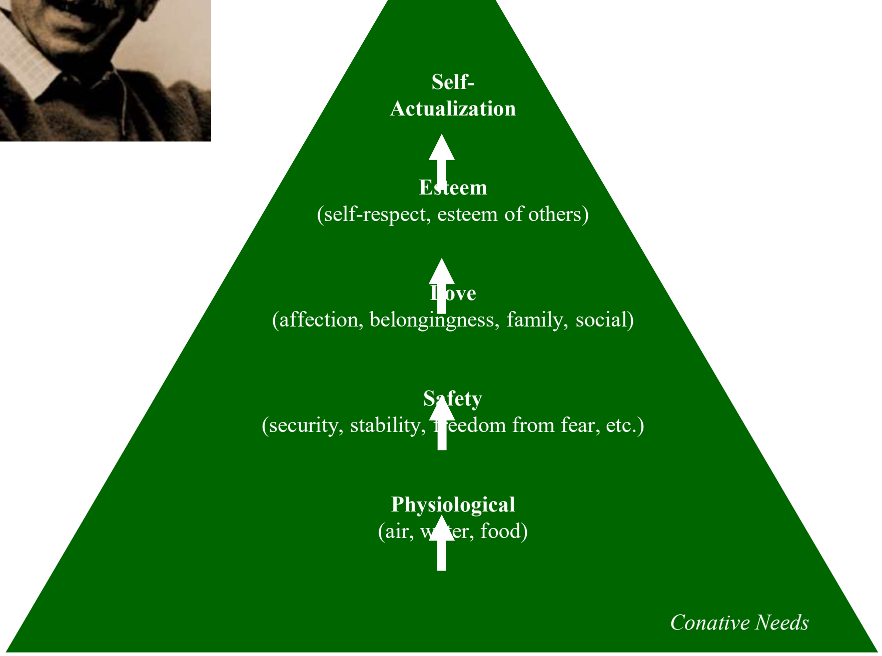
- Persons & households respond to their environment (the state of "the World") and act into the World (and thereby affect its state) by making (and eventually executing) decisions with respect to the acquisition, allocation & usage of tangible household and personal resources:
  - Time
  - Money
  - Goods & Services (notably housing & cars)
  - Knowledge
- The resources available to an agent define the physical/technological/fiscal context within which all activity occurs.

Activities are engaged in to generate utility (benefit). They both consume and generate resources.



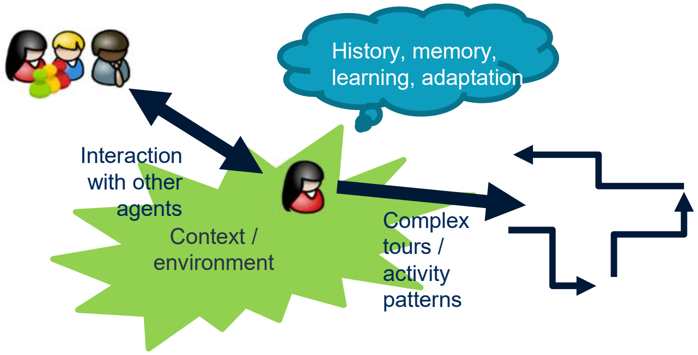


Human Agency (2): Motivated Behaviour

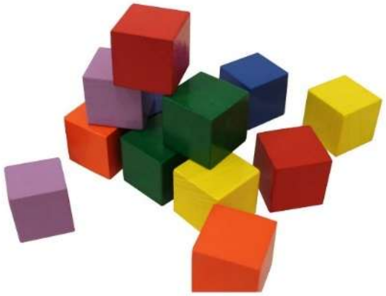


Maslow (1970)

- Agents (people) are motivated decision-makers attempting to satisfy needs / achieve goals & objectives.
- To do this, they take on *projects*.
  - All human action is generated out of a comprehensive set of projects.
  - Include "biological" processes such birth, death, aging, etc. as projects.
  - Both persons & households have projects.
- Within their projects, agents decide to engage in activities (*activity episodes*).
  - Episodes are the actual object. "Activity" is simply the type of episode.
- Decide how to allocate *resources* to activities (*resource management*; time & monetary budgets).
  - All activity can be characterized as the consumption and generation of resources.
- Decide to enter *markets* in order to acquire/exchange resources.
- Generate flows through *networks* (travel, goods, water, energy, information, …).



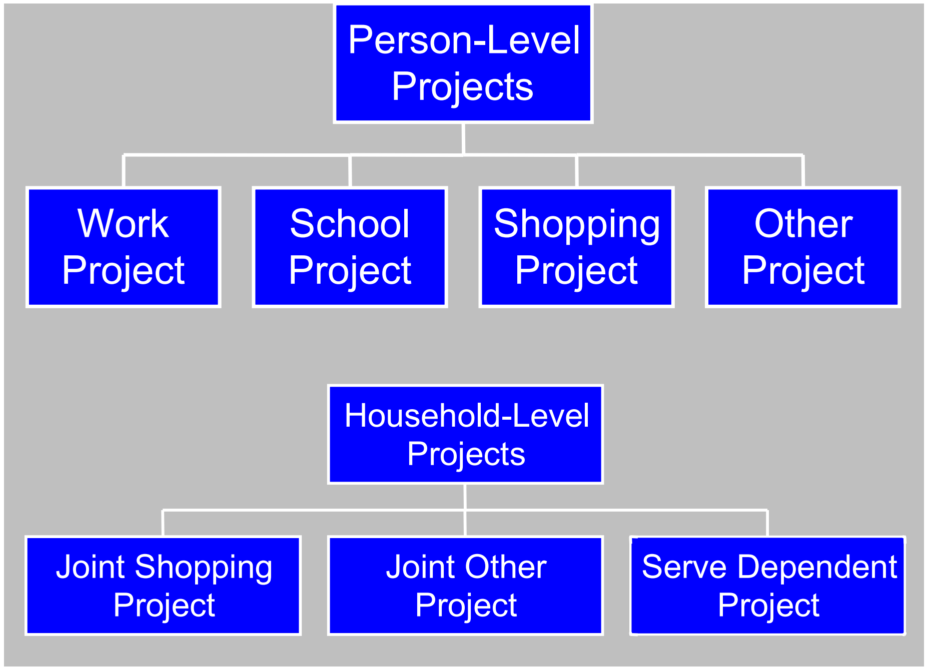
Human Agency (3): Projects



- Axhausen (1998) defines a **project** as a coordinated set of activities tied together by a common goal or outcome.
- In this conceptual model, the project is **the** fundamental organizing principle.
- It is argued that **all** activities (short- and long-run) are embedded within and generated by projects.
- Projects may have sub-projects, which can have sub-sub-projects, and so on.
- An activity episode is thus an "elemental" project which contains exactly one type of action.

Projects, cont'd

- Persons & households have a number of *projects* that require one or more types of activities to be undertaken to achieve project goals.
- *Activity episodes* are generated by projects to meet project needs.
- Projects *encapsulate* the decision-making logic, information, etc. needed to generate activity episodes.
- Projects operate independently of one another to generate an *agenda* of episodes in which it would like to engage.



An *activity scheduler* mediates between projects and determines what activity episodes get scheduled, and eventually, executed.

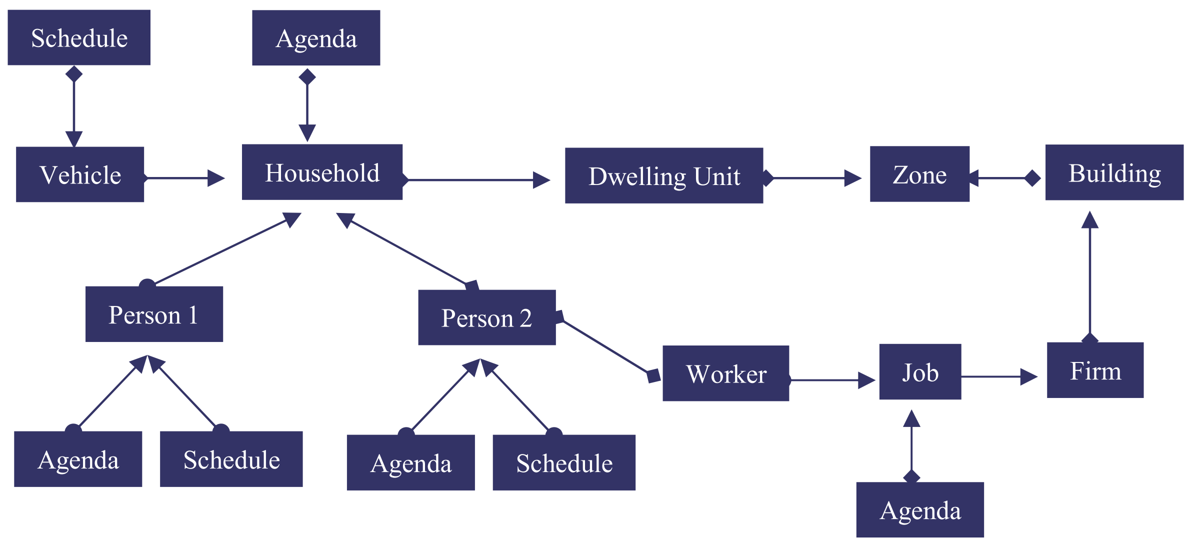
Activities & Episodes

- We live our lives through a sequence of **activities** in which we engage.
- Activities are manifested in terms of individual **episodes.**
- Each episode has:
  - duration.
  - start time (end time = start + duration)
  - location
- We travel to engage in activities.
- Trips are **travel episodes**; additional attributes:
  - location involves two points: origin & destination
  - mode
  - route

Agent-Based Microsimulation (A^{gent}BM)

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

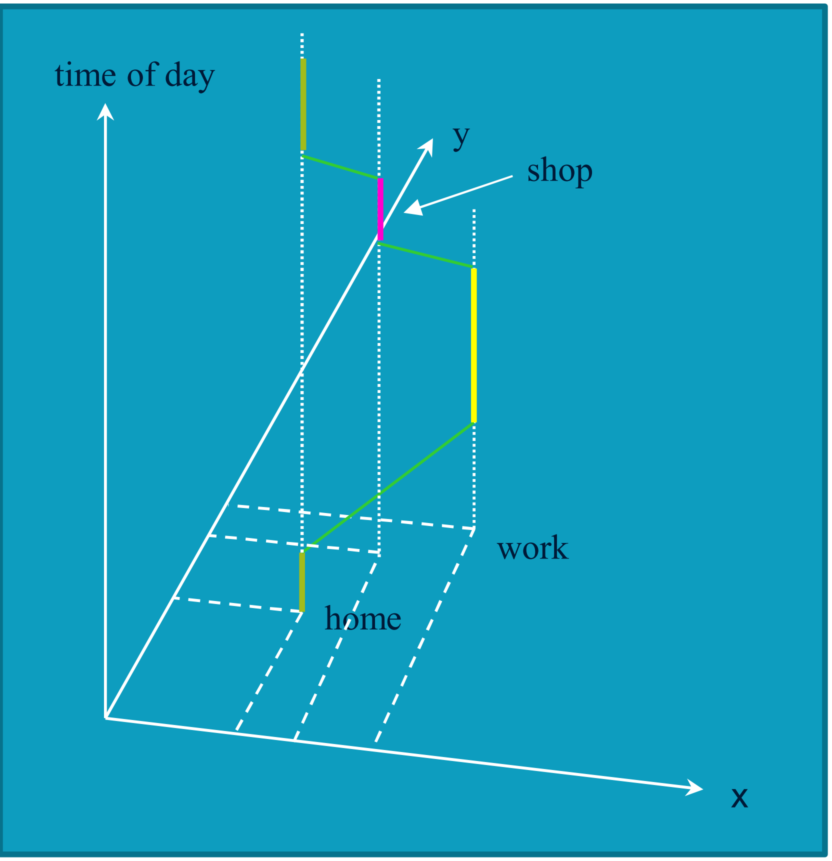
Agents:
- perceive the world around them.
- make autonomous decisions.
- act into the world.



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

This is a very different representation of activity participation than in the tour-based models previously shown!

Tour-Based Modelling

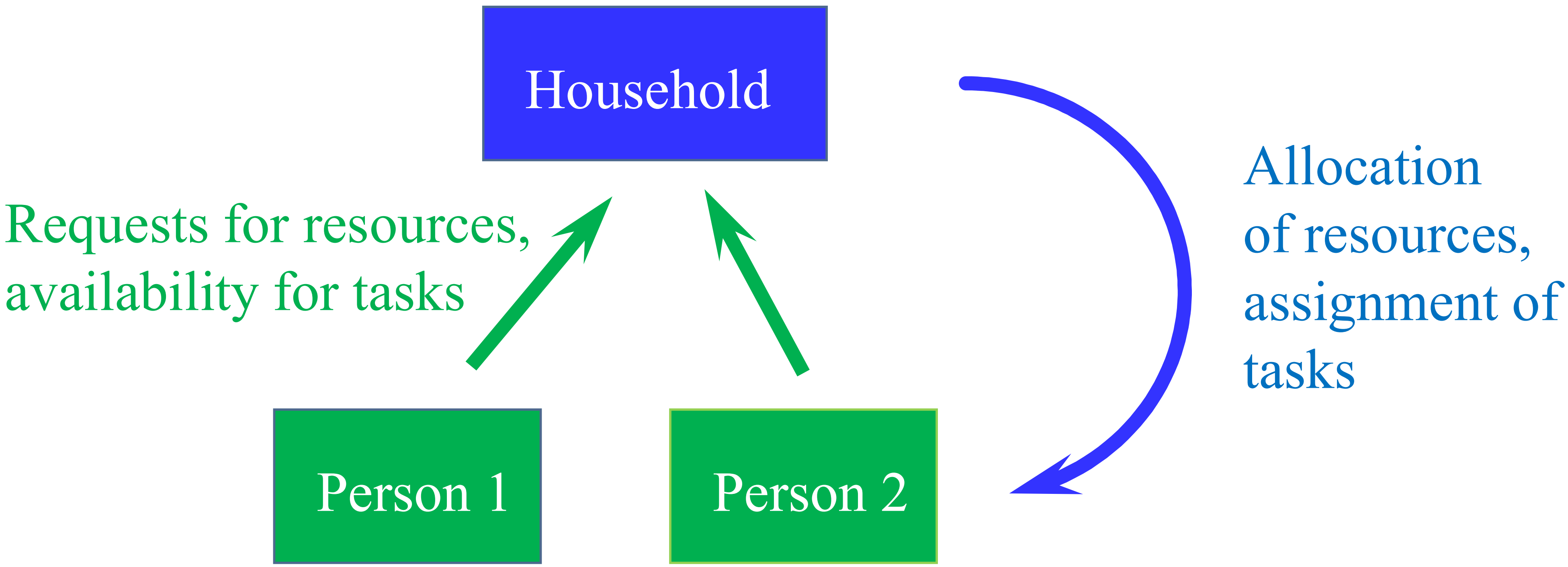


- It is impossible to predict trip characteristics "adequately" outside of the context of the tour (trip-chain) in which the trip occurs.
- Perhaps the single biggest advance due to the "activity-based" approach is that it is intrinsically tour-based.
- The technical challenge is how to model complex tours in a behaviourally sound & computationally efficient way.

Household-Based Modelling

- Household-based: Each person's travel is conditioned by the household within which s/he lives:
  - Allocation of household vehicles.
  - Joint activities.
  - Household member ride-sharing.
- Models that do not explicitly represent household-level interactions ignore many important constraints, interactions, etc.

Households & Persons

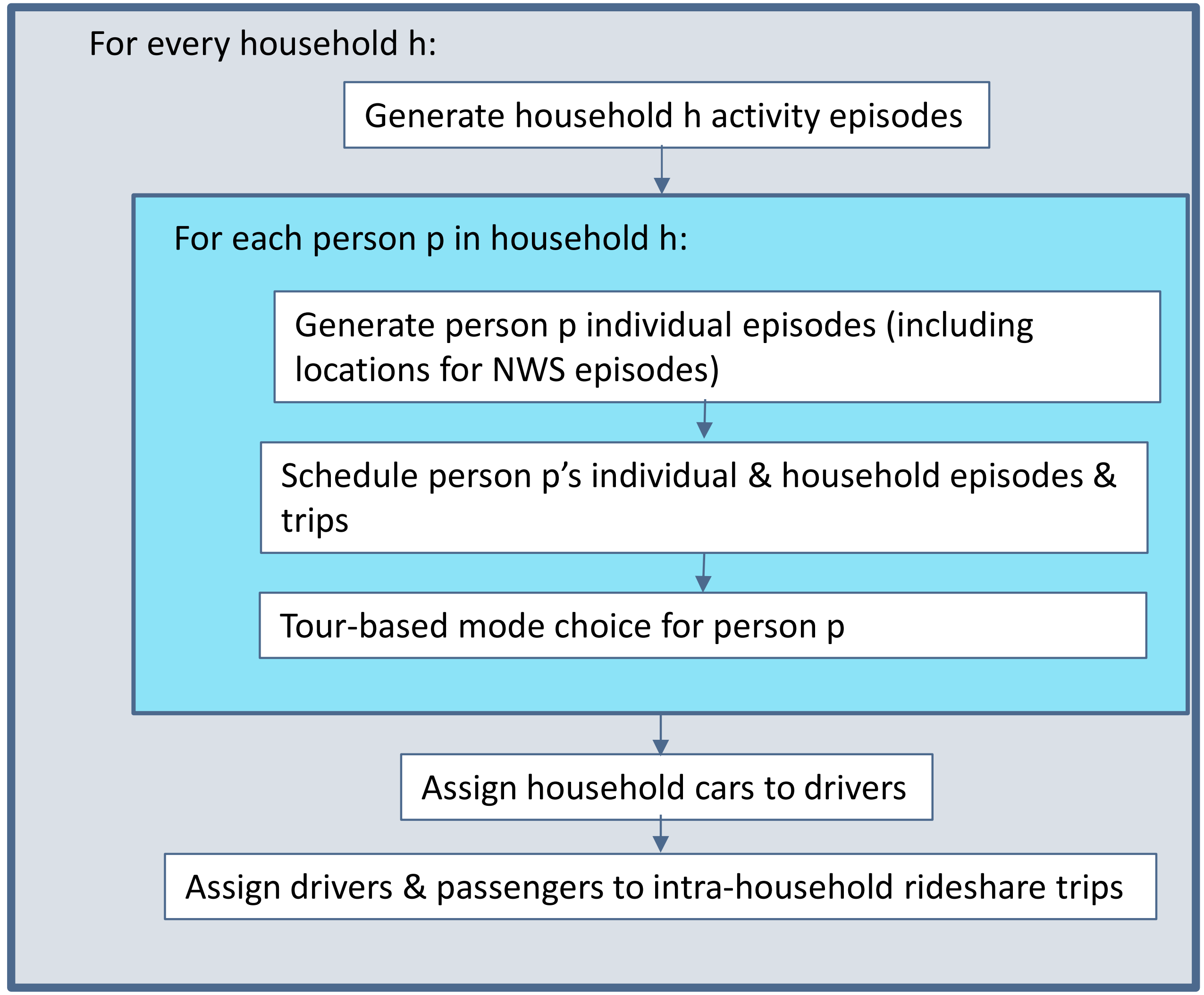


Activities are the outcome of the interaction between individual and household decision processes.

TASHA: Travel/Activity Schedule for Household Agents

- TASHA has been developed by the University of Toronto. Key characteristics:
  - Activity-based: explicit activity scheduling.
  - Agent-based: both persons & households interactively determine behaviour.
  - Household-based: first operational household-based model system.
  - Project-based: all activities are generated by the agent's projects, which encapsulate the agent's goals, preferences, etc.
  - Fully microsimulation-based.
  - Continuous time modelling for a 24-hour typical weekday.
  - Tour-based.
    - Fully multi-modal tours generated, with a strong emphasis on transit modelling.
  - Computationally efficient.
  - Implementable using standard household travel survey data.

TASHA Computational Structure



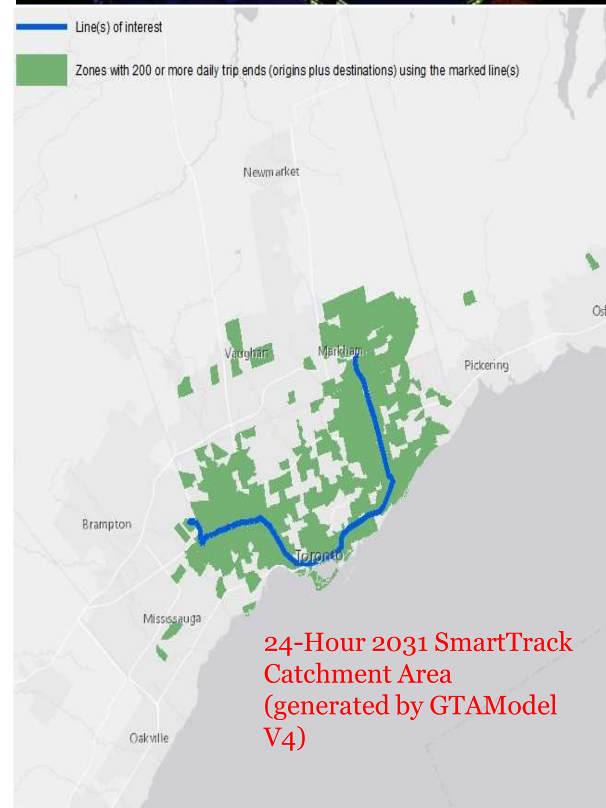
Case study: First We Take Toronto …

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

- TASHA has been in operational use by most planning agencies in the Greater Toronto Area (GTA) since early 2016.
  - Going operational.
  - Current status.
- Subsequent implementations:
  - Montreal; Halifax; Monterrey, Mexico; Sydney; …

City of Toronto implementation (1)

- In late 2014 the UofT Travel Modelling Group (TMG) was asked by the City of Toronto to implement TASHA as their operational travel demand modelling system.
- Work on this started in early 2015.
- The operational version went "live" in early 2016 & has been operational use ever since.
- The first major application was the assessment of several major rail transit investment options.

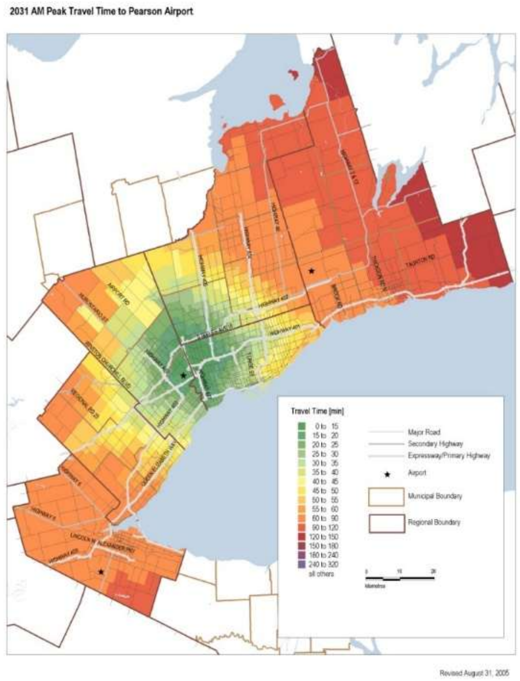


24-Hour 2031 SmartTrack Catchment Area (generated by GTAModel V4)

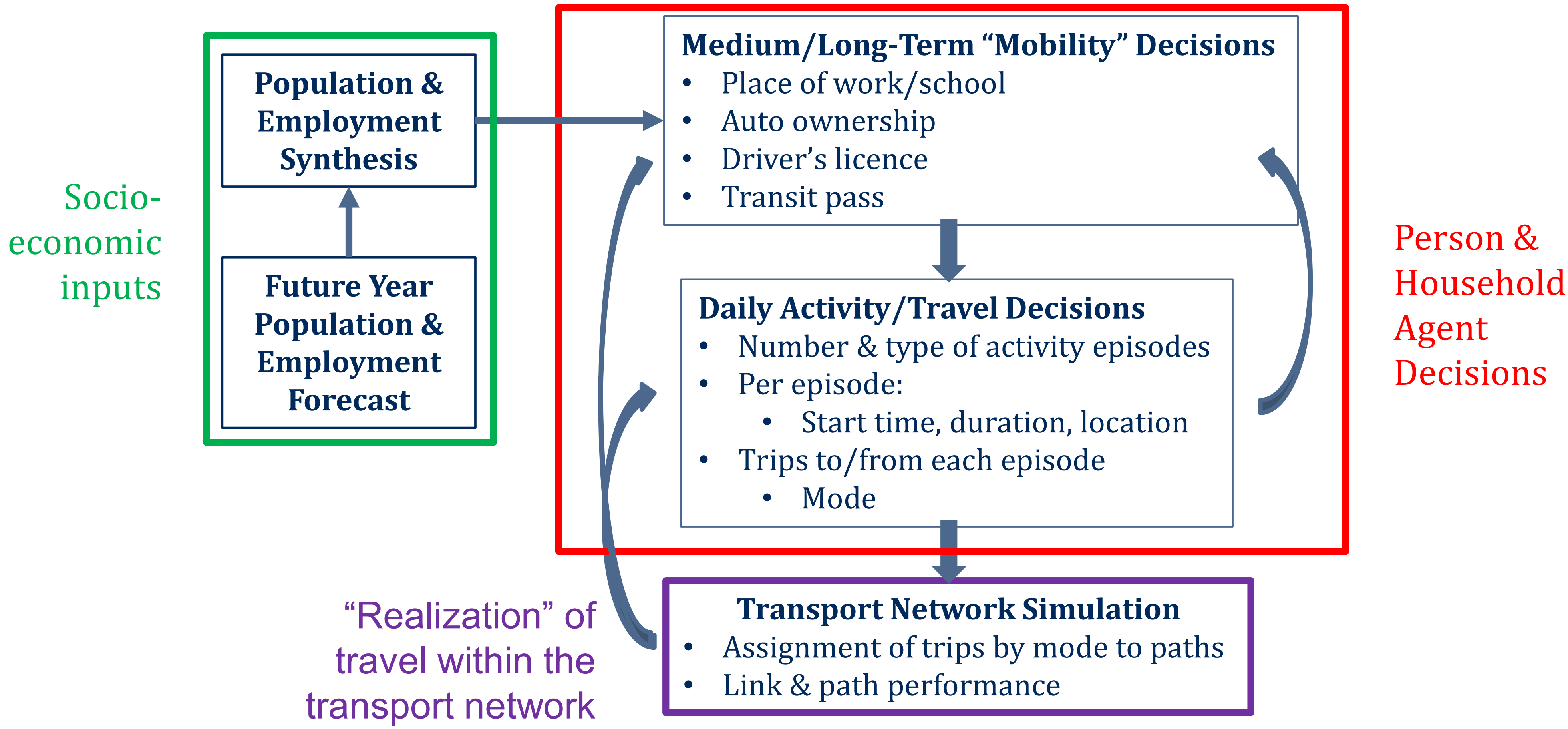
travel modelling group

City of Toronto implementation (2): GTAModel V4

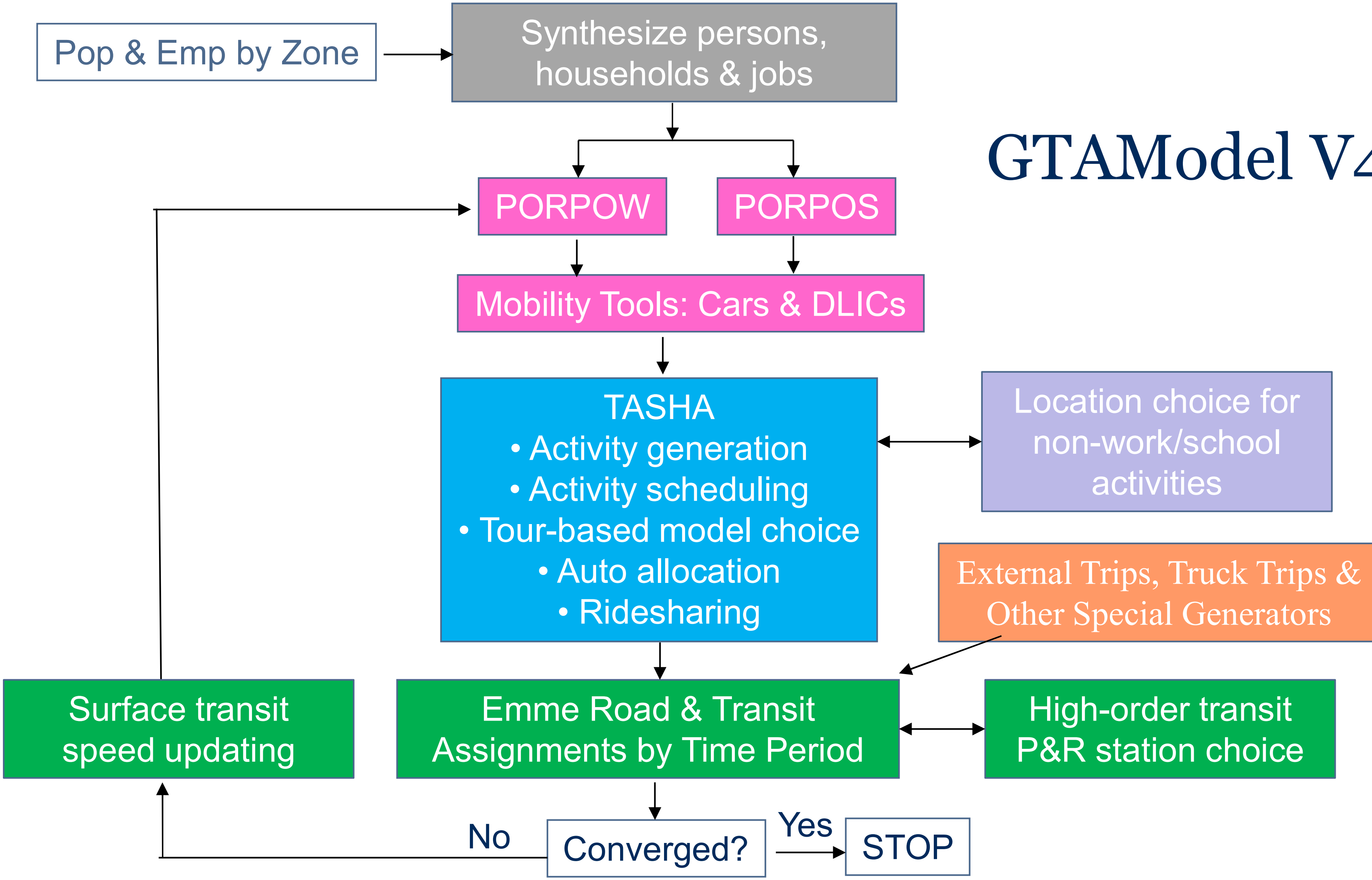
- TASHA operates on a list of persons & households possessing known work & school locations, demographics and household auto ownership levels.
- For operational use it needs to be embedded within an overall model system. This model system is designated GTAModel V4.



High-Level Architecture of Activity/Travel Model Systems



GTAModel V4



http://tmg.utoronto.ca/doc/1.6/gtamodel/index.html?

At a very high level of abstraction, the overall structure of GTAModel is similar to other models. The key difference is in how daily activities, trips & tours are built.

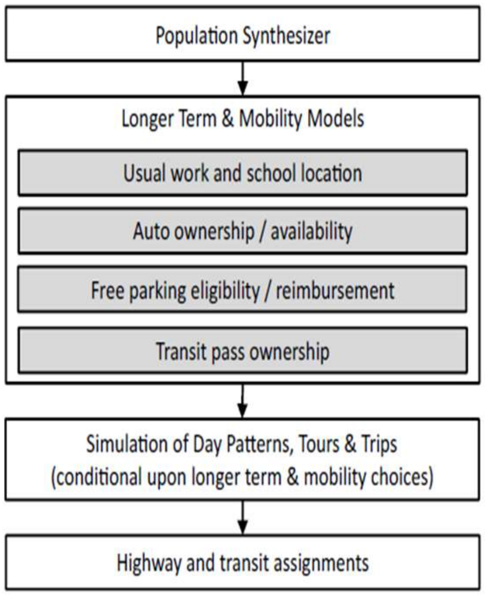
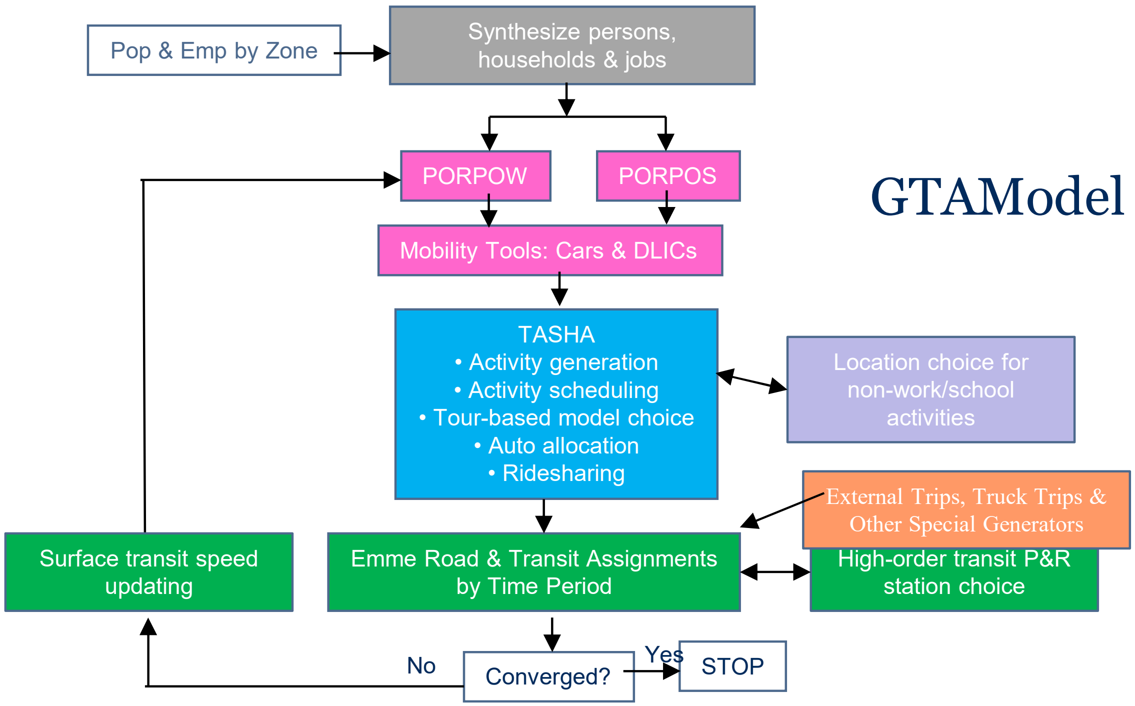


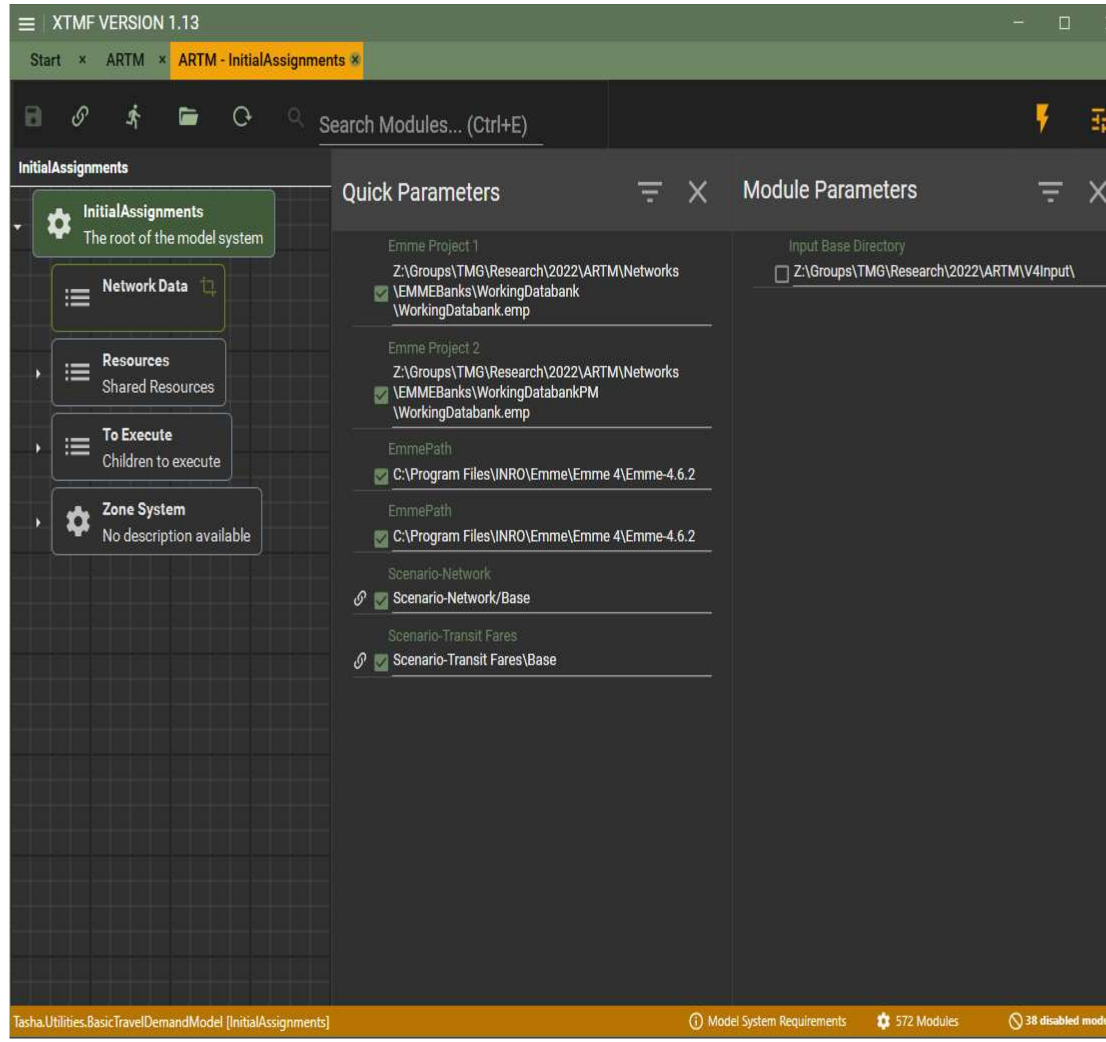
Figure 3.20. *Longer-term and mobility choice models in an activity-based model.*



GTAModel V4

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.
- XTMF is written in C# under .net.
- It currently consists of over 789 modules within an integrated platform to support:
  - Model system construction.
  - Model parameter estimation.
  - Model and model system validation.
  - Input data preparation.
  - Model system runs.
  - Output results analysis & visualization
- XTMF supports a full interface with Emm, Vissum & Aimsun through the TMG Toolbox.
- Both XTMF & the Toolbox are open source (GPLv3) & available on GitHub.
- Computational efficiency emphasized!



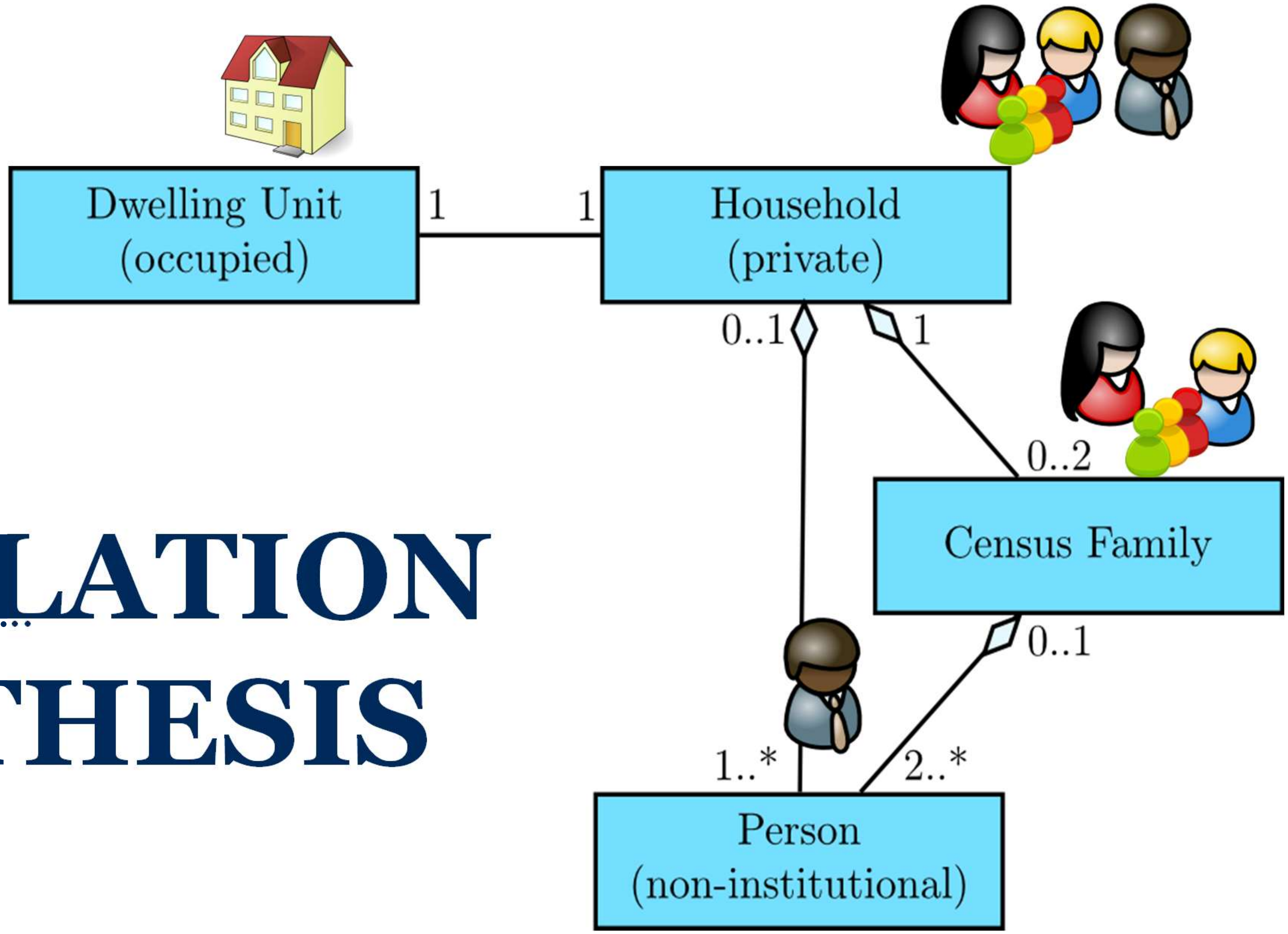
Computational Efficiency

- XTMF, V4 and TASHA have all been "optimized" as far as possible to generate quick run times. This requires detailed attention to both:
  - 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.
- Can run on laptops, desktops, servers (recommended).
- Currently, full model system runs take approx. 1 hour on a high-end server.
  - Vast majority of this time is taken by the road & transit assignments.

Model System Components

- Population Synthesis.
- Medium/Long-Term Choices
- TASHA.
- Network Models.
- Ancillary Models.

POPULATION SYNTHESIS



Synthesizing Person & Households

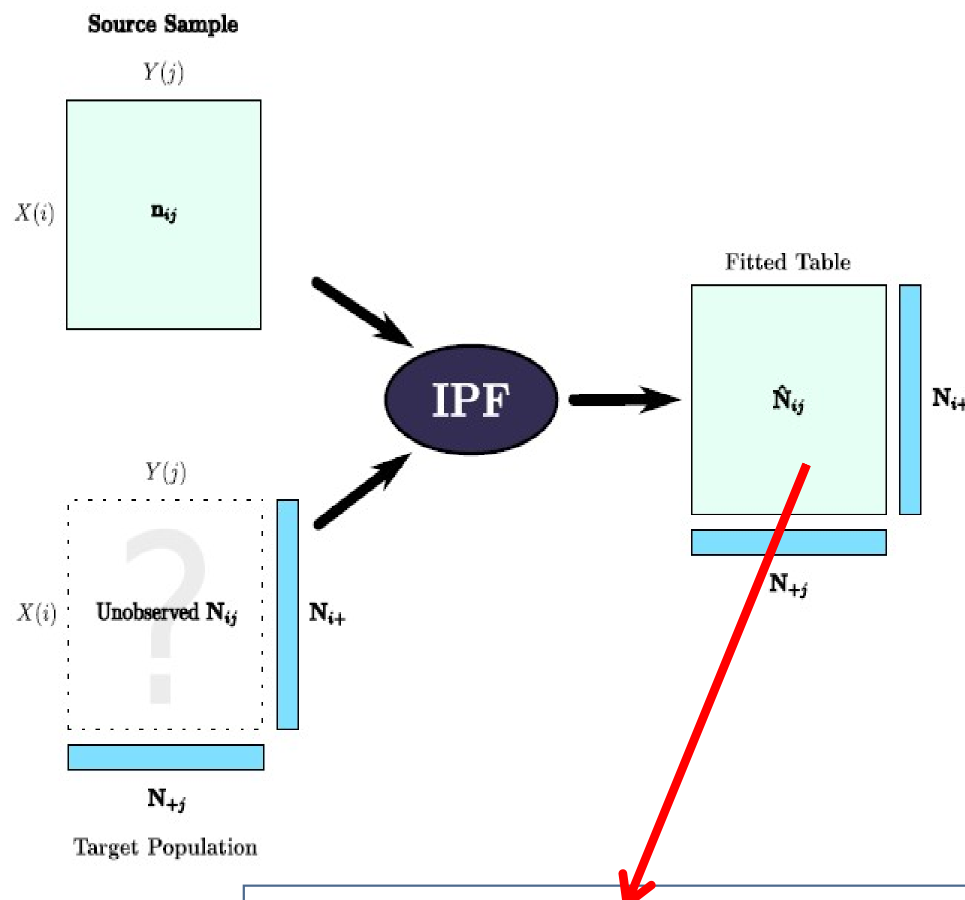
- In an activity/agent-based microsimulation model, every person in every household in the study area is synthesized from aggregate data using a population synthesis procedure.
- Person & household attributes required by the model system are generated so as to be as statistically consistent as possible with known control totals.

Population Synthesis

1. It is a data fitting procedure; *not* a behavioural model of the synthesized agents. It is a numerical approximation method.
2. It is a solution to circumvent the statistical disclosure control to produce micro data without violating the privacy protection regulations of individuals' data.
3. It is the first step in the activity-based microsimulation of agents (households and persons) travel behaviour in the study area.
4. It is based on fusing different datasets; e.g., sample and universal sets to generate a disaggregate agents' representation of the study area.
5. It results in a structured (controlled) cross-tabulation/cross-classification of the disaggregate population for agent-based behavioural microsimulation methods.

E.g.: Synthesis Using IPF

- Aggregate tables characterizing the population in the area of interest for the base year must be available. These define "marginals" of the unknown full joint distribution of the population to be synthesized.
- The IPF procedure produces a statistically most-likely joint distribution.
- Individual agents with a full set of specific attributes are then randomly drawn from this joint distribution.



Person List

Person ID	Age	Sex	Educ. Code	Occ. Code	Emp. Status	….
….						
1207	36	M	4	1	FT	….
….						
1354	32	F	5	2	PT	….
….						
9623	6	F	1	-1	-1	….
….						

PopSyn Procedure (1)

- What should be included in the PopSyn procedure. Agents' attributes that are not transportation system / accessibility-dependent (or are determined by residential location choices that lie outside the model system). E.g.,:
  - Demographics.
  - Labour force participation.
  - School participation.
- What should not be included:
  - Transportation system-dependent decisions. E.g., mobility tools:
    - Driver's licences.
    - Auto ownership.
    - Work & school location choices.
- Optional:
  - Income (usually included).
  - How to handle Work-at-Home.

PopSyn Procedure (2)

- Many procedures exist.
- Key criteria:
  - Both persons & households need to be jointly & consistently synthesized.
  - All attributes required by the activity/travel model must be generated.
  - Future year characteristics must be synthesizable.

PopSyn Procedure (3)

- GTAModel supports several procedures:
  - Cloning of survey records.
  - PopSyn3
  - MetroPop
    - Custom procedure developed for the Toronto region.
    - Hybrid IPU & logit probability models.
    - Jobs as well as population.
  - Any other procedure that generates required person & household attributes.

MetroPop Structure

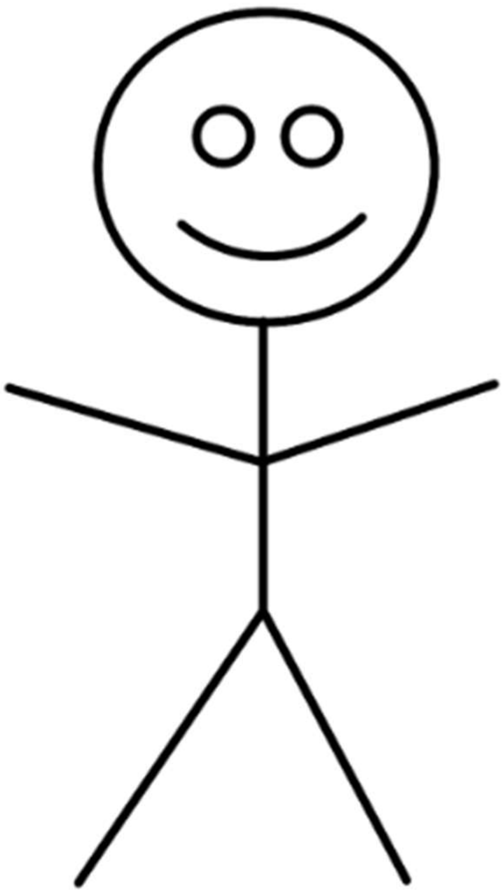
Synthetic Population and Households

Allocator; TTS; Census → TTS "Fitting" → Basic Synthesis (Draws) → Econometric Generation of Attributes → Synthetic Household and Persons

"Synthetic" Jobs (at place of work) and Enrollment

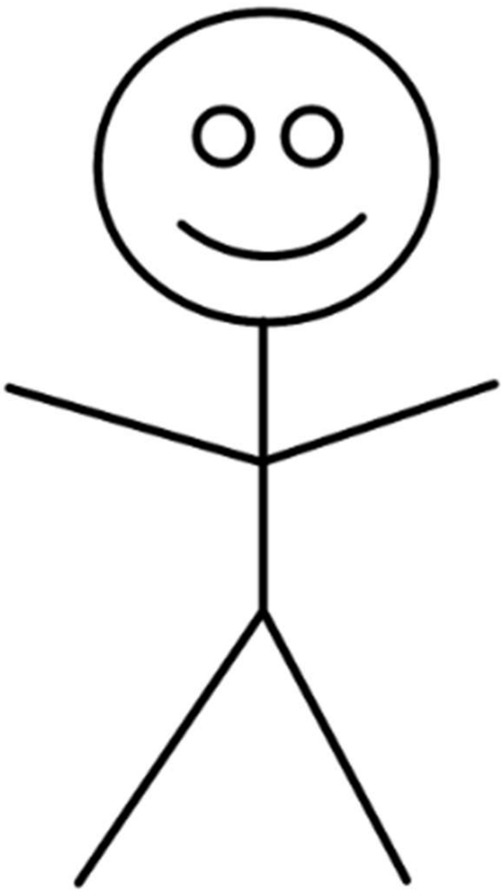
Allocator; TTS; Census → Factoring → Jobs; Enrollment

E.g., Person Attributes (1)



- Synthesized:
  - Age (continuous integer)
  - Sex (M/F)
  - School Status (FT; PT; not a student)
- Modelled:
  - School Zone
  - Driver License (Yes/No)

Person Attributes (2)



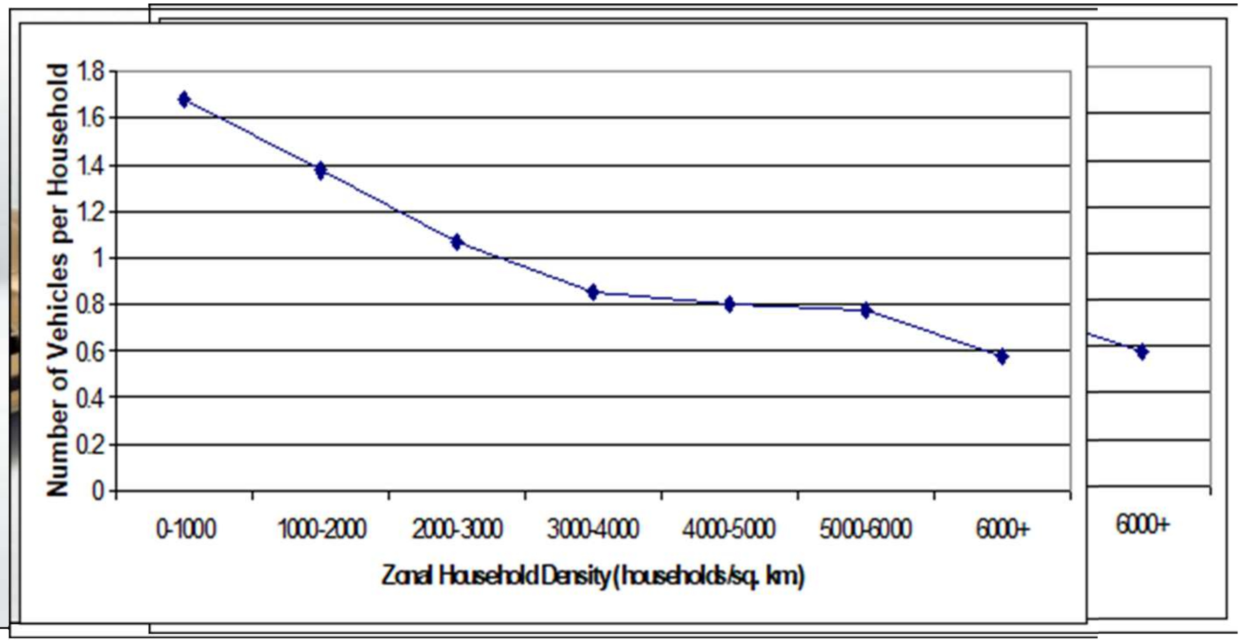
- Synthesized:
  - Occupation
    - Professional
    - General Office
    - Sales/Service
    - Manufacturing/Other
  - Employment Status
    - Full-time, work out of home
    - Part-time, work out of home
    - Full-Time WaH
    - Part-Time WaH
- Modelled:
  - Employment Zone (Primary)

Household Attributes

- Synthesized:
  - – Household TAZ
  - – Number of persons
  - – Income Class
- Modelled:
  - – Number of cars (0, 1, 2, 3+)

Job "Synthesis"

- Total employment by traffic zone is an input to the model system.
- TTS PD-level distributions are used to disaggregate total employment into jobs by the 4 TTS occupation groups:
  - Professional, managerial, technical
  - General office
  - Sales & Service
  - Manufacturing, construction, other
- and 2 employment status categories:
  - Full-time worker
  - Part-time worker

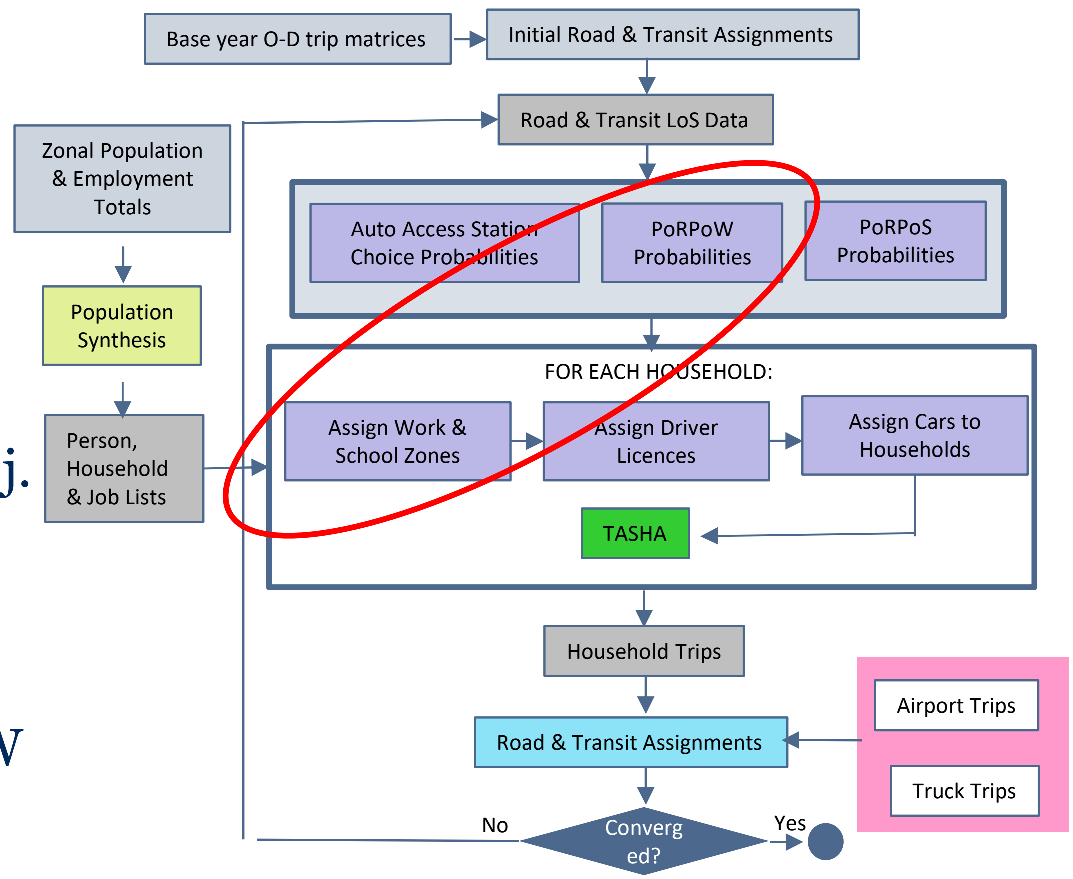


MEDIUM/LONG-TERM MODELS

1. Place-of-Resident-Place-of-Work (PoRPoW)
2. Place-of-Residence-Place-of-School (PoRPoS)
3. Driver's License (DLIC)
4. Number of Vehicles (NVEH)

Place of Residence – Place of Work (PoR-PoW) Model

- Specific work zones are allocated to each worker.
- Separate models for each Occupation and Employment Status category.
- A doubly-constrained gravity model is used to define the probabilities of a worker living in zone i working in zone j.
- Uses an auto-, transit-, and distance-based logit model for the impedance function.
- Monte Carlo simulation allocates a PoW to each worker.



WaH, NUPW, Usual Place of Work & WfH

- Three types of work location:
  - WaH: “Work at Home”: The worker has no out-of-home workplace.
    - Identified during population synthesis.
  - NUPW: “No usual place of work”: The worker is employed outside the home but does not have a fixed workplace (e.g., construction workers; service repairmen; etc.).
    - Also identified during population synthesis.
    - If a work episode is generated by TASHA, then a work location for this episode is generated using a MNL location choice model.
  - Worker has a usual, out-of-home workplace.
    - PoRPoW model assigns a specific workplace to each of these workers.
    - In the TASHA work project it is determined if the worker will work from home (WfH) this day or engage in an out-of-home work episode (i.e., commute to work).

Model Specification (1)

- Doubly constrained gravity model.
- Occupation groups: General Office (G), Sales & Service (S), Professional/Managerial/Technical (P) and Manufacturing/Other (M).
  - Current Toronto survey occupation categories.
- Worker types: Full-time (FT) and part-time (PT)
- WaH & NUPW workers are excluded.
  - WaH: Generated in PopSyn. No workplace to choose.
  - NUPW: Workplace location chosen when the episode is generated.

Model Specification (2)

$$L_{ij} = \frac{W_i E_j e^{V_{ij}}}{\sum_{j'} W_i E_{j'} e^{V_{ij}}} \qquad P_{j|i} = \frac{L_{ij}}{W_i} \qquad V_{ij} = \alpha_s + \beta_{s1}\delta_{ij} + \beta_{s2}\gamma_{IJ} + K_{ij} + \beta_{s3} f_{ij}$$

L_{ij} = Number of workers living in zone i & working in zone j
$P_{j|i}$ = Probability that a worker living in zone i works in zone j
W_i = Number of workers living in zone i
E_j = Number of job in zone j
V_{ij} = Impedance function for O-D pair i-j
δ_{ij} = 1 if i=j (intrazonal linkage); = 0 otherwise
γ_{ij} = 1 if $PD_i = PD_j$ (i & j are in the same Planning District); = 0 otherwise
K_{ij} = K-factor for O-D pair i-j; default=0
f_{ij} = Logsum term for O-D pair i-j
$\alpha_s \beta_{sk}$ = Parameters for spatial segment s

Separate model for each occupation – employment status segment.

Model Specification (3)

- Logsum term:

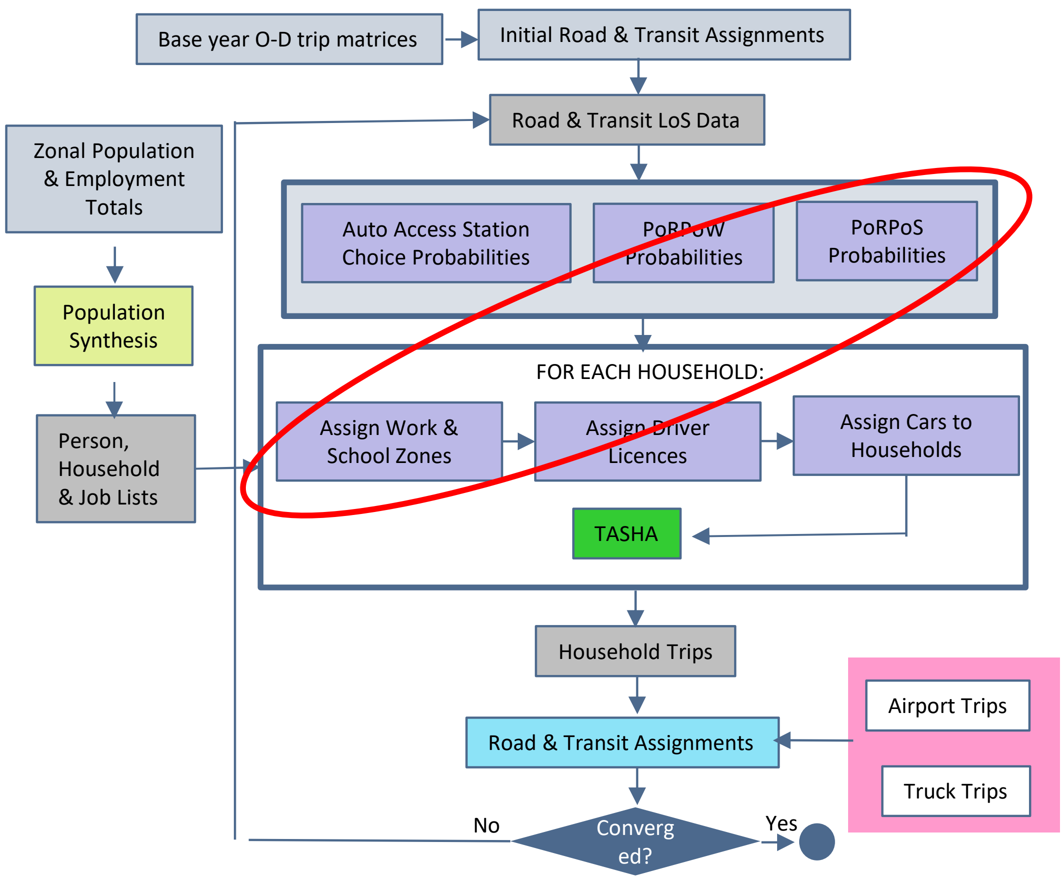
$$f_{ij} = \ln\left(e^{\beta_{aivtt} aivtt_{ij}} + e^{\beta_{Transit} + \beta_{tptt} tptt_{ij}} + e^{\beta_{Active} + \beta_{dist} dist_{ij}}\right)$$

Where:

$aivtt_{ij}$	= The expected auto in-vehicle travel time between zone i to zone j
$\beta_{Transit}$	= A constant for the transit branch
β_{tptt}	= Weight for transit perceived travel time
$tptt_{ij}$	= The transit perceived travel time between zone i and zone j
β_{Active}	= A constant for the active transportation branch
β_{dist}	= Weight for the distance
$dist_{ij}$	= The walking distance between zone i and zone j

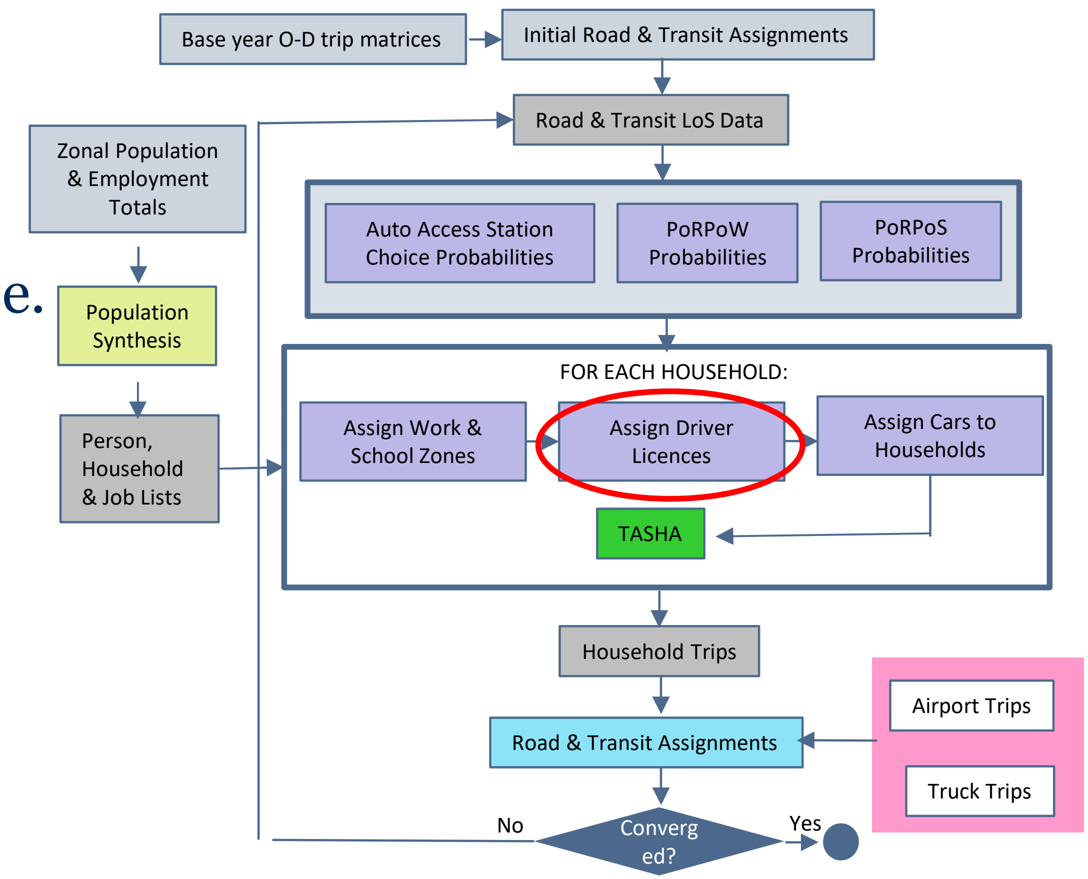
Place of Residence – Place of School (PoR-PoS) Model

- Two versions:
  - Toronto: Simply factor up base year distributions based on population growth.
  - Montreal: Multinomial logit models generate school location choice probabilities.
- Every student is allocated a specific PoS, using Monte Carlo simulation, based on these probabilities.
- Separate categories for elementary, secondary & post-secondary students.
  - Can add more categories if needed.



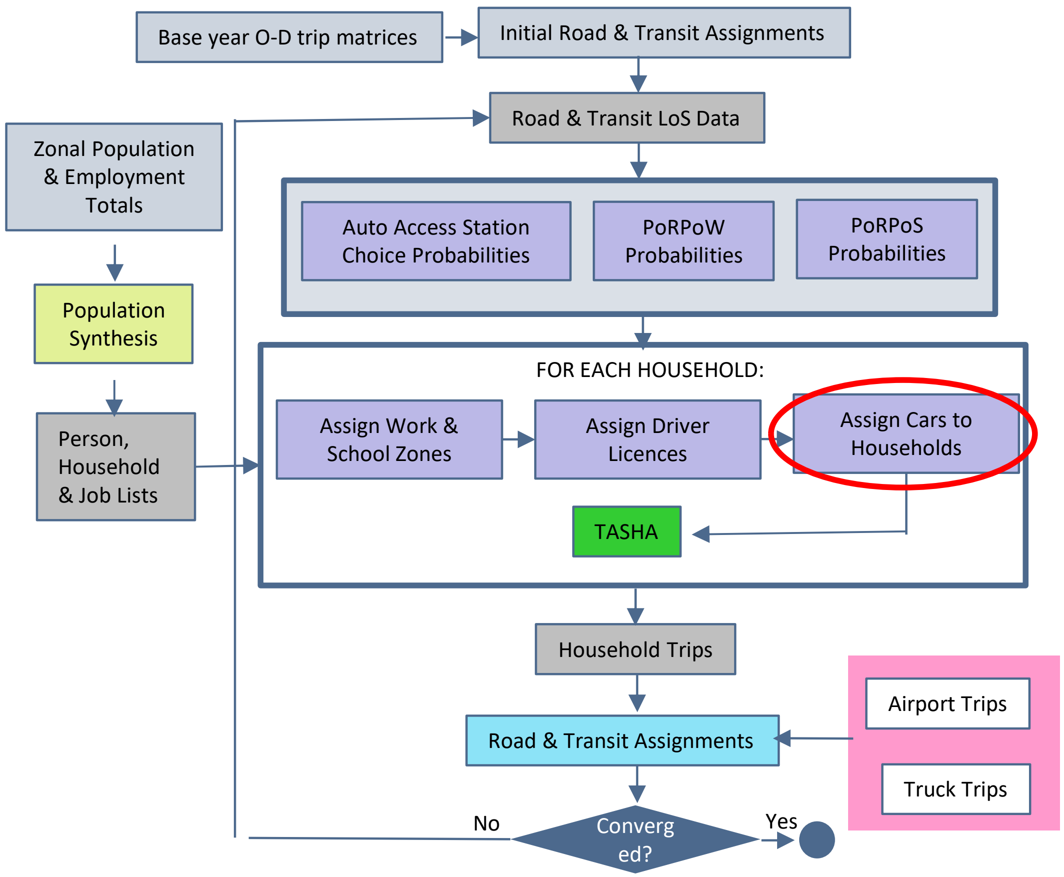
Assign Driver Licenses

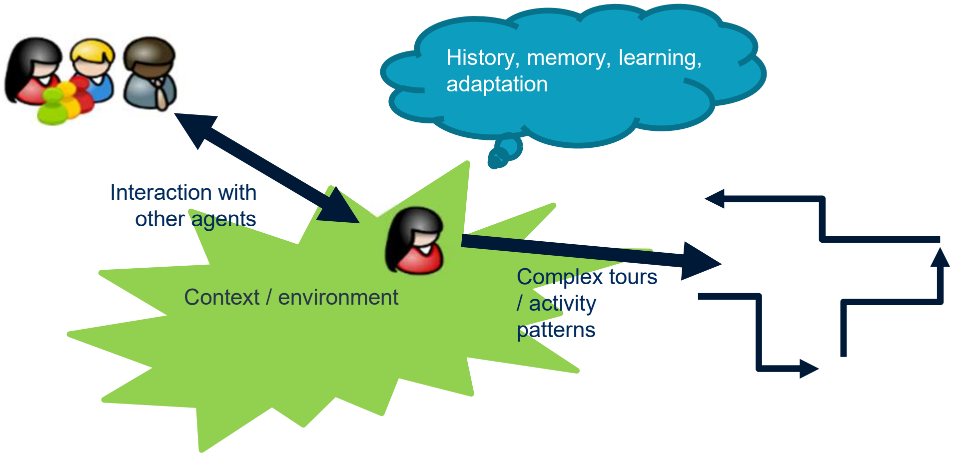
- Binary logit model to determine driver licence possession for all persons 16+ years old.
- Base alternative: No driver's license.



Assign Cars to Households

- Car ownership categories: 0, 1, 2, 3+
- Base category: 0 vehicles
- Modelled at household level.
- Two versions:
  - Toronto: Ordered logit.
  - Montreal: MNL.

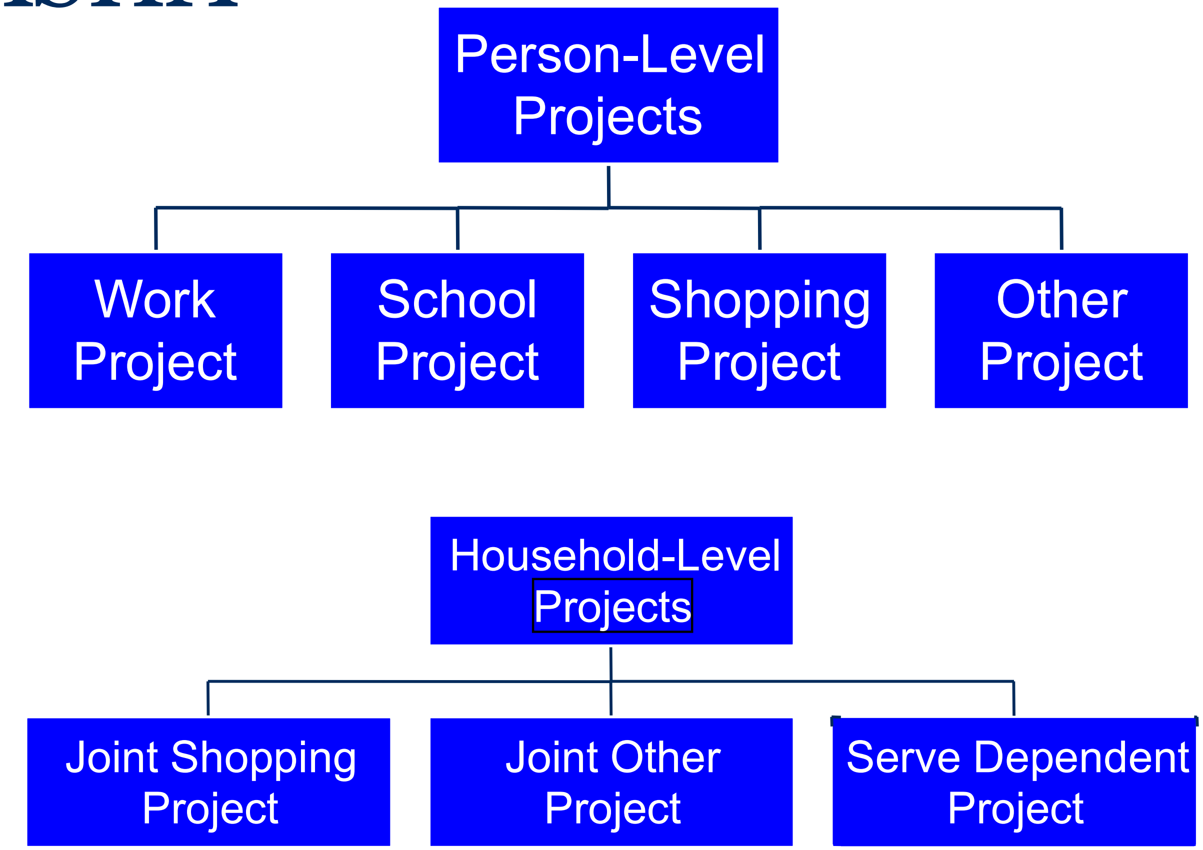




TASHA

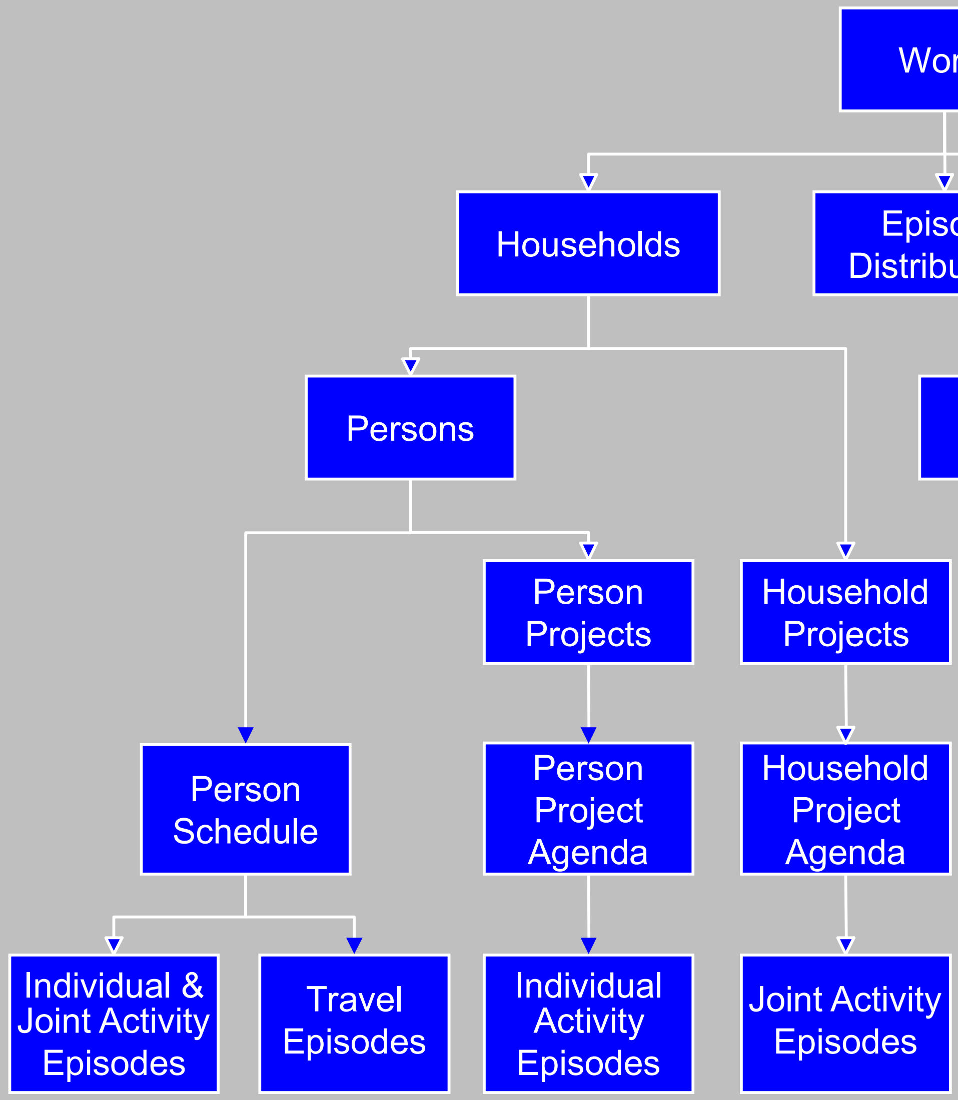
1. Activity episode generation.
2. Activity scheduling.
3. Non-work-school (NWS) location choice.
4. Tour-based mode choice.

Projects in TASHA



The current project structure in TASHA is quite crude: it reflects that available data used to build the model (an ordinary one-day household travel survey).

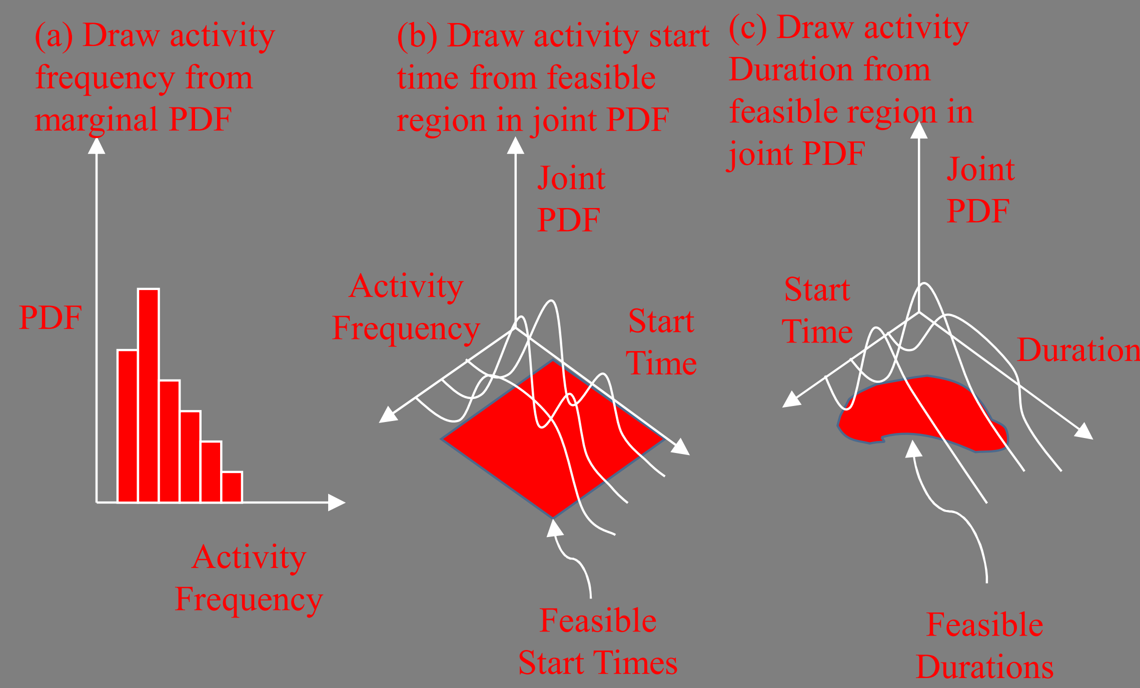
Household-Based



Persons exist within households. This allows TASHA to deal explicitly with:

- Vehicle allocation
- Ridesharing
- Joint activities/trips
- Serve-dependent activities/trips

Activity Episode Frequency, Start Time and Duration Generation

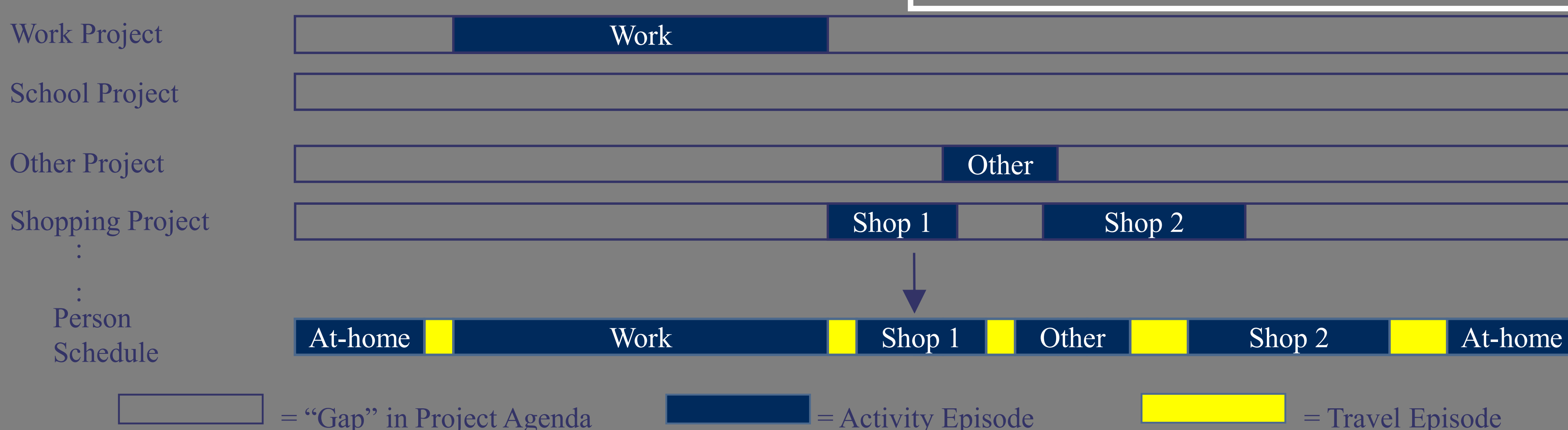


TASHA generates the number of activity episodes from a set of "projects" that a person (or household) might engage in during a typical weekday. It also generates the desired start time and duration of each episode.

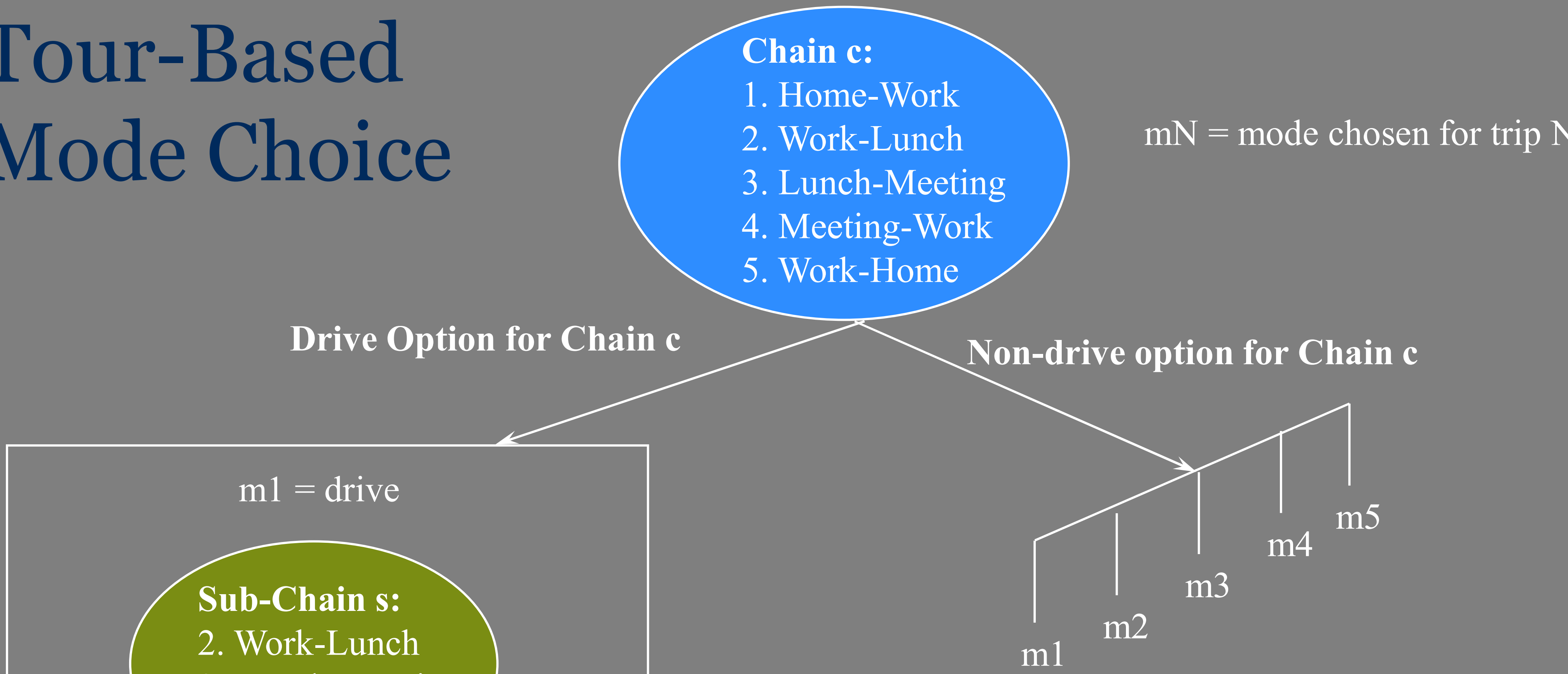
It then builds each person's daily schedule, adjusting start times and durations to ensure feasibility.

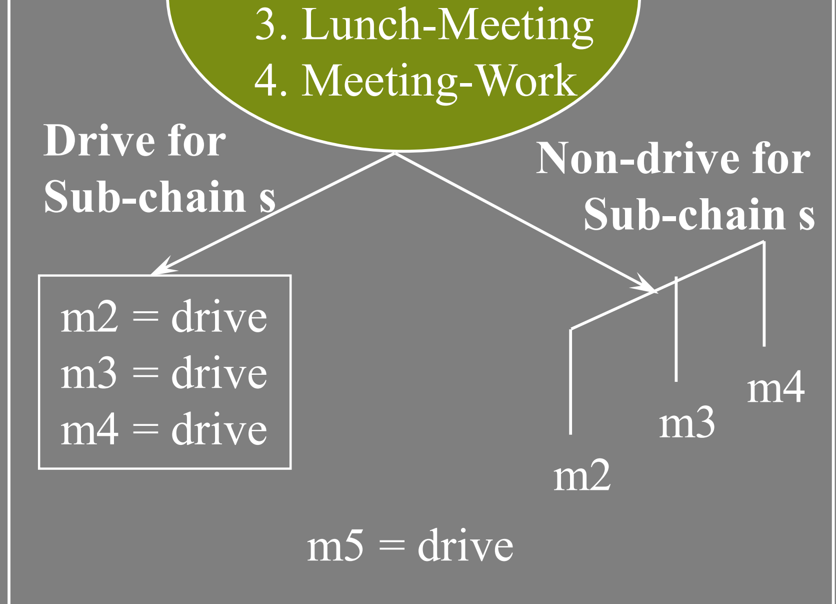
Travel episodes are inserted as part of the scheduling process.

Scheduling Activity Episodes into a Daily Schedule



Tour-Based Mode Choice



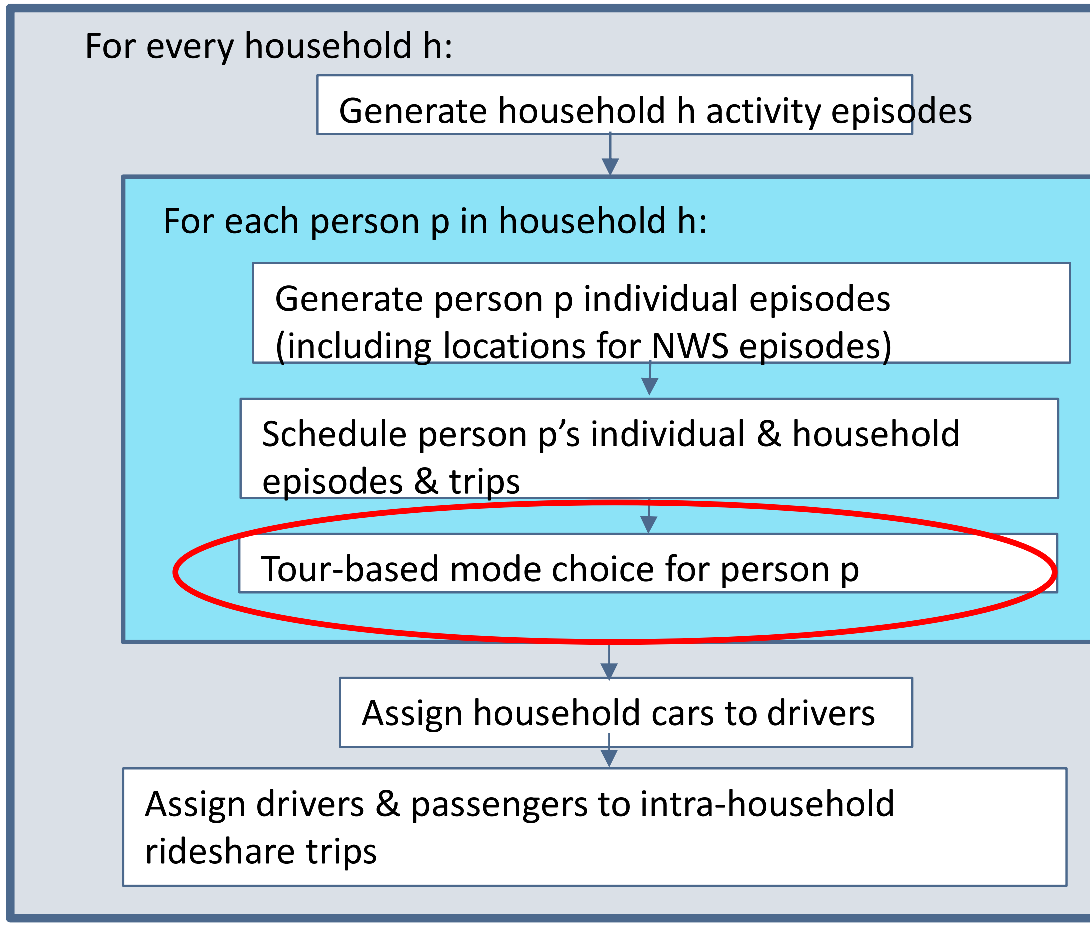


TASHA's tour-based mode choice model:

- Handles arbitrarily complex tours and sub-tours. without needing to pre-specify the tours
- Dynamically determine 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.

Constructing Trip Chains (Tours)

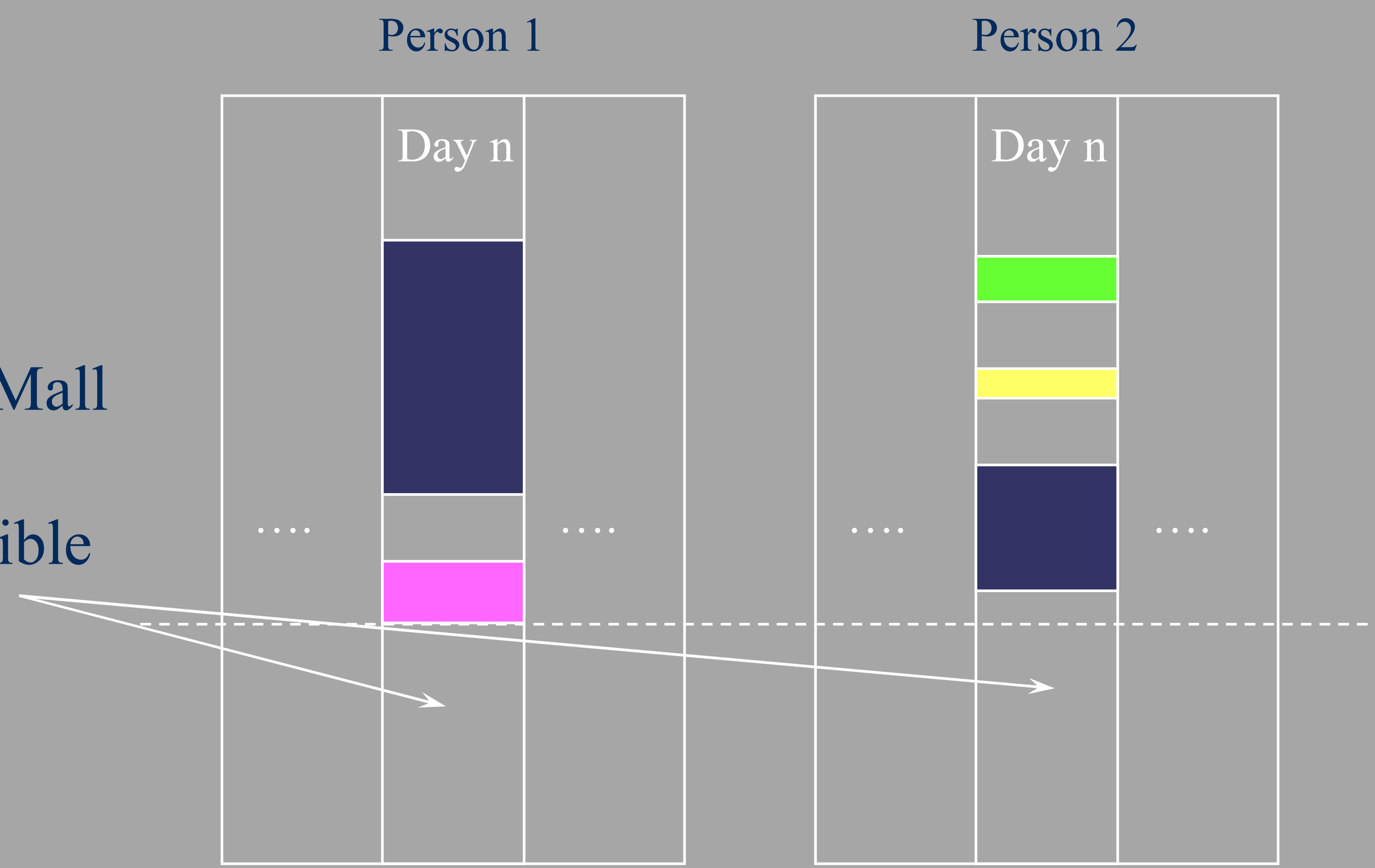
- Trips are generated to travel to/from activity episode locations (including the home location at the beginning of the day).
- A home activity is added if the trip-maker is able to travel to home and stay before going to the next activity.
  - I.e., home is the “default location” if there is not an out-of-home activity to engage in at any given point of time.
- Trips are grouped from home-to-home sequences into trip chains (tours).
- Non-home-based sub-chains may exist.



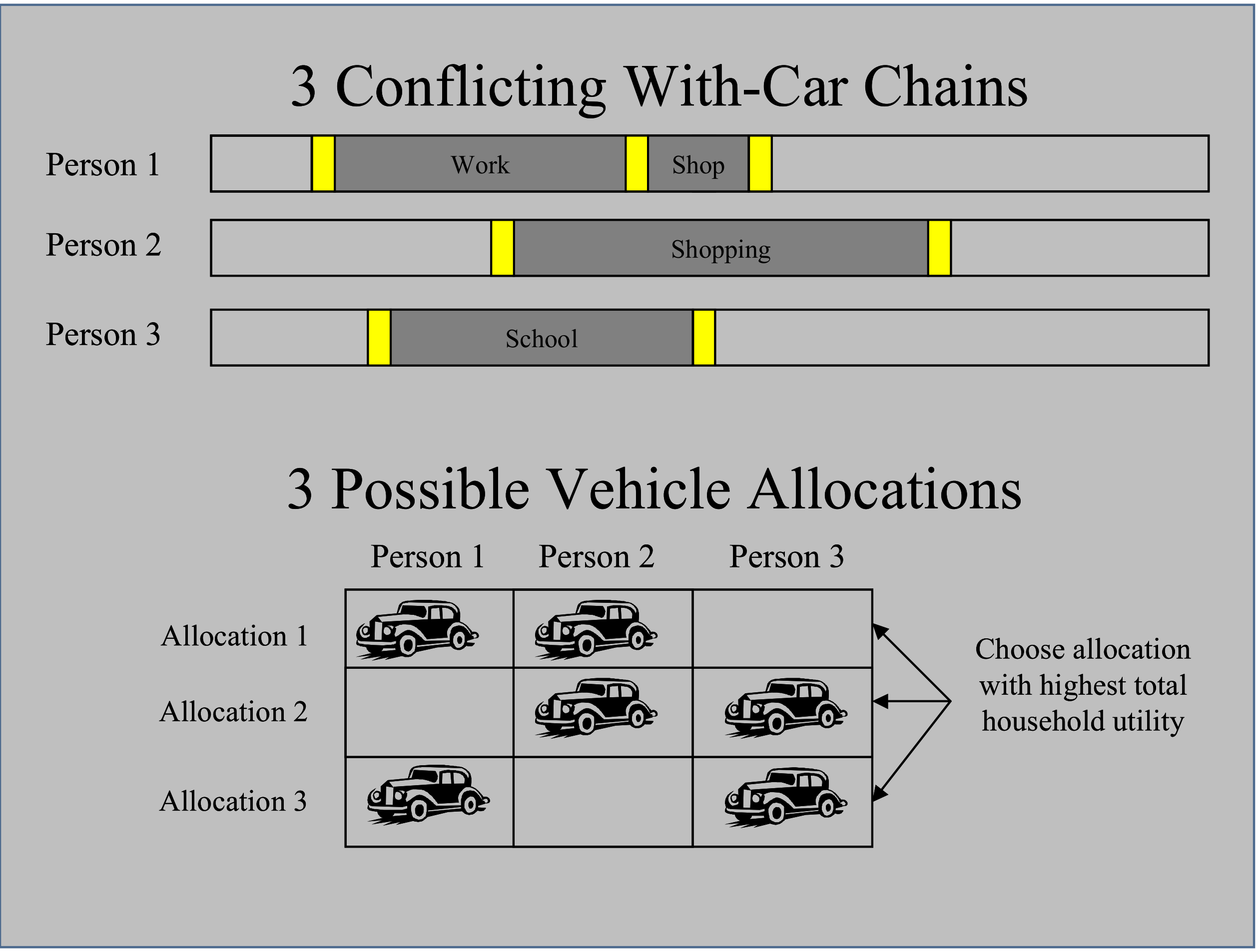
Household Based (1): Joint Activities

Joint Shopping
Activity:
Duration: 2 hrs
Location: The Mall

Search for feasible
joint time slot

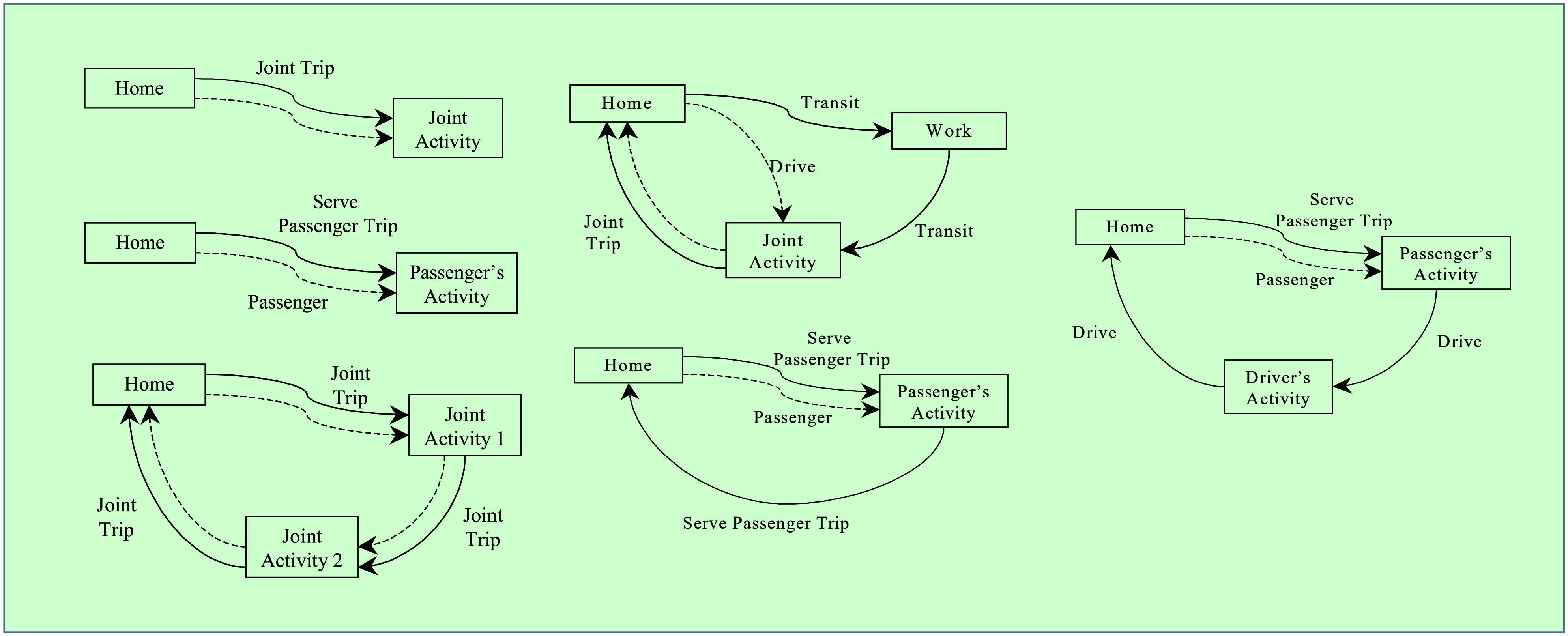


Household Based (2): Vehicle Allocation



TASHA assigns household vehicles to drivers based on overall household utility derived from the vehicle usage. Drivers not allocated a car must take their second-best mode of travel.

Household Based (3): Ridesharing



Within-household ridesharing is explicitly handled within TASHA. Drivers will "offer" rides to household members if a net gain in household utility is obtained and feasibility criteria are met.

Time Periods

- Although TASHA generates episode (and hence trip) start times on a second-by-second basis over the entire 24-hour weekday period being modelled, for network assignment purposes, these trips need to be aggregated into O-D trip matrices by time period.
- 5 time periods are used.
- Note that the day being modelled starts at 6:00am and "wraps around) until 5:59am the next morning.

Time Period	Start	End
AM	6:00 AM	9:00 AM
Mid Day	9:00 AM	3:00 PM
PM	3:00 PM	7:00 PM
Evening	7:00 PM	0:00 AM
Overnight	0:00 AM	6:00 AM

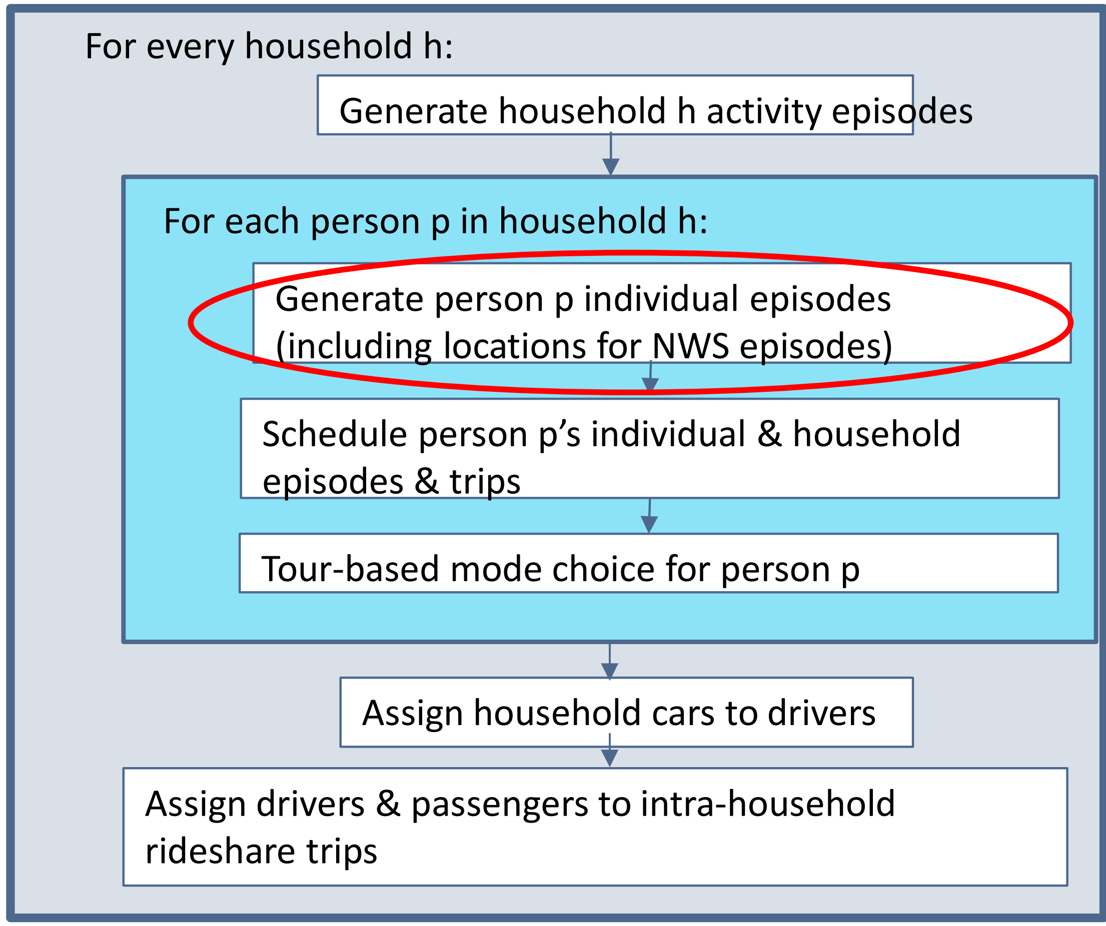
Activity Episode Generation

Each project generates desired activity episodes.

Episode Attributes:

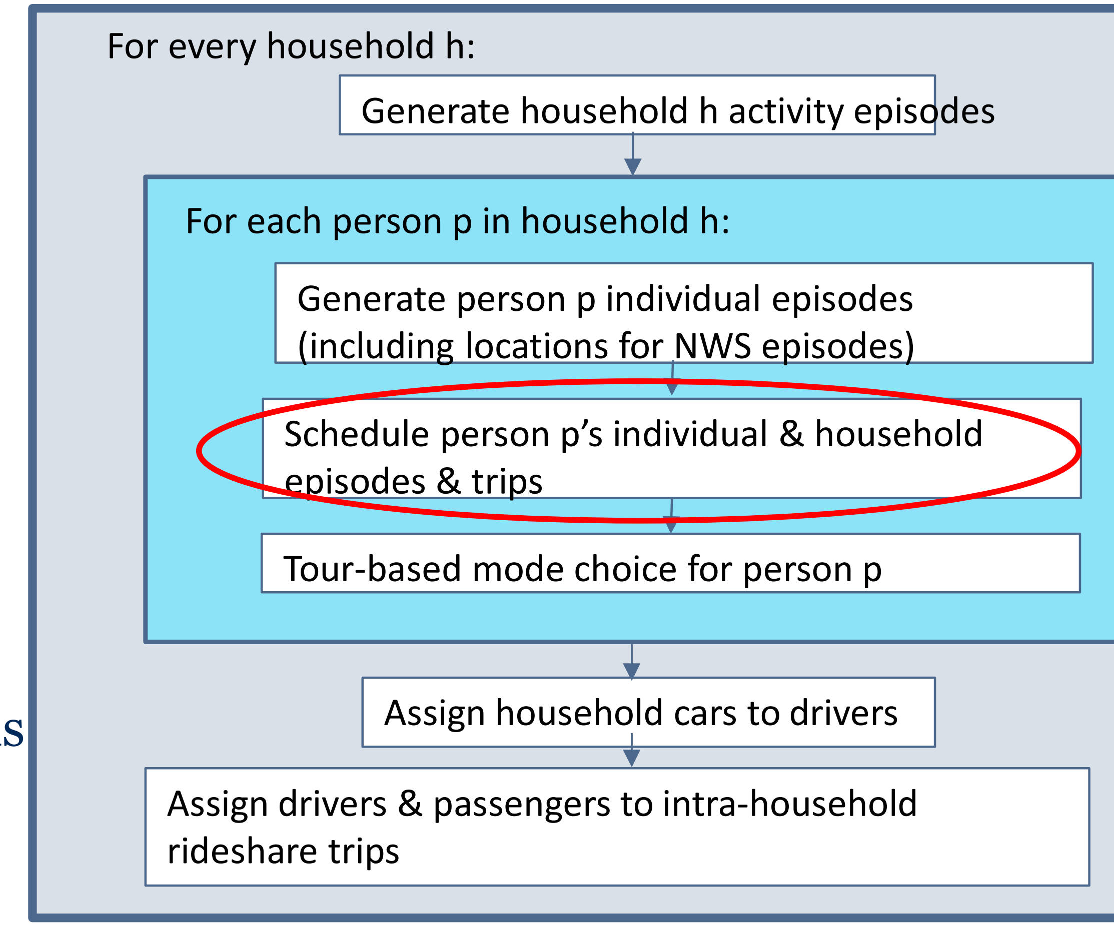
- Purpose (work, etc.)
- Start-time
- Duration
- Location

- Currently: randomly generated from observed episode generation distribution rates.



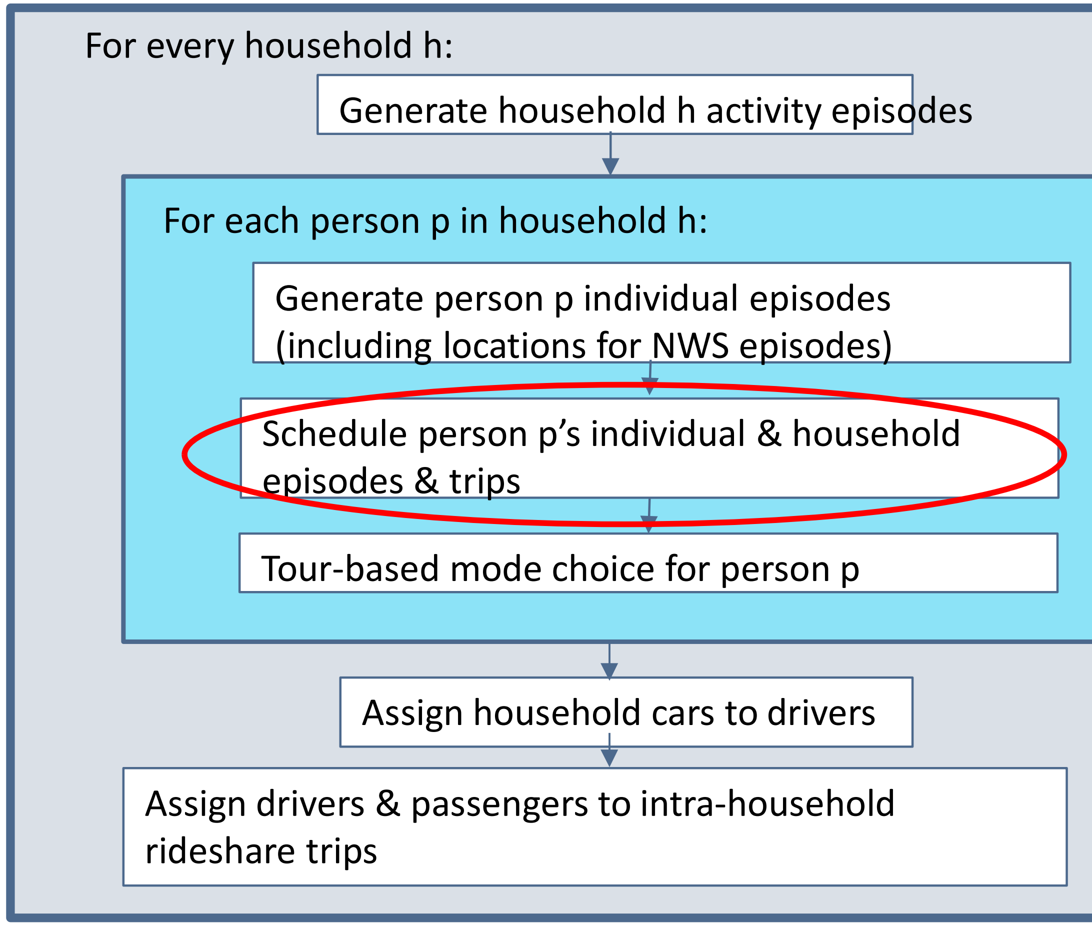
Activity Scheduler

- The scheduler takes activity episodes from each of the project agendas and assigns them to the person's 24-hour schedule.
- Rule-based assignment procedure.
- Episodes are scheduled in terms of assumed priority:
    1. Work (if a worker).
    2. School (if a student).
    3. Household "other".
    4. Household market.
    5. Individual "other".
    6. Individual market.
- NWS episodes are assigned locations as they are scheduled.
- Episode start times and durations can be adjusted marginally to resolve scheduling conflicts.

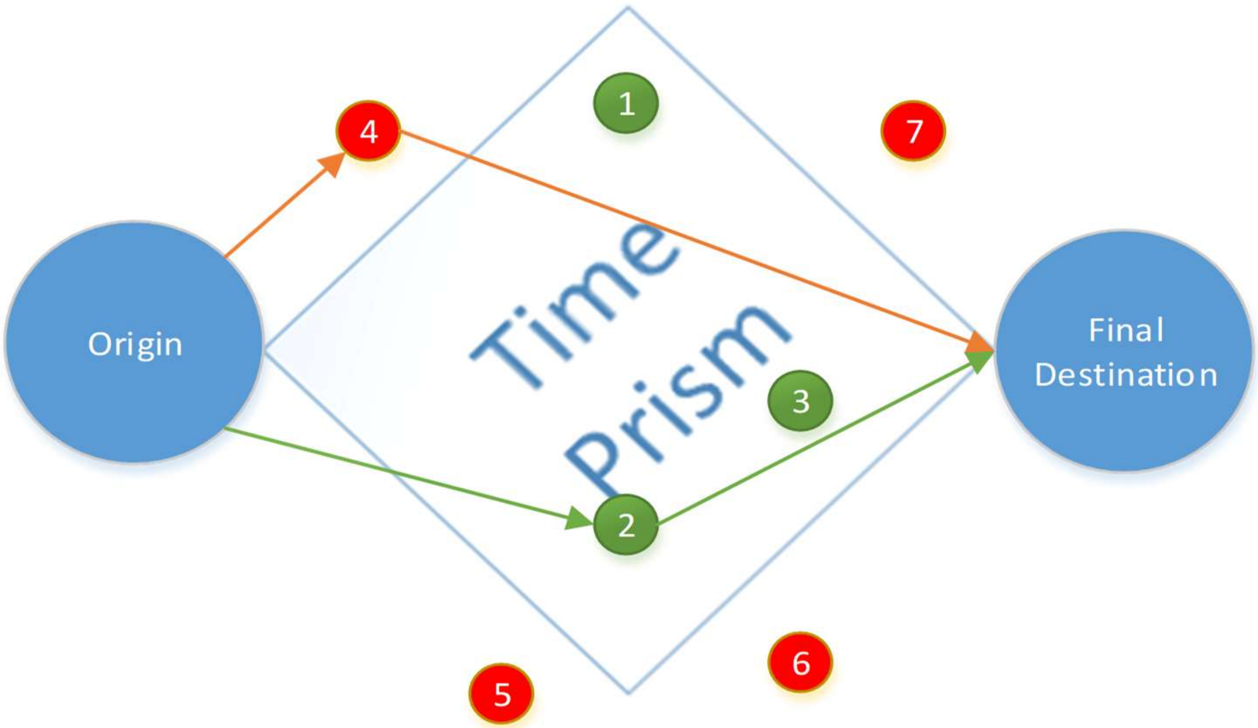


NWS Activity Location Choice

- Usual work & school locations are determined prior to executing TASHA.
- For all other activity types, the episode location is determined during the activity scheduling process.
- This includes locations for:
  - Market (shopping) episodes.
  - Work locations for workers without a usual place of work.
  - “Work-business” episodes (e.g., an out-of-office business meeting).
  - Other episodes.



Time Prism Location Choice



- Time-space prisms are used to restrict the feasible choice set for each episode location choice.
- Provides for a more feasible schedule as the destination choice-set is restricted by how far the person is able to travel by auto in the allotted schedule.

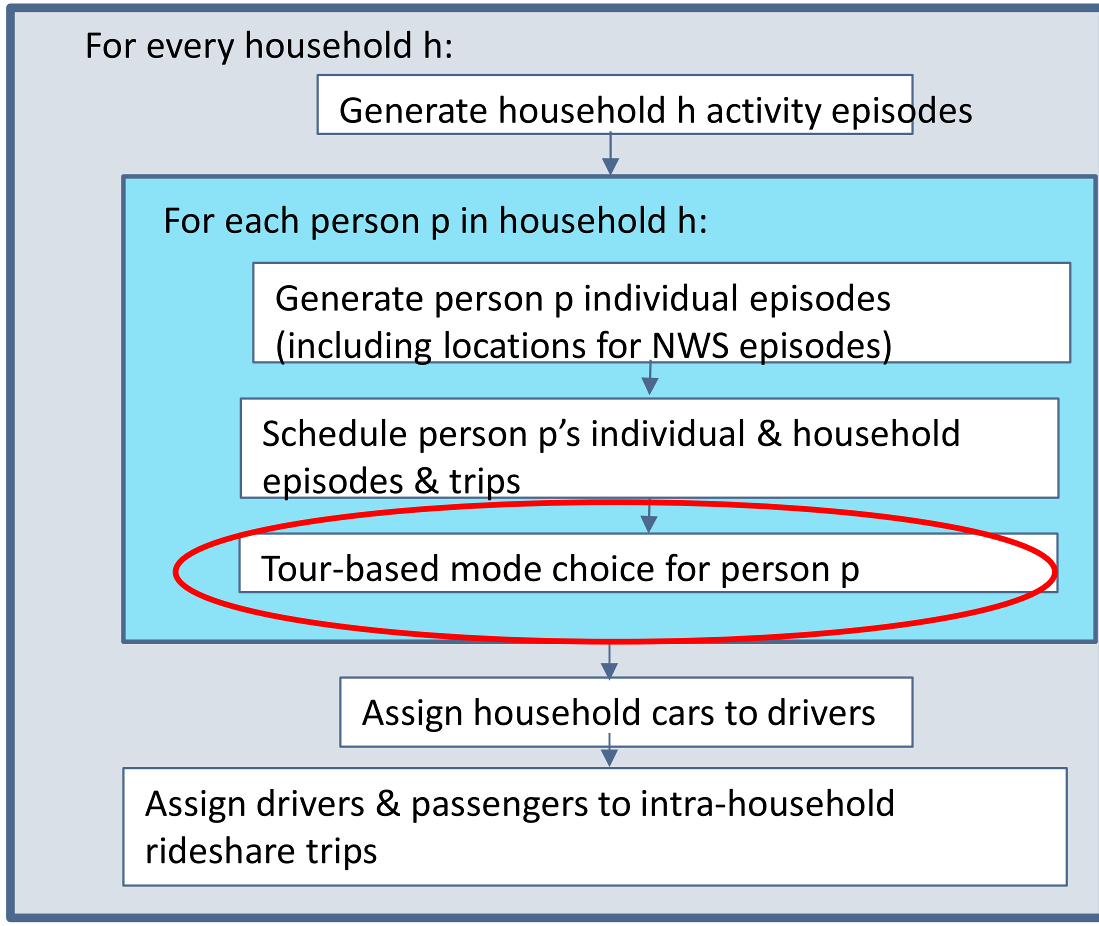
NWS Location Choice Model Specification

$$V_{ijk} = Accessibility_{ijk} + \beta_{population} * ln(Pop_j) + \sum_{occemp} \beta_{occemp} * occempRatio_{occemp|j} * ln(1 + emp_j)$$

$$Accessibility_{ijk} = \beta_{TravelLogsumScale} * \left(ln \left(\begin{array}{l} e^{\beta_{aivtt} * AIVTT_{ij} + \beta_{cost} * ACOST_{ij}} \\ + e^{\beta_{TransitConstant} + \beta_{TransitBoarding} * TPTT_{ij} + \beta_{cost} * TFARE_{ij}} \\ + e^{\beta_{ActiveConstant} + \beta_{ActiveDistance} * Distance_{ij}} \end{array} \right) + ln \left(\begin{array}{l} e^{\beta_{aivtt} * AIVTT_{jk} + \beta_{cost} * ACOST_{jk}} \\ + e^{\beta_{TransitConstant} + \beta_{TransitBoarding} * TPTT_{jk} + \beta_{cost} * TFARE_{jk}} \\ + e^{\beta_{ActiveConstant} + \beta_{ActiveDistance} * Distance_{jk}} \end{array} \right) \right)$$

Tour-based Mode Choice (TBMC)

- Tour-based probit model
- Household level constraints
- Intra-household passenger/ridesharing explicitly modelled.
- Multiple person categories:
  - Student
  - Employed, by occupation:
    - Professional
    - General
    - Sales/Service
    - Manufacturing
  - Unemployed non-student



Probit 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:

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

Travel Modes (Current Toronto Model)

- Auto Drive
- Walk-Access-Transit (WAT)
- Drive-Access-Transit (DAT)
- Passenger-Access-Transit (PAT)
- Passenger-Egress-Transit (PET)
- Vehicle-For-Hire (VFH):
  - Private Transport Company (PTC)
  - Taxi
- Inter-household Carpool
- Household Passenger
- Rideshare (Intra-Household joint travel)
- School bus
- Bicycle
- Walk

NOTE: Given the modular structure of XMF and the probit formulation, additional modes an be readily added to the model system, providing that the modal LOS can be computed

Travel Modes (Current Toronto Model)

- Auto Drive
- Walk-Access-Transit (WAT)
- Drive-Access-Transit (DAT)
- Passenger-Access-Transit (PAT)
- Passenger-Egress-Transit (PET)
- Vehicle-For-Hire (VFH):
  - Private Transport Company (PTC)
  - Taxi
- Inter-household Carpool
- Household Passenger
- Rideshare (Intra-Household joint travel)
- School bus
- Bicycle
- Walk

- A car must be available to use (see below).
- Must have a driver's license.
- Cars must return home at the end of a trip chain.
- Value of time based on each person's category.

Travel Modes (Current Toronto Model)

- Auto Drive
- Walk-Access-Transit (WAT)
- Drive-Access-Transit (DAT)
- Passenger-Access-Transit (PAT)
- Passenger-Egress-Transit (PET)
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  - Private Transport Company (PTC)
  - Taxi
- Inter-household Carpool
- Household Passenger
- Rideshare (Intra-Household joint travel)
- School bus
- Bicycle
- Walk

Transit modes: See below.

Travel Modes (Current Toronto Model)

- Auto Drive
- Walk-Access-Transit (WAT)
- Drive-Access-Transit (DAT)
- Passenger-Access-Transit (PAT)
- Passenger-Egress-Transit (PET)
- Vehicle-For-Hire (VFH):
  - Private Transport Company (PTC)
  - Taxi
- Inter-household Carpool
- Household Passenger
- Rideshare (Intra-Household joint travel)
- School bus
- Bicycle
- Walk

Car passenger modes.

Auto Passenger Modes (1): Intra-Household

Intra-household passenger

- Intra-household facilitated trips
- Broken into 3 legs
  - Driver to passenger
  - To Passenger's Destination
  - To Driver's Destination
- Household utility must be improved in order to be selected
  - I.e., the "utility gain" of the passenger outweighs the "utility loss" of the driver
- Not available if the potential passenger already has a vehicle
- Value of time based on the driver's person category

Intra-Household Rideshare

- Intra-Household joint trip
- Assigned if the tour's representative picks Auto

Auto Passenger Modes (2): Driver Not within Household

Carpool

- <u>Inter</u>-household passenger
- <u>Not</u> taxi or PTC.
- Value of time based on each person's demographic category
- Carpool passengers are not assigned to drivers/vehicles (e.g., "HOV" is not explicitly modelled).

Vehicle for Hire (VfH)

- Two VfH modes are currently modelled.
  - Private Transportation Company (PTC) – aka TNC.
  - Taxi.

Travel Modes (Current Toronto Model)

- Auto Drive
- Walk-Access-Transit (WAT)
- Drive-Access-Transit (DAT)
- Passenger-Access-Transit (PAT)
- Passenger-Egress-Transit (PET)
- Vehicle-For-Hire (VFH):
  - Private Transport Company (PTC)
  - Taxi
- Inter-household Carpool
- Household Passenger
- Rideshare (Intra-Household joint travel)
- School bus
- Bicycle
- Walk

Active transport modes.

Active Modes

Bicycle:

- A bicycle must leave from and return to home at the end of the trip-chain
- Uses network-based distances for intra-zonal travel
- Uses $\frac{2\sqrt{Area}}{6}$ to approximate the distance for intra-zonal travel
- Bicycles are not assigned to the network.
- O-D network distances used to compute average bicycle travel times.

Walk:

- On-network O-D distances for inter-zonal trips
- Intra-zonal trips use:
  - $\frac{2\sqrt{Area}}{6}$ to approximate the distance

Summary of Current Modes by Type

Auto
(drive)

Public Transit
- WAT
- DAT
- PAT/PET

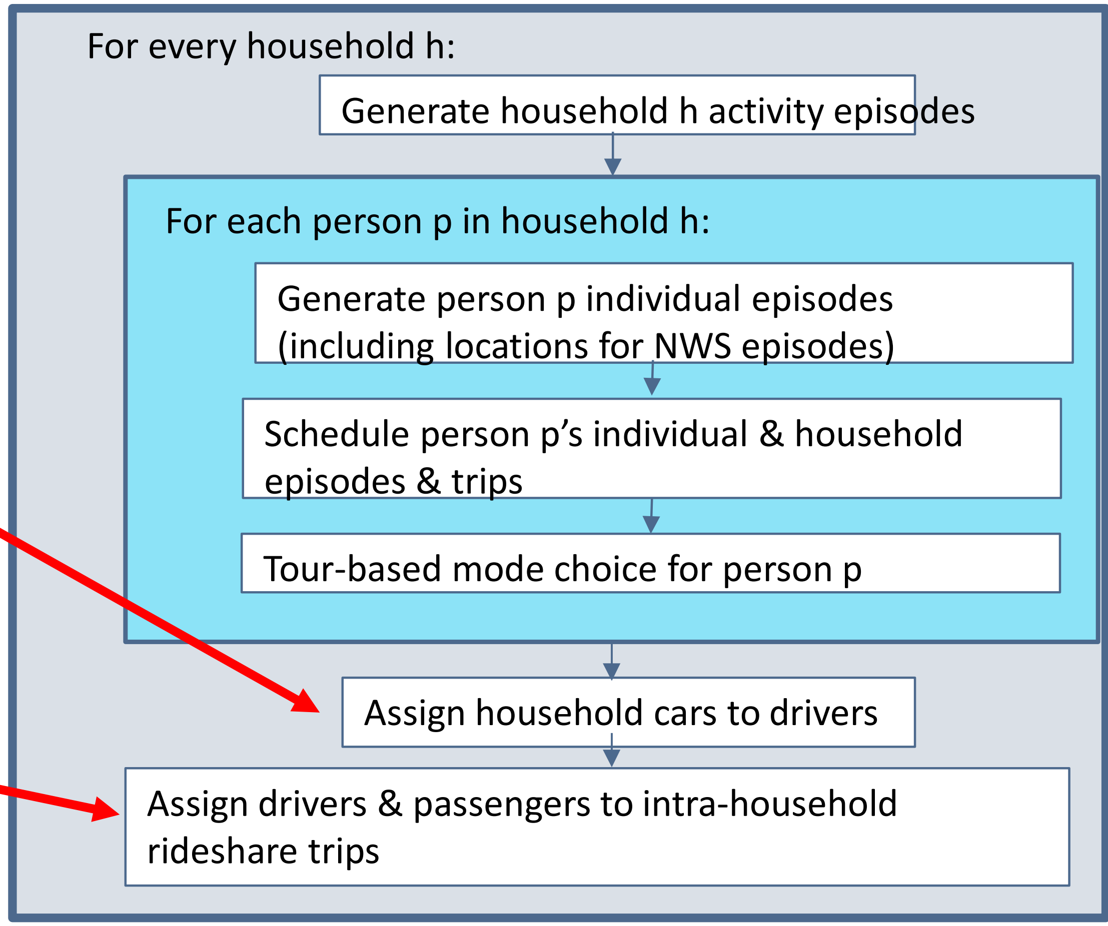
"Auto-Based Passenger"
Intra-household:
- Passenger
- Rideshare

Inter/non-household:
- Carpool
- PTC
- Taxi

Active Modes
- Bicycle
- Walk-all-way

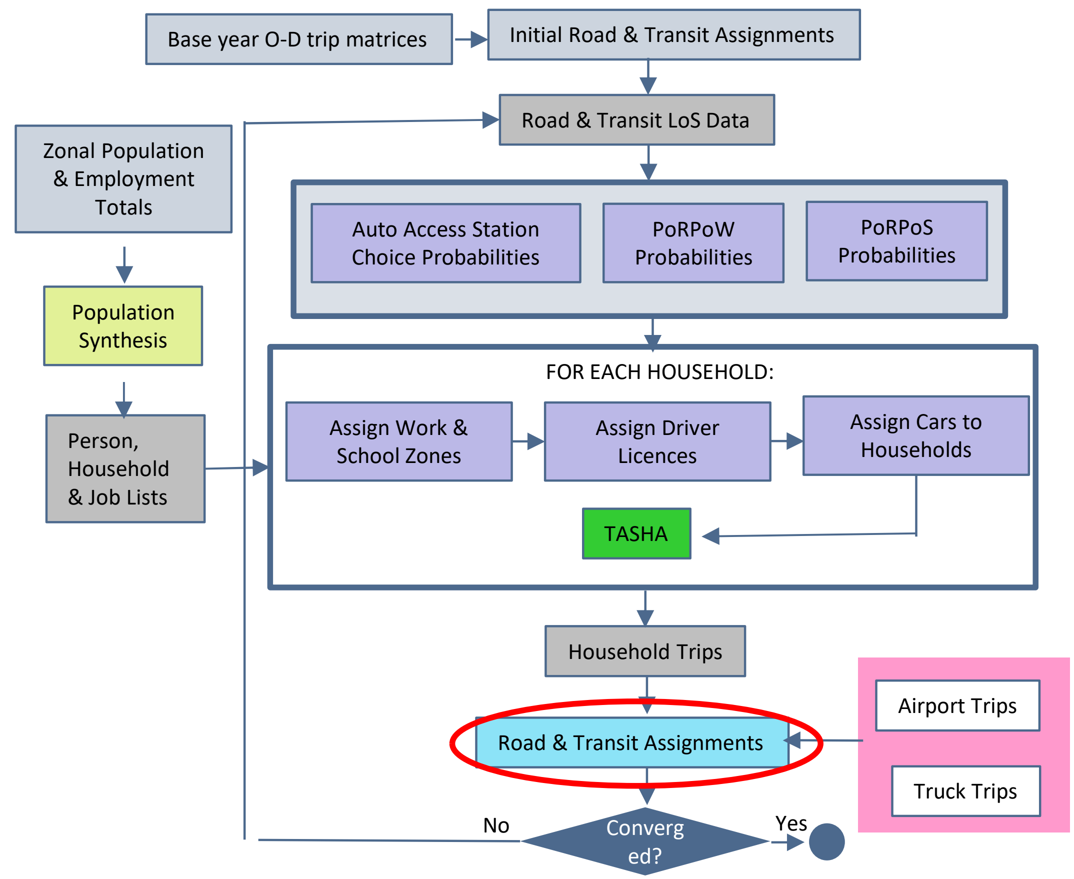
Mode Choice Algorithm

- Compute all feasible tours
- Compute tour-level utilities
- Get highest utility tours for both with auto and without-auto
- Complete discrete station choices
- Resolve the household to assign vehicles to tours and optimize household utility
- Find and apply passenger trips given from drivers currently on the road
- Find and apply passenger trips given from drivers currently at home



Network Models

1. Road Assignment.
2. Transit Assignment.
3. Transit Access Station Choice.



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.

Network Modelling Platforms

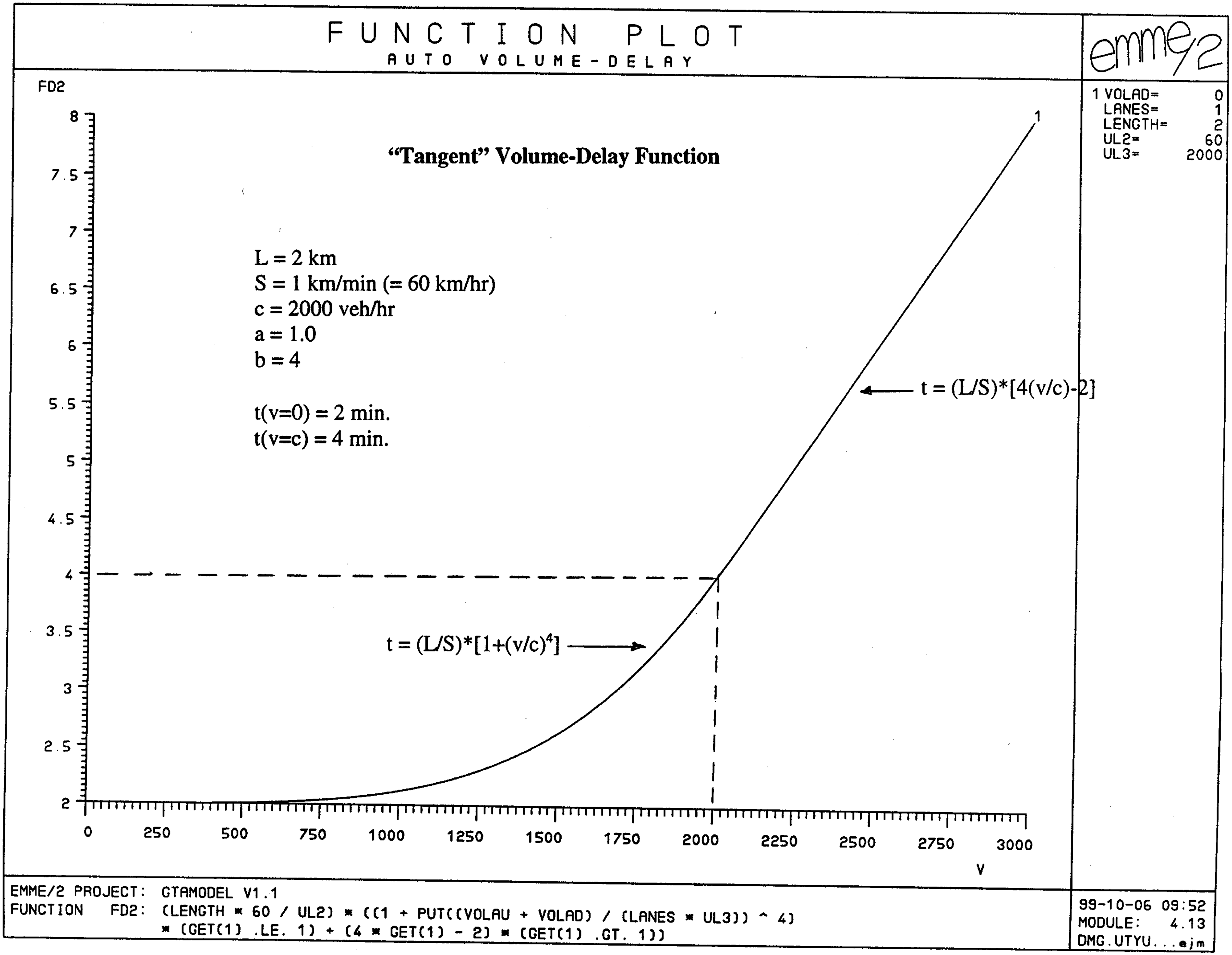
- Our design approach has been to develop TASHA to interface with "any" network modelling package, rather than reinvent this well-developed wheel.
- The "default" package in Emme.
- Also have interfaces with:
  - Vissum (Halifax & Monterrey, Mexico implementations).
  - Aimsun.
  - MATSim.
- "Network Toolbox" developed to handle the interface between TASHA & each of the network modeling platforms.
- Will focus on the Emme implementation here.

Road Assignment

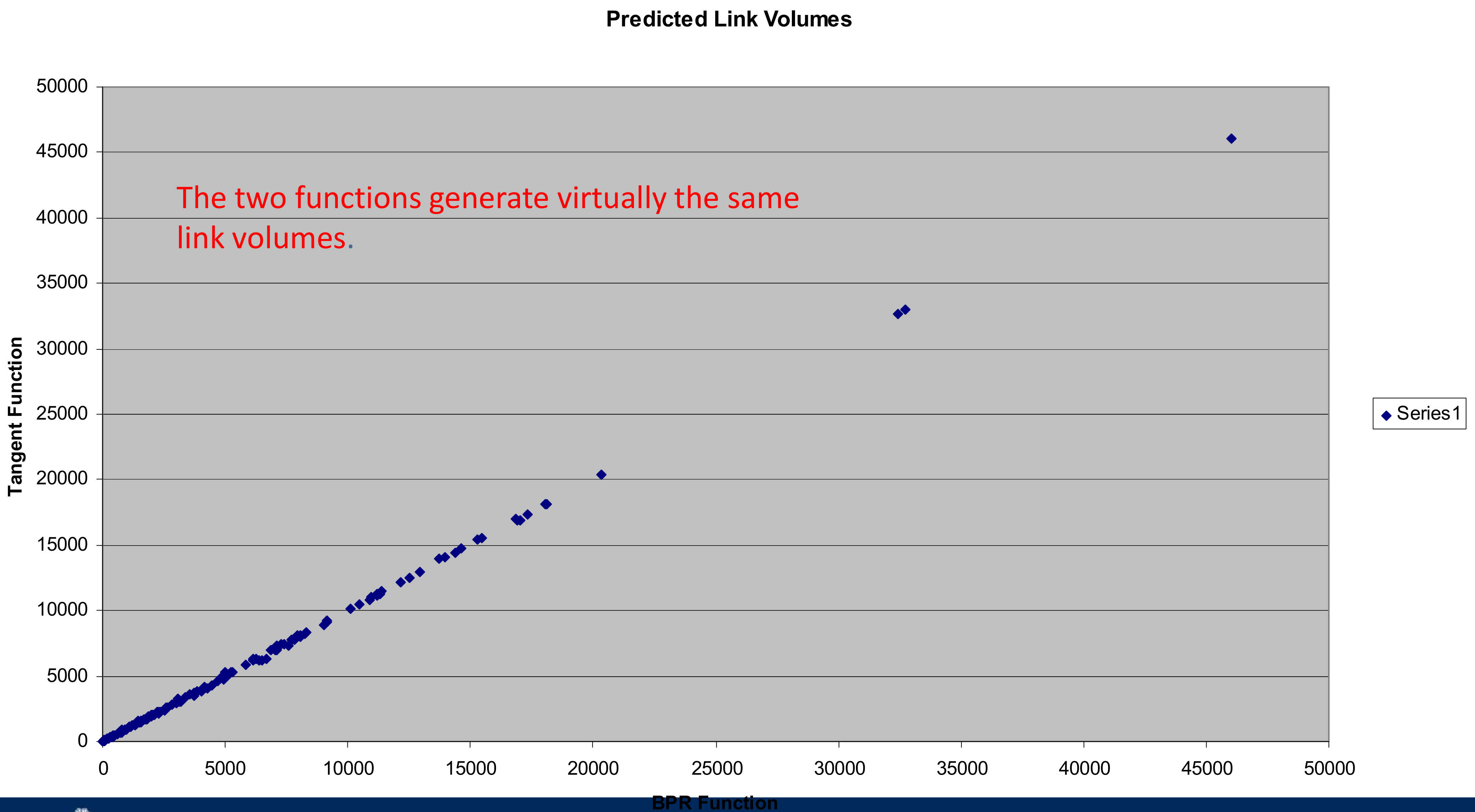
- Multi-class assignment.
  - Passenger cars.
  - Trucks (light & heavy).
- On-street buses contribute to congestion.
- Second-Order Linear Approximation (SOLA) algorithm used to speed up equilibration process.
- Tangent Volume Delay Functions (VDFs).
- Montreal: Space-Time Traffic Assignment (STTA).
- Assignments calibrated vs. screenline data.

Tangent Volume-Delay Function (VDF)

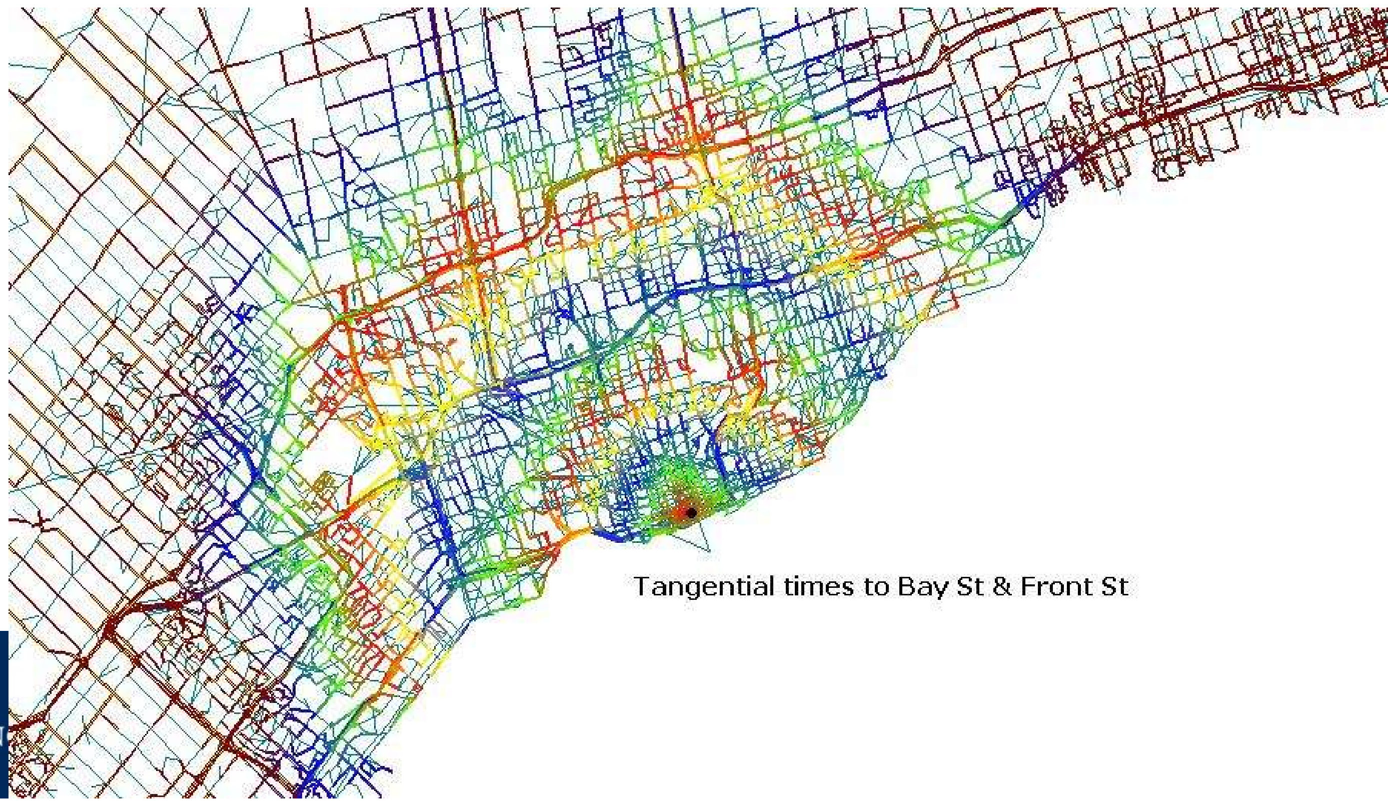
- GTAModel does not use the conventional BPR VDF.
- Instead it uses a modification of the BPR:
  - The same as BPR for v<c.
  - Linear delay for v>c = tangent of the BPR function @ v=c.
- Advantages of the tangent function:
  - Converges much more quickly than BPR for congested networks.
  - Arguably a better representation of oversaturated delay than BPR.


FUNCTION PLOT
AUTO VOLUME-DELAY
emme/2
FD2
"Tangent" Volume-Delay Function
L = 2 km
S = 1 km/min (= 60 km/hr)
c = 2000 veh/hr
a = 1.0
b = 4
t(v=0) = 2 min.
t(v=c) = 4 min.
t = (L/S)*[4(v/c)-2]
t = (L/S)*[1+(v/c)^4]
1 VOLAD= 0
LANES= 1
LENGTH= 2
UL2= 60
UL3= 2000
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
2750
3000
V
EMME/2 PROJECT: GTAMODEL V1.1
FUNCTION FD2: (LENGTH * 60 / UL2) * ((1 + PUT((VOLAU + VOLAD) / (LANES * UL3)) ^ 4)
* (GET(1) .LE. 1) + (4 * GET(1) - 2) * (GET(1) .GT. 1))
99-10-06 09:52
MODULE: 4.13
DMG.UTYU...ejm

Comparison of BPR & Tangent Link Volumes (Toronto case)



Comparing 5-minute travel-time isochrones to selected destinations reveals very little difference in predicted travel times.
(e.g., these plots are for trips to Bay & Front Streets)



Comparison of BPR & Tangent Functions (Toronto case: 400 series highways)

	Trip Time of Selected Routes in 1996				
	Field Data	EMME/2 Tangential VDF		EMME/2 BPR VDF	
	Time (hh:mm:ss)	Time (hh:mm:ss)	% Difference (vs Field Data)	Time (hh:mm:ss)	% Difference (vs Field Data)
Route 1	00:53:54	00:48:12	-10.58%	00:49:26	-8.29%
Route 2	00:58:12	00:58:47	1.00%	01:03:52	9.74%
Route 3	00:54:58	00:46:47	-14.89%	00:47:44	-13.16%
Route 4	00:16:48	00:15:43	-6.45%	00:15:56	-5.16%
Route 5	01:04:35	00:52:10	-19.23%	00:50:19	-22.09%
Route 6	00:33:12	00:32:43	-1.46%	00:32:39	-1.66%
Route 7	00:38:28	00:31:55	-17.03%	00:31:43	-17.55%
Route 8	00:28:14	00:28:13	-0.06%	00:29:10	3.31%

Speed-Time Traffic Assignment (STTA)

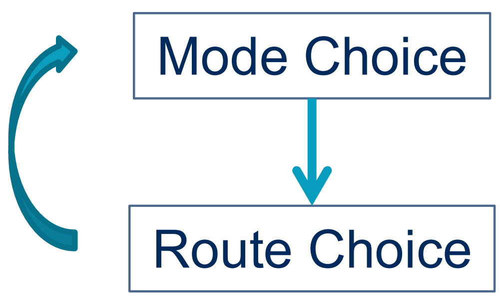
- In the Montreal implementation the Emme STTA procedure to generate "quasi-dynamic" traffic assignment.
- Static equilibrium assignments are run for each hour of the day.
  – Trips that are not completed during a given hour remain loaded on the network to complete the trips in the next hour, thereby contributing to congestion in the second hour.

Transit Assignment

- Theory.
- Transit mode definitions.
- Implementation.

The Joint Mode-Route Choice Problem

- The joint transit mode-route choice problem in the abstract can always be represented as an "O-D" path choice through a hyper-network.
- In practice, we usually *a priori* split the problem into a two-stage model system:



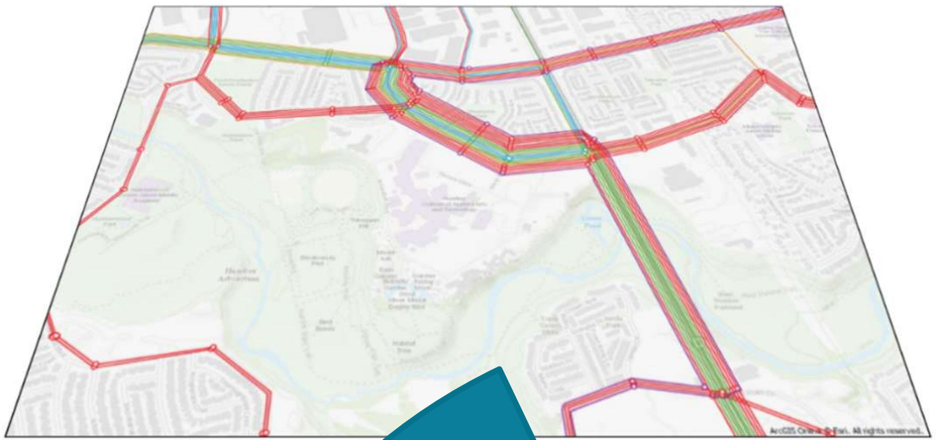
Issues with the two-stage approach:

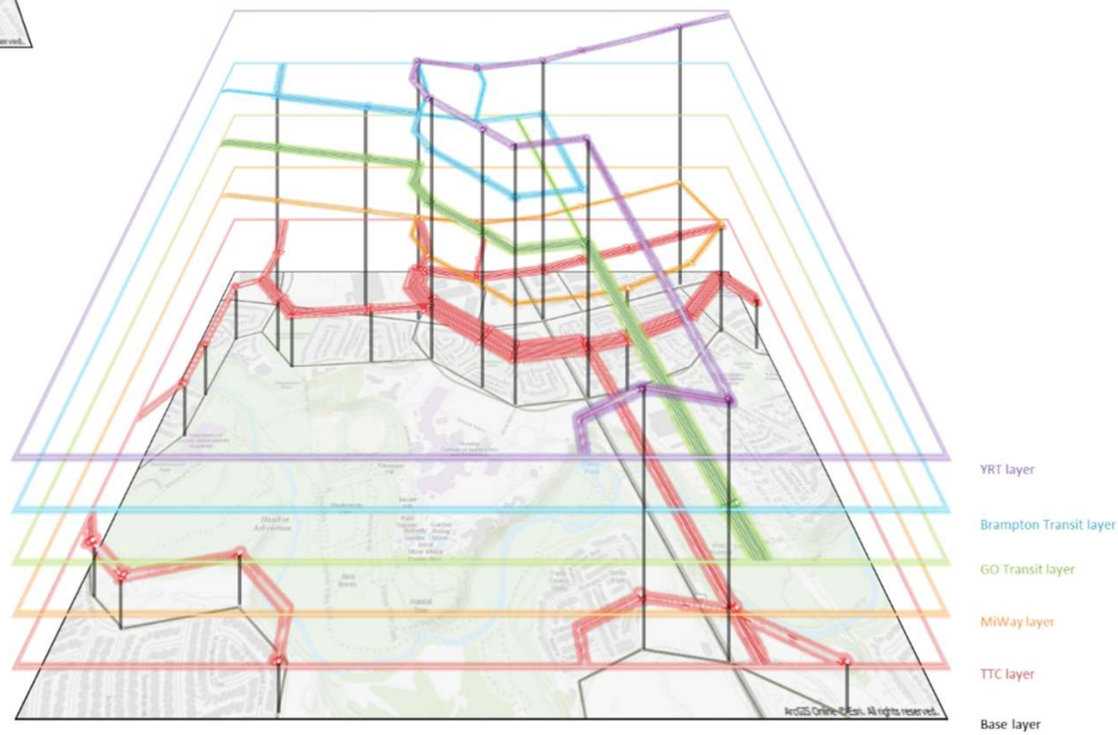
- Requires *a priori* specification of the mode choice model decision (error) structure: "hard wires" modes that can be modelled.
- Separate LOS "skims" are required for each "mode".
- Predicted O-D trips for each "mode" must be correctly assigned to the transit network.
- …

Adopted Approach

- "Push" all transit "sub-mode" choices "down" into route choice:
  - Choices between commuter rail, subway, LRT, bus, etc. is treated as a path choice within the assignment model, rather than as choices among competing modes.
- Probably one of the biggest innovations in GTAModel is the adoption of this "integrated", "technology neutral" representation of the transit network.

Integrated Transit Hyper-network





Integrated Transit Network, cont'd

- Advantages of the integrated approach:
  - Much 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!).

Integrated Transit Network

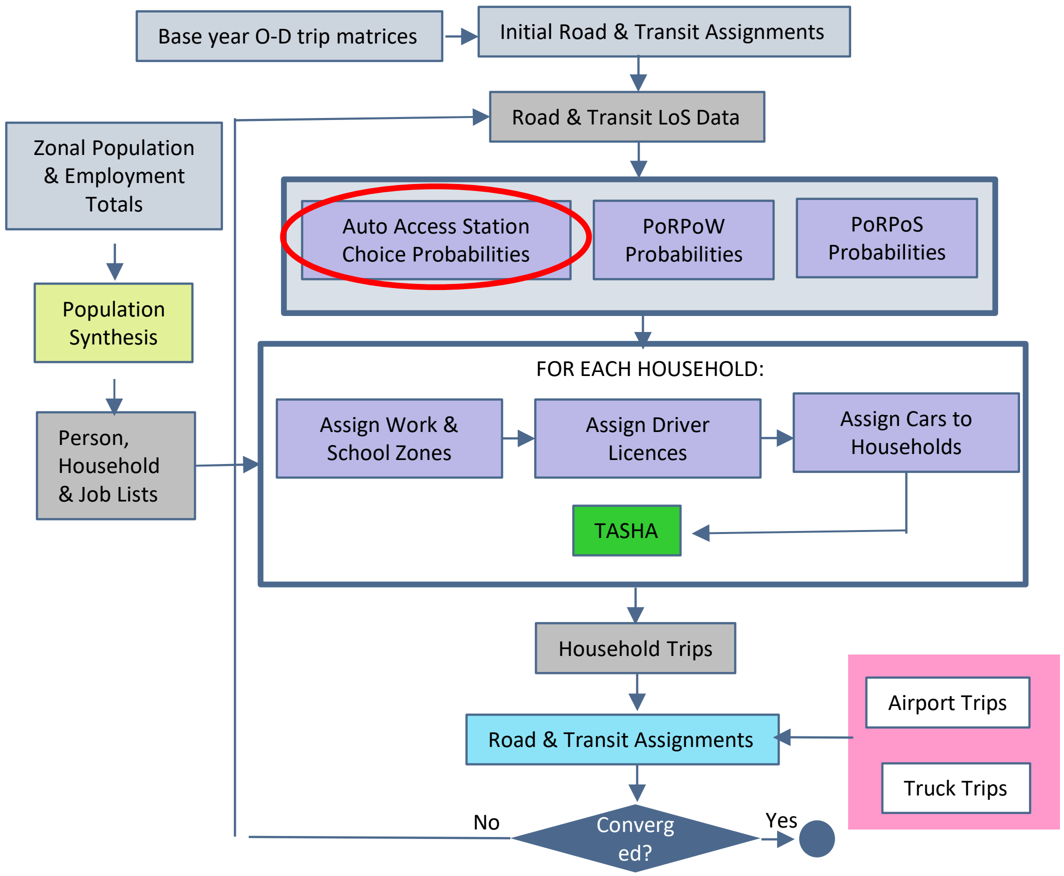
- This results in an “integrated”, “technology neutral” representation of the transit network.
- Transit “sub-modes” (commuter rail, subway, LRT, buses, etc.) are all treated as alternative paths through the network, NOT as separate modes.
- Transit “modes” in the mode choice model are only based on access-egress sub-modes used.

Transit Modes in GTAModel

- Walk-access transit (WAT): Walk is the access & egress mode for the transit trip.
  - People can “walk on the road network” to get to/from transit.
- Drive-access transit (DAT): The transit rider drives to a park & ride station. The rider must return to this station to egress from the transit system.
  - Person must have a driver’s licence & an auto available.
- Passenger-access transit (PAT): The transit rider gets a ride to the transit station (kiss & ride, access).
- Passenger-egress transit (PET): The transit rider gets a ride from the transit station (kiss & ride, egress).
  - No linkage between PAT & PET (i.e., trip-based modes, not tour-based).
  - Currently not attached to an explicit driver.
- Currently VfH bicycle, etc. are not available as access/egress modes.

Access Station Models

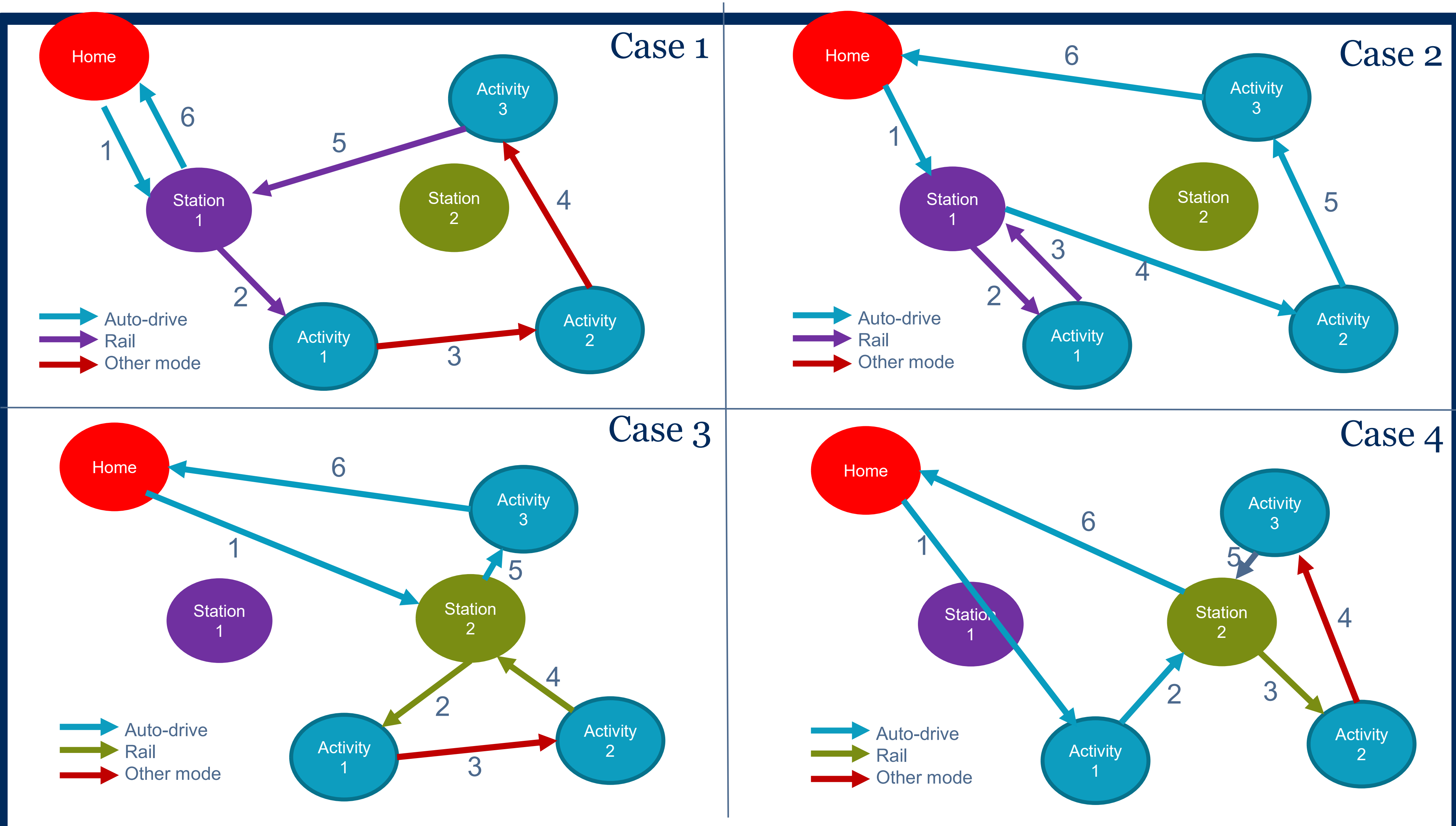
- Drive Access Transit (DAT)
  - Tour-based logit
  - Attractiveness varies as available parking changes
- Passenger Access Transit (PAT)
  - Trip-based logit model
- Passenger Egress Transit (PET)
  - Trip-makers are not constrained to use the same station for access & egress; nor are they constrained to use PAT & PET on the same tour.
  - Trip-based logit model



Tour-Based Access Station Choice Model

- Drive Access/Egress Transit (DAT/DET) require:
  - Choice of the access/egress station.
  - Ensuring that the access & egress station of a given tour (e.g., Home-Work-Home) are the same.
- A novel tour-based access station choice model is implemented.
- Access/egress station choice probabilities are precomputed prior to running TASHA to reduce computational burden.
- Station parking lot capacities are treated as a "soft constraints" with a conical "penalty function" used to decrease the probability of a station being chosen when it is approaching/exceeding capacity.

Example station & tour insertion location choices



Model Specification

- Given the very large number of alternatives & number of tours to be evaluated, V_A does not include socio-economic attributes & is pre-computed prior to mode choice calculations.

$$
\begin{aligned}
V_A \\
&= \beta_{atime}[atime] \\
&+ \beta_{cost}\left[acost_A + ParkingCost_{A_x} + tfare_A\right] \\
&+ \beta_{tptt}[perceivedTransitTime_A] \\
&+ \beta_{Capacity}[\log(Capacity_A + 1)] \\
&+ \beta_{ClosestStation}[ClosestStation_A]
\end{aligned}
$$

Parameter Estimation Results

	Estimated Parameters		
Variable	**DAT**	**PAT**	**PET**
Auto Travel Time (min)	-0.3344	-0.3063	-0.3504
Perceived Transit Time (min)	-0.0216	-0.2679	-0.2315
Transit fare ($)	-0.0357	-0.0210	-0.0246
Parking cost ($)	-0.0357	-0.0210	-0.0246
Auto Travel Cost ($)	-0.0357	-0.0210	-0.0246
Parking Capacity (no. of spaces)			
AM Period	2.1458	0.5504	0.0940
MD Period	1.7701	1.0257	1.2466
PM Period	1.8802	0.5995	0.4640
EV Period	2.5419	0.6653	0.6190
Closest Statiion (=1 if Yes)			
AM Period	2.0862	0.9449	0.0016
MD Period	0.0076	0.6021	0.5092
PM Period	0.0002	0.0076	0.0090
EV Period	1.5184	0.4630	0.7693

DAT: Drive Access Transit (deterines egress station as well)
PAT: Passenger Access Transit
PET: Passenger Egress Transit

Transit Assignment Extensions

- The Emme transit assignment procedure has been extended to include:
  - Surface Transit Speed Updating (STSU).
  - Onboard crowding (“congestion) effects.
  - Fare-based assignment.
- Montreal: integration with the road assignment STTA procedure.

Transit Assignment with Surface Transit Speed Updating (STSU)

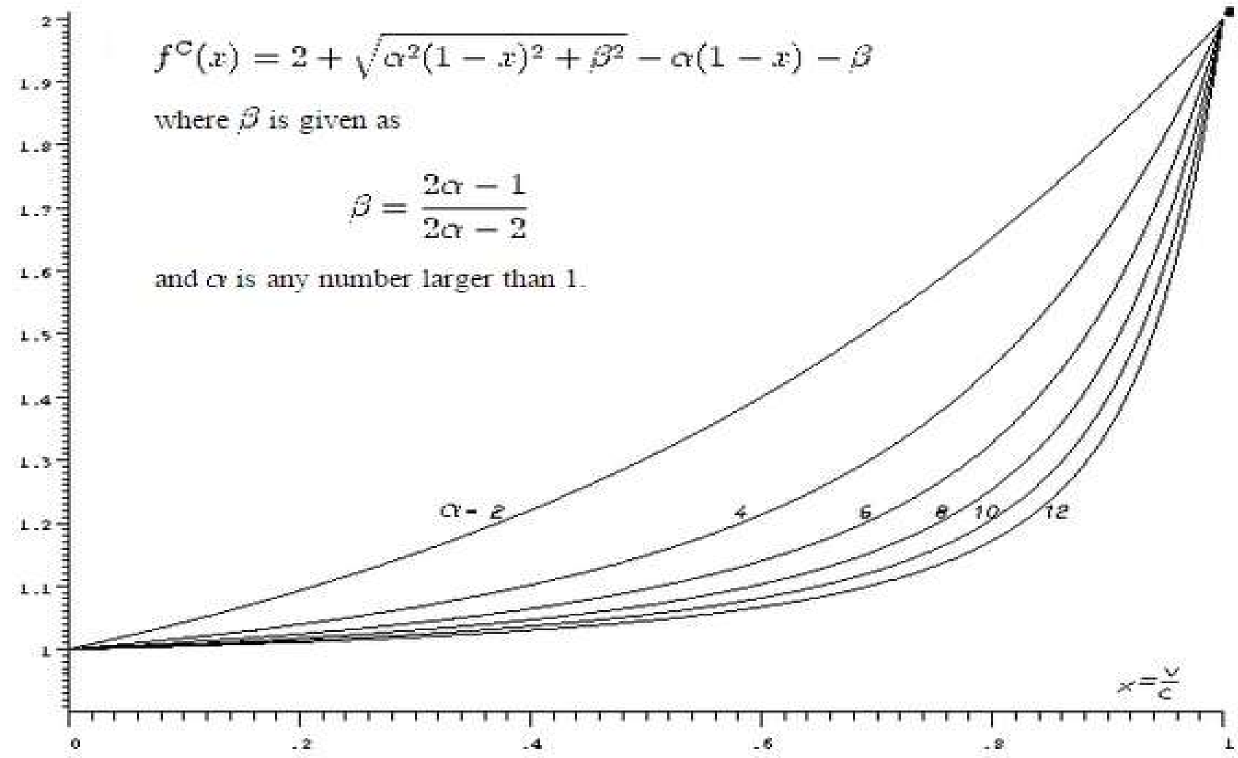
- STSU accounts for roadway congestion effects on surface transit speeds in shared-right-of-way(SROW) operations.
- STSU adjusts the bus speeds on SROW segments
- Exclusive-right-of-way (EROW) are modelled with fixed stop-to-stop speeds.
- Transit lines can be a combination of EROW & SROW.

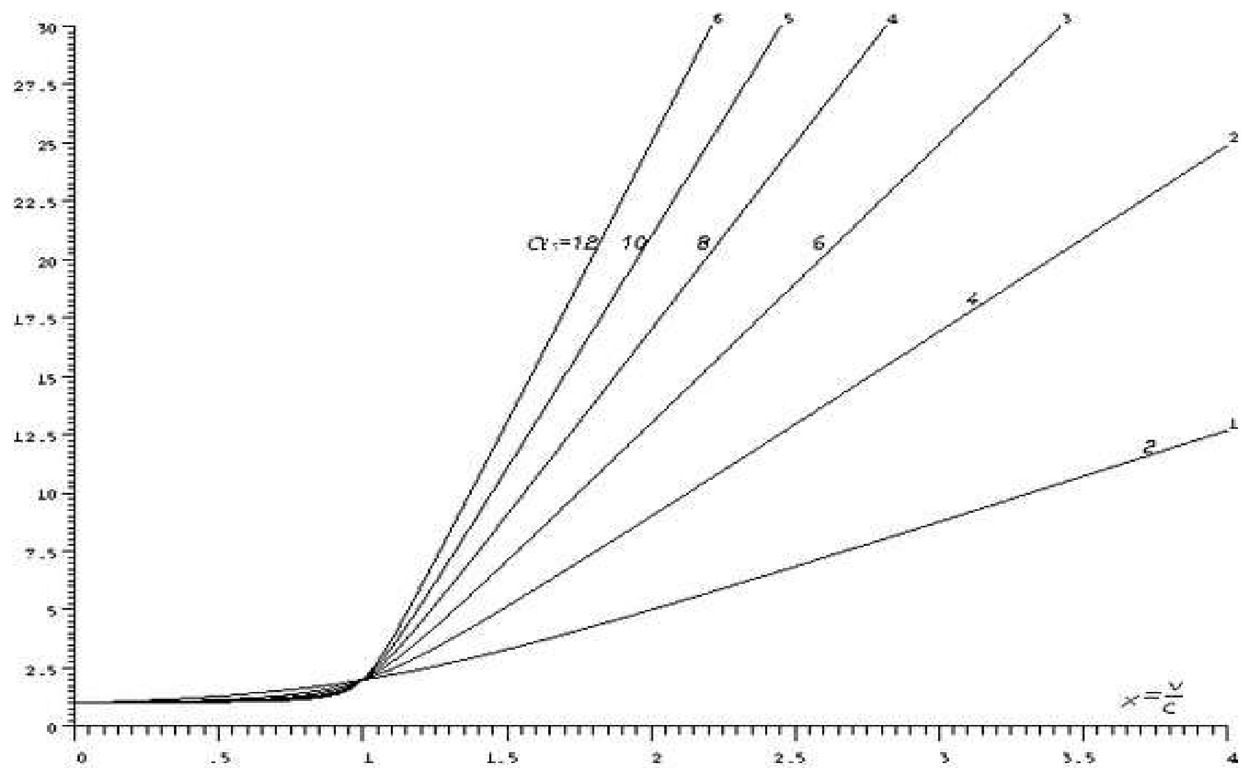
Transit Vehicle Crowding/Congestion

- The transit Travel Time Functions (TTF) model adjusts the "perceived" transit in-vehicle travel times to reflect crowding/overloading of transit vehicles.
- This is directly equivalent to the volume-delay functions routinely used in road assignments.
- Our experience in Toronto is that is very important in capturing route choice behaviour.
  - In particular, the impacts on both route and mode choice as new capacity is added to the transit network.
    - Provides "relief" to over-crowded lines (notably, in Toronto, the Yonge subway line).
    - Provides flexibility in the model system for capacity increases to "induce" new transit ridership (really, transit mode choice increases) that might not be otherwise captured if capacity constraints are not modelled.

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!



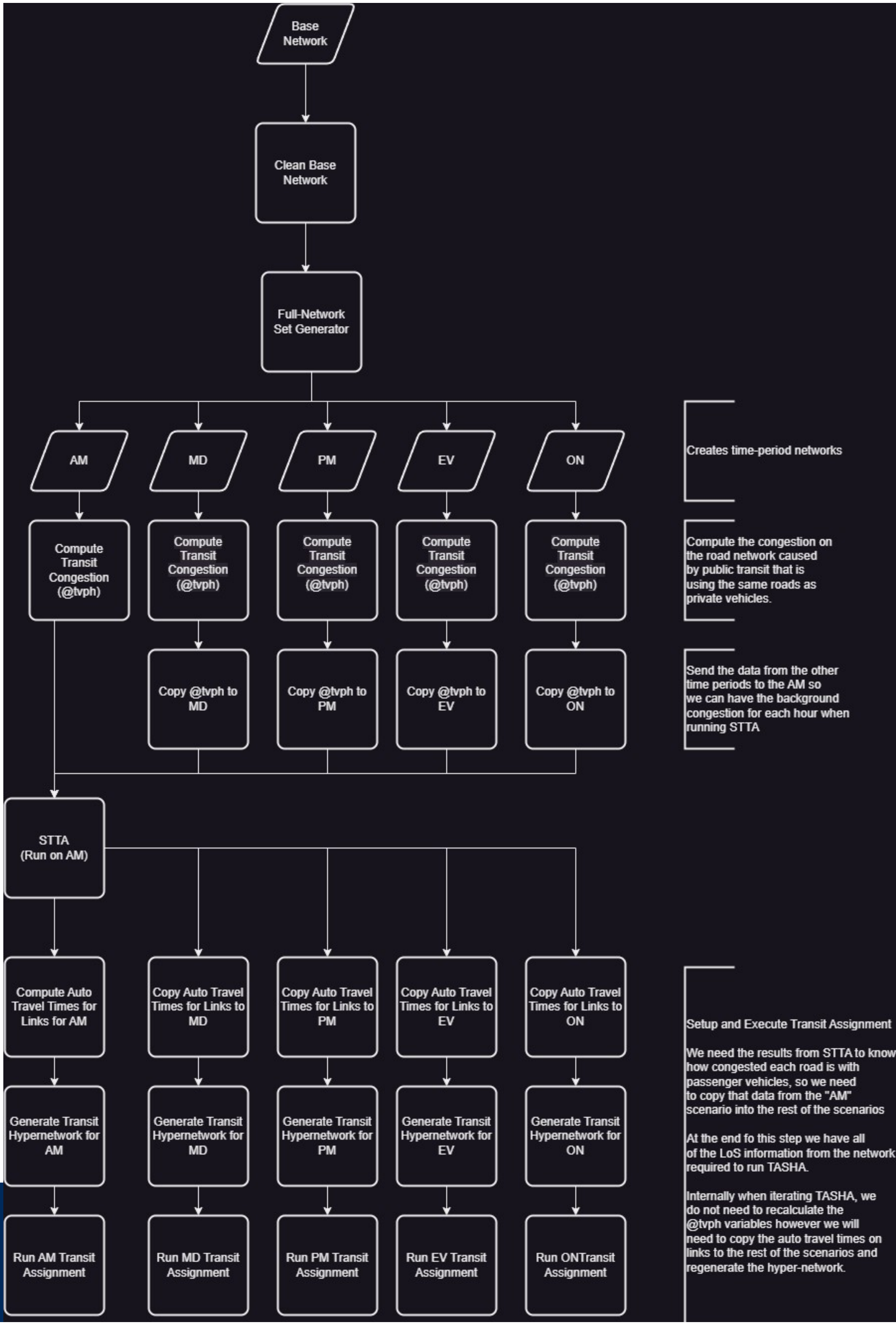


Fare-Based Transit Assignment

- 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.

Transit Assignment with STTA: Algorithm

- For each hour compute the background traffic
- Copy the background traffic into an AM network
- Run STTA in an AM scenario
- Compute the hourly auto travel times and copy them to their respective scenarios
- Run transit assignment.



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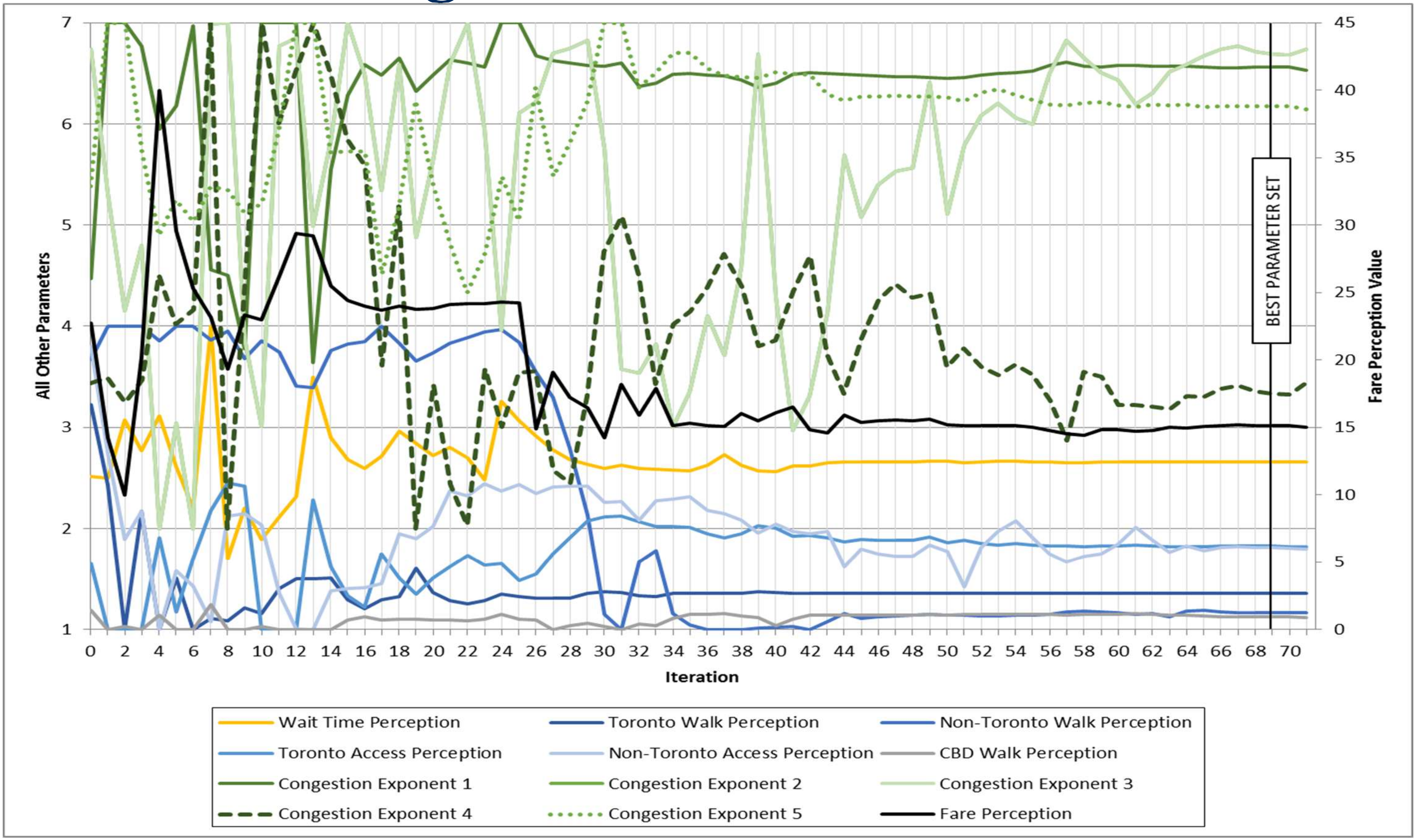
Transit Assignment Model Estimation



Transit Assignment & ABM

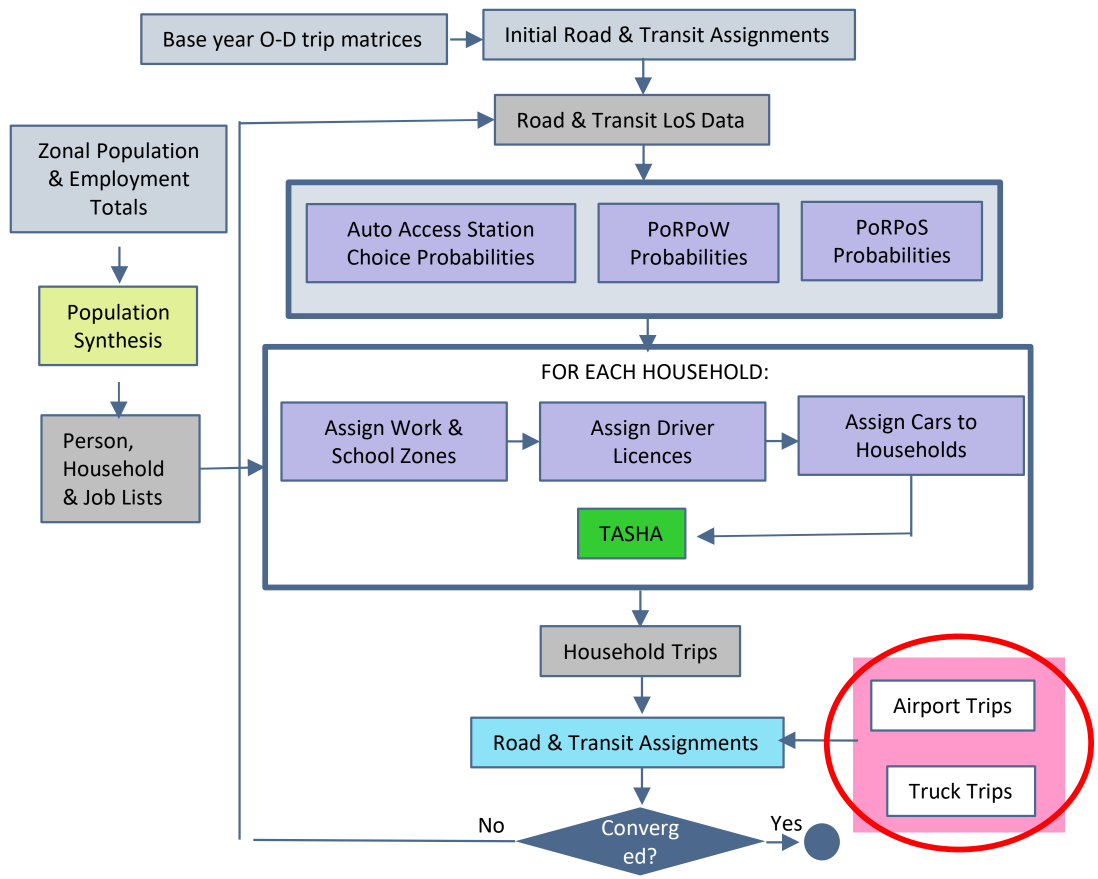
- While we are fairly proud of what we have accomplished with our current Emme-based transit assignment model, it is clear that we have reached the limit of what can be done within an aggregate, static framework.
- We very much need an operational ABM transit assignment model!
- We need to "retain the agent" throughout the path choice / network simulation process.
- This will greatly simplify and improve our current processes in many ways:
  - Fare-based assignment
  - Utility path choice that is consistent with mode choice & includes a wider range of variables
  - Ability to "feed up" sub-mode attributes into the mode choice model.
- We need to move to **schedule-based assignment** to properly handle wait & transfer time calculations in complex networks.

ANCILLARY MODELS

1. Airport access.
2. Trucks.

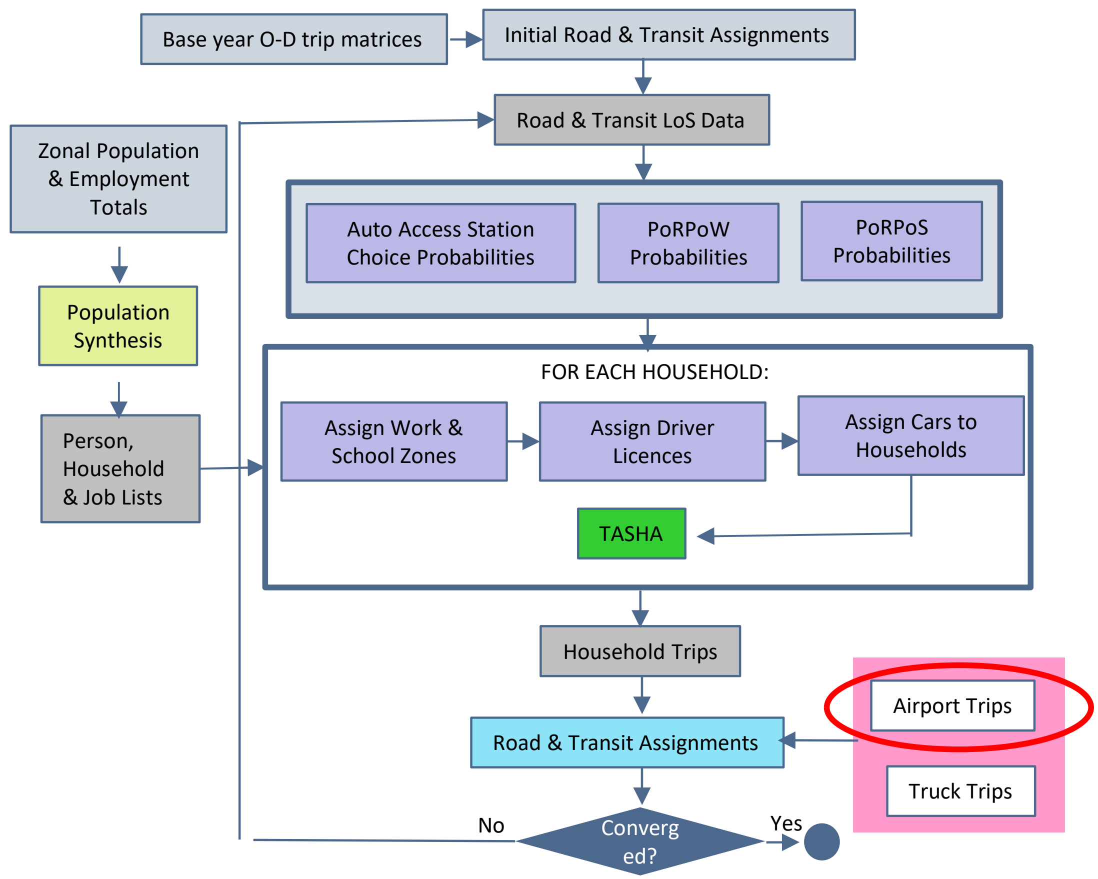
“Special Generator” Trip-Based Models

- Two non-household-based, trip-based “special generator” models are currently implemented :
  - Air passenger trips to/from Pearson Airport (Trudeau Airport in Montreal).
  - Truck freight model.



Airport Passenger Model

- Generates both auto and transit air passenger trips to/from Pearson International Airport
- Splits demand by time period by GTHA residents and visitors.
- Has origin/destination location and mode choice models.
- Fare sensitive.
- Results are added back to the network demand matrices
- Based on Pearson Airport groundside survey data.



Model Specification (1)

- GTHA residents: Nested logit (NL) model

  - Upper-level location choice → for trips generated from traffic analysis zones (TAZs) to airport
    - Probability of making a trip from zone i to the airport

$$P_i = \frac{\exp(\beta X_i + \mu I_i)}{\sum_{i'|C} \exp(\beta X_i{}' + \mu I_{i'})}$$

    - Inclusive value (log-sum) for origin zone i

$$I_i = log\left(\sum_{m'|i} \exp(\alpha\, Z_{m'}/\mu)\right)$$ ($0 \le \mu \le 1$, μ is the scale parameter)

  - Lower-level → mode choice model
    - Probability of a trip from zone i using mode m to the airport

$$P_{m|i} = \frac{\exp(\alpha\, Z_m/\mu)}{\sum_{m'|i} \exp(\alpha\, Z_{m'}/\mu)}$$

Model Specification (2)

- GTHA visitors: two Multinominal Logit (MNL) models given that the nested logit structure did not generate a sensible nesting (scale) parameter

- Location choice MNL → for trips generated from TAZs to airport
    - Probability of a trip from zone i to the airport

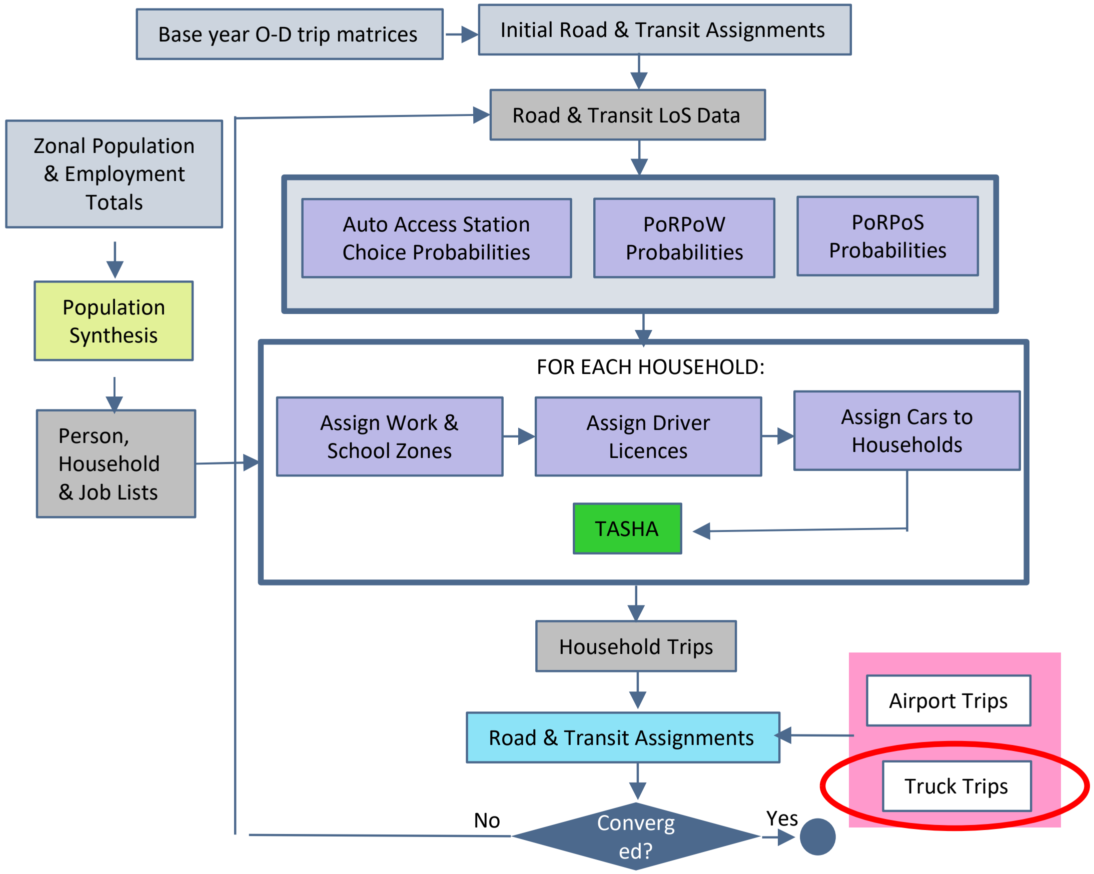
$$P_i = \frac{\exp(\beta X_i)}{\sum_{i'|C} \exp(\beta X_{i'})}$$

- Mode choice MNL →
    - Probability of using mode m for a trip to the airport

$$P_{m|i} = \frac{\exp(\alpha Z_m)}{\sum_{m'|i} \exp(\alpha Z_{m'})}$$

Truck Model

- Two-stage truck model:
  - Generation (regression model).
  - Distribution (doubly-constrained gravity model).
- Light, medium & heavy trucks.
- Employment by 15 industry categories generates trips.

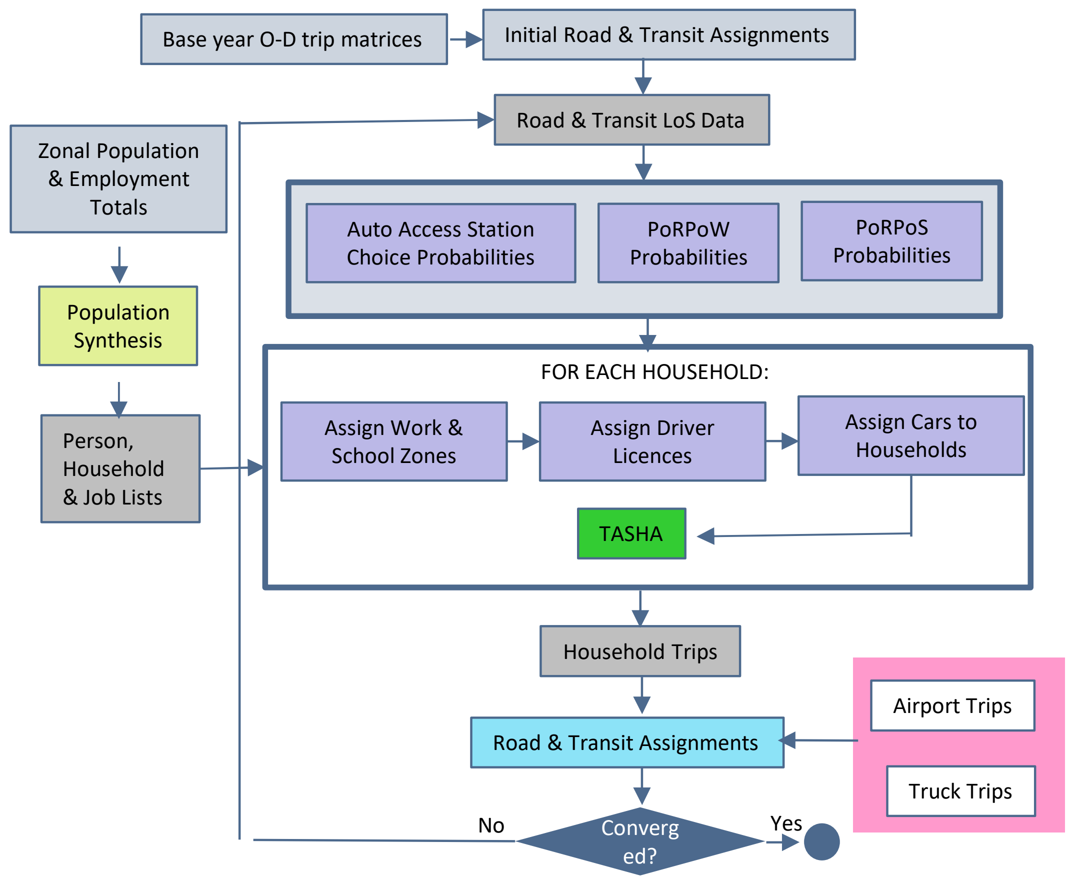


THE IMPLEMENTED MODEL SYSTEM

1. eXtensible Travel Modelling Framework (XTMF)
2. Running the Model System
3. Outputs
4. Model System Run Example Results

Model System Outputs

- Assigned Networks
  - Auto and Transit Network Package's (NWP's) with all assignment results
- Aggregate O-D trip matrices (by mode, purpose, time of day)
- Level of Service (LoS) matrices (travel times, costs, etc. by mode).
- Microsimulation results. Disaggregate lists of:
  - Households
  - Persons
  - Trips
  - Trip modes
  - Trip stations
  - Facilitate passenger trips



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

Model System Outputs

The model system generates all forecast year travel estimates that are expected of such a system:

- 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.
- A full set of trips & tours, travel times experienced, etc. by <u>each person</u> 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).
- …

Microsimulation Results (1): Households

- Household ID
- Home Zone
- Expansion Factor
- Number of Persons
- Dwelling Type
- Number of Vehicles
- Income Class

Microsimulation Results (2): Persons

- Household ID
- Person ID
- Age
- Sex
- License
- Transit Pass
  - Not implemented in V4.2
- Employment Status
- Occupation
- Free parking at work
  - Not implemented in V4.2
- Student Status
- Work Zone
- School Zone
- Weight (expansion factor)

Microsimulation Results (3): Trips

- Household ID
- Person ID
- Trip ID
- Origin Activity
- Origin Zone
- Destination Activity
- Destination Zone
- Weight (expansion factor)

Microsimulation Results (4): Trip Modes

- Household ID
- Person ID
- Trip ID
- Mode
- Departure time*
- Arrival Time*
- Weight (number of times chosen)

* Times are in minutes from midnight

Microsimulation Results (5): Trip Stations

- Household ID
- Person ID
- Trip ID
- Station ID
- To / From Transit
  - auto2transit
  - transit2auto
- Weight (number of times chosen)
- Mode
  - PAT/PET/DAT

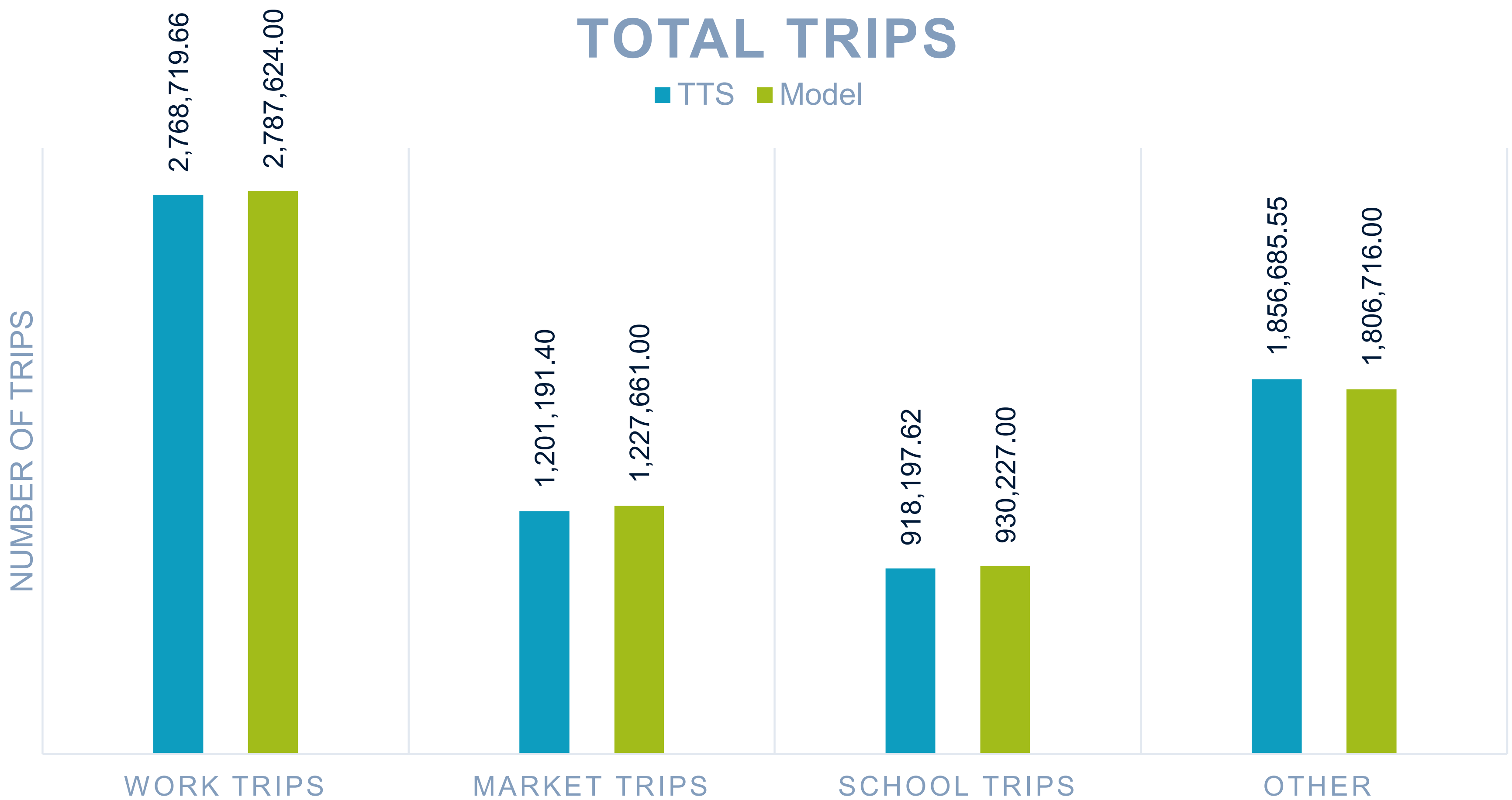
Microsimulation Results (6): Facilitate Passenger

- Household ID
- Passenger Person ID
- Passenger Trip ID
- Driver Person ID
- Driver Trip ID
  - -1 if the driver facilitated the trip by going from home and returning back
- Weight (number of times chosen)

GTAModel V4.0: Validation Results

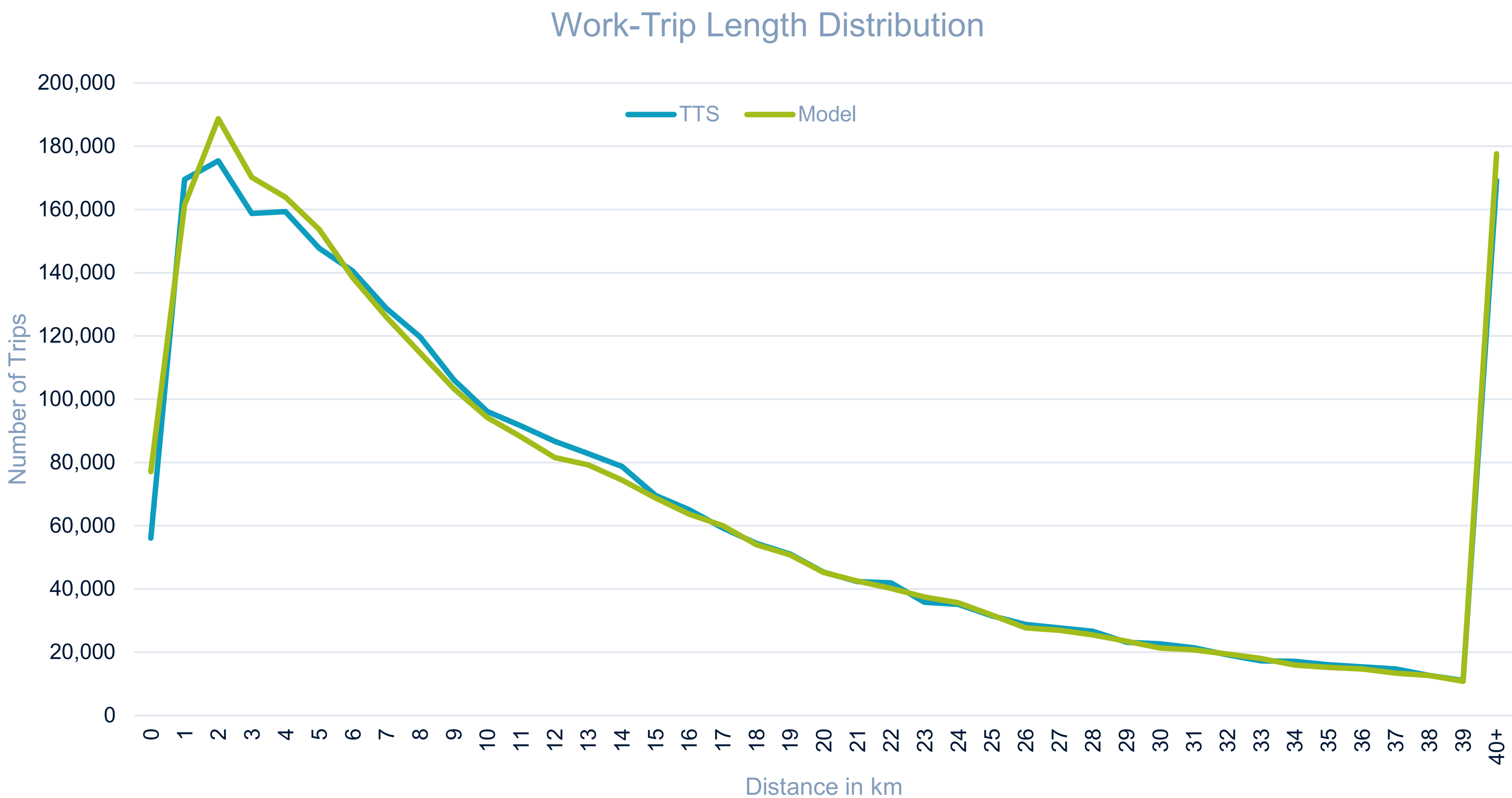
Trip Generation Validation

- Validating the Model's ability to generate the correct number and correct type of trips



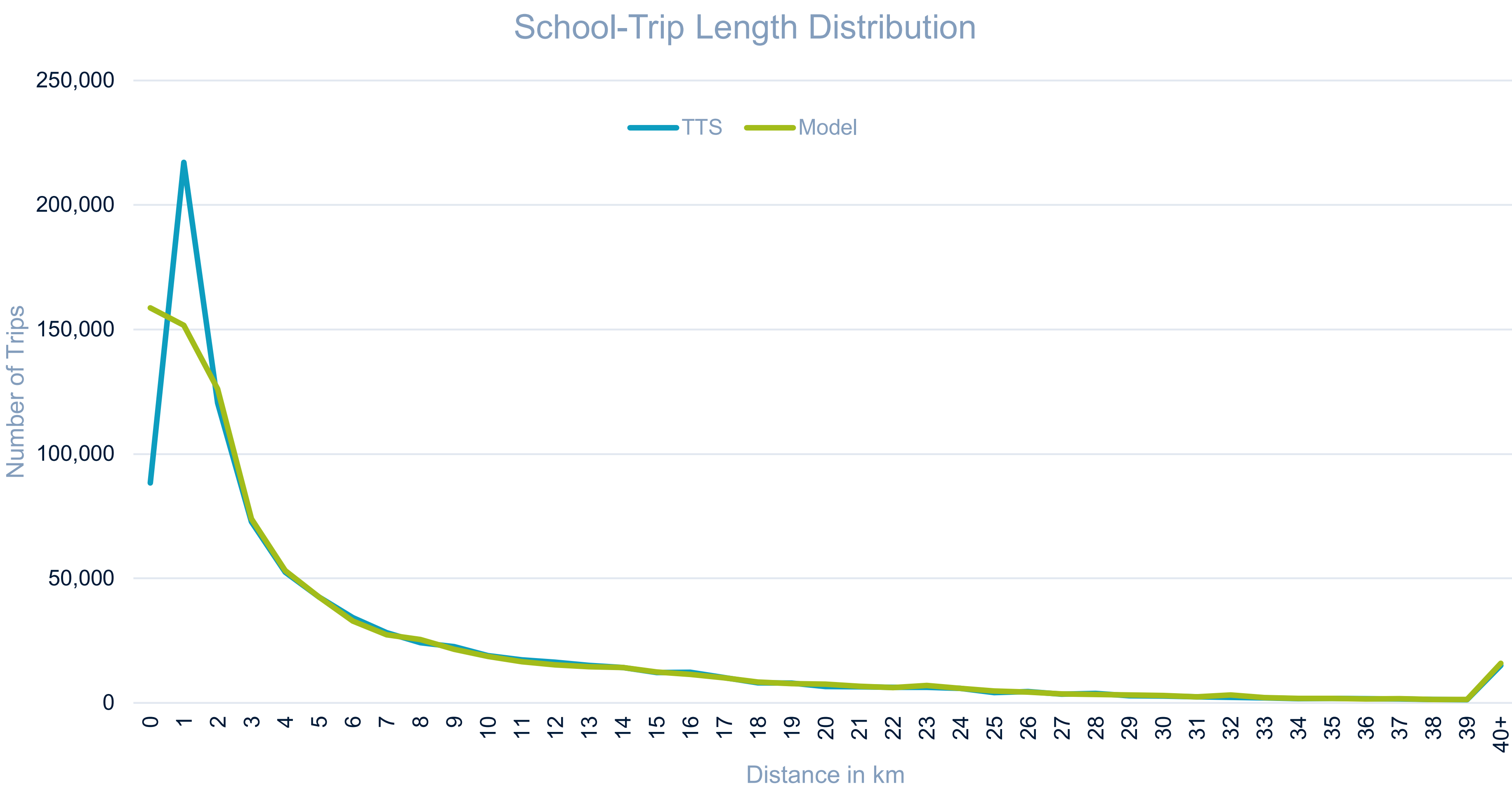
Trip Length Validation

- Validating the Model's ability to generate the correct length of trips



Trip Length Validation

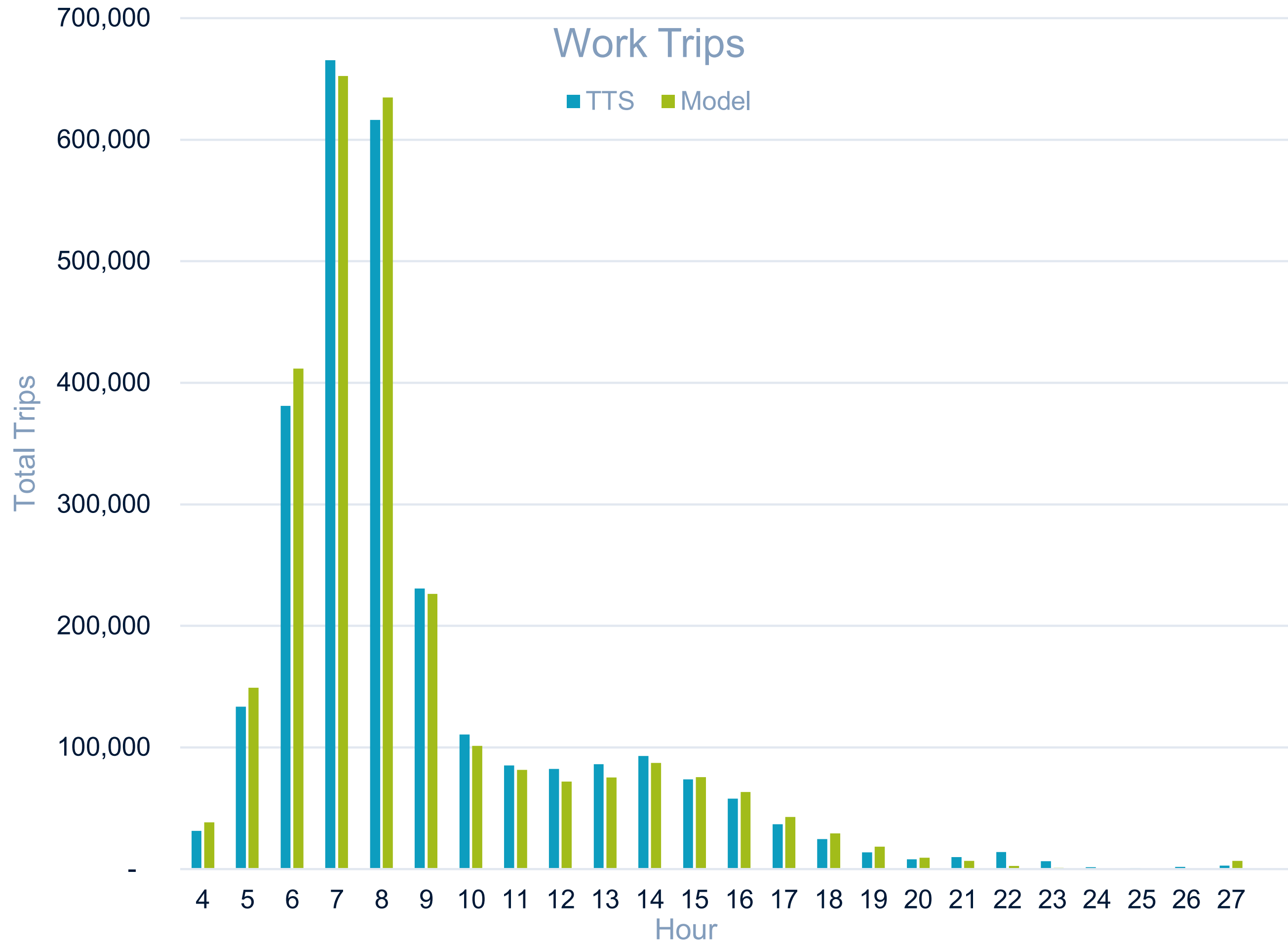
- Validating the Model's ability to generate the correct length of trips



Trip Start Time Validation

- Validating the Model's ability to generate the correct start time for different types of trips

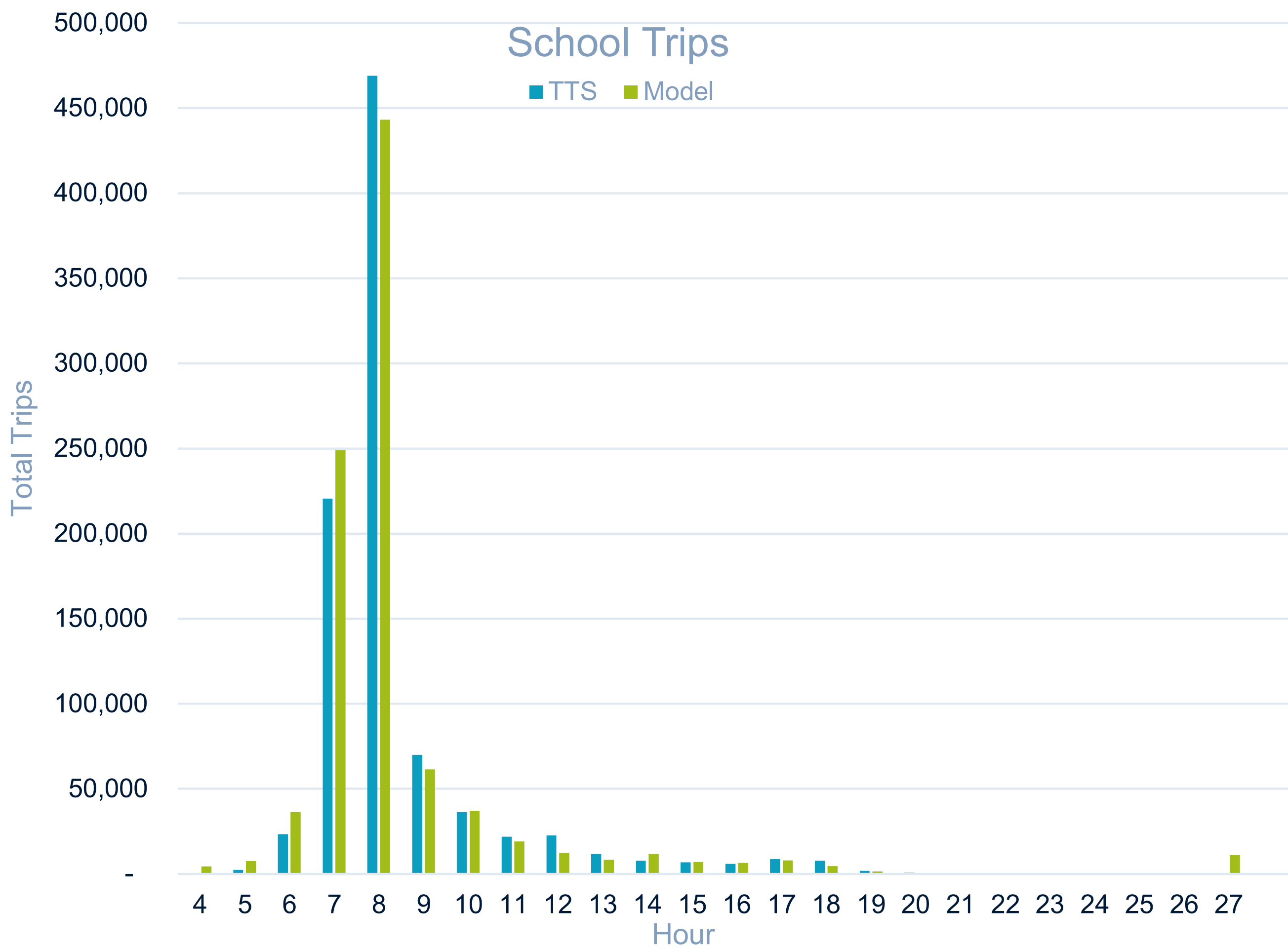
Hour	Difference in Trips	% Diff
4	7,171	23%
5	15,562	12%
6	30,660	8%
7	-12,888	-2%
8	18,459	3%
9	-4,502	-2%
10	-9,472	-9%
11	-3,588	-4%
12	-10,605	-13%
13	-10,829	-13%
14	-5,765	-6%
15	1,768	2%
16	5,488	9%
17	5,958	16%
18	4,727	19%
19	4,552	33%
20	1,264	16%
21	-3,132	-32%
22	-11,434	-82%
23	-5,476	-84%
24	-1,317	-85%
25	-354	-41%
26	-1,328	-74%
27	3,985	144%



Trip Start Time Validation

- Validating the Model's ability to generate the correct start time for different types of trips

Hour	Difference in Trips	% Diff
4	4,014	1193%
5	5,298	227%
6	13,039	56%
7	28,337	13%
8	-25,913	-6%
9	-8,600	-12%
10	806	2%
11	-2,652	-12%
12	-10,170	-45%
13	-3,290	-28%
14	3,800	49%
15	111	2%
16	661	11%
17	-850	-10%
18	-3,099	-40%
19	-307	-17%
20	-198	-26%
21	-107	-35%
22	-134	-75%
23	-19	-68%
24	2	N/A
25	3	N/A
26	241	N/A
27	11,058	N/A



Trip Start Time Validation

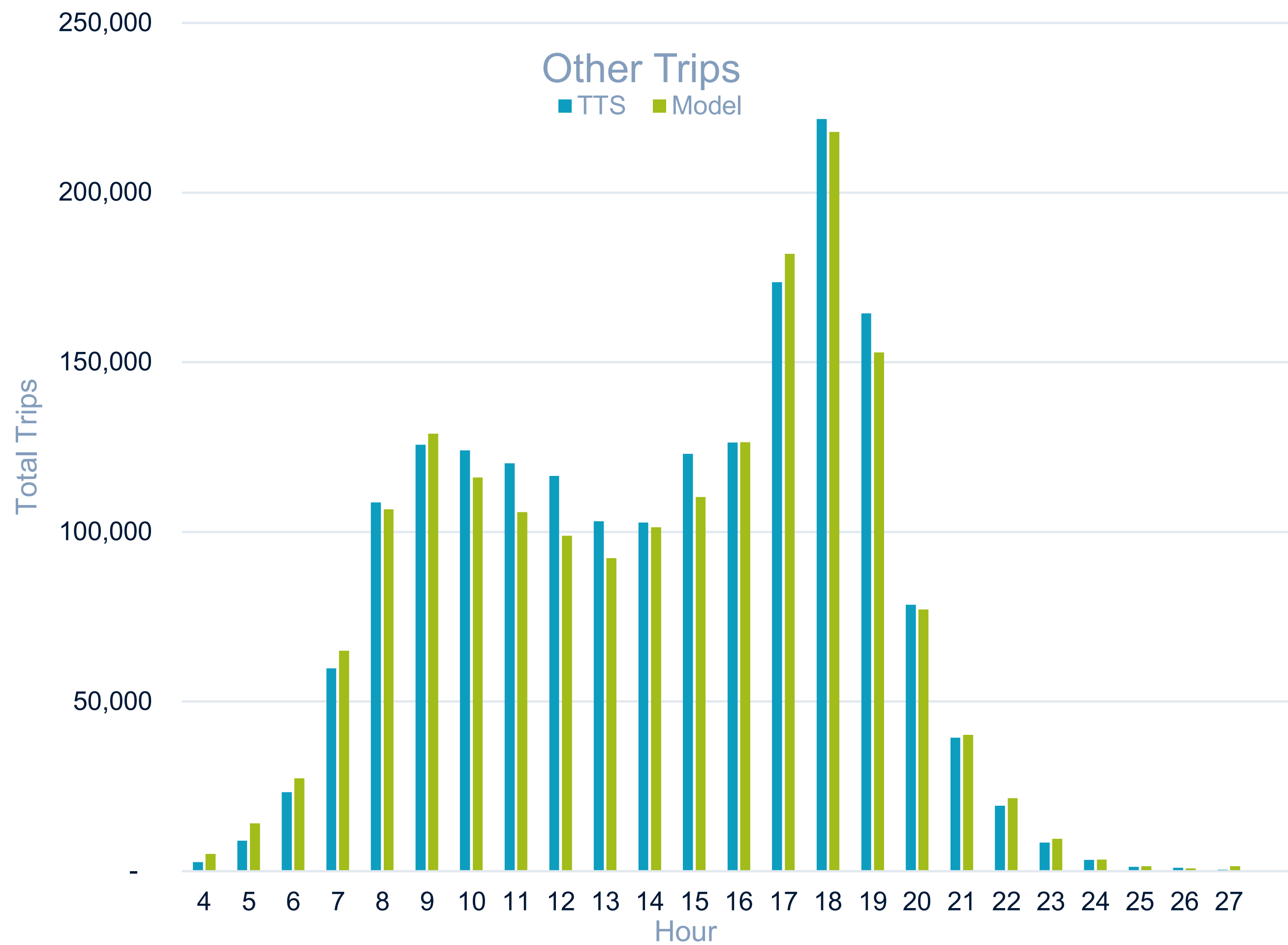
- Validating the Model's ability to generate the correct start time for different types of trips

Hour	Difference in Trips	% Diff
4	3	1%
5	455	53%
6	903	39%
7	629	9%
8	922	4%
9	-8,711	-13%
10	693	0%
11	-12,901	-10%
12	6,849	7%
13	12,740	13%
14	-5,740	-6%
15	-2,044	-2%
16	-2,987	-3%
17	13,441	14%
18	15,109	15%
19	-1,821	-2%
20	-1,676	-4%
21	4,673	39%
22	2,991	65%
23	1,383	87%
24	854	157%
25	398	210%
26	229	256%
27	77	98%

Trip Start Time Validation

- Validating the Model's ability to generate the correct start time for different types of trips

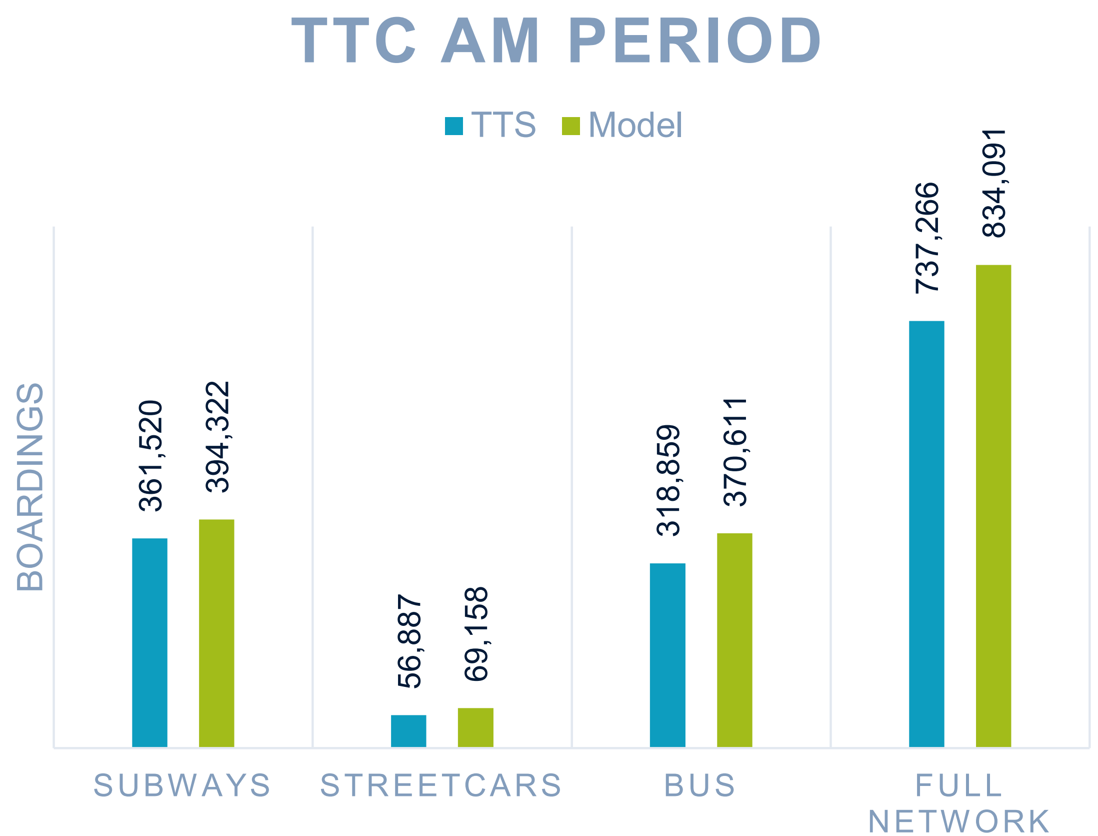
Hour	Difference in Trips	% Diff
4	2,440	92%
5	5,135	57%
6	4,109	18%
7	5,238	9%
8	-2,014	-2%
9	3,232	3%
10	-8,042	-6%
11	-14,436	-12%
12	-17,668	-15%
13	-10,937	-11%
14	-1,418	-1%
15	-12,696	-10%
16	105	0%
17	8,357	5%
18	-3,738	-2%
19	-11,504	-7%
20	-1,409	-2%
21	839	2%
22	2,235	12%
23	1,056	12%
24	120	4%
25	186	14%
26	-199	-19%
27	1,039	237%



Trip Assignment: Transit Boardings

- Validating the Model's ability to assign trips to the correct transit modes

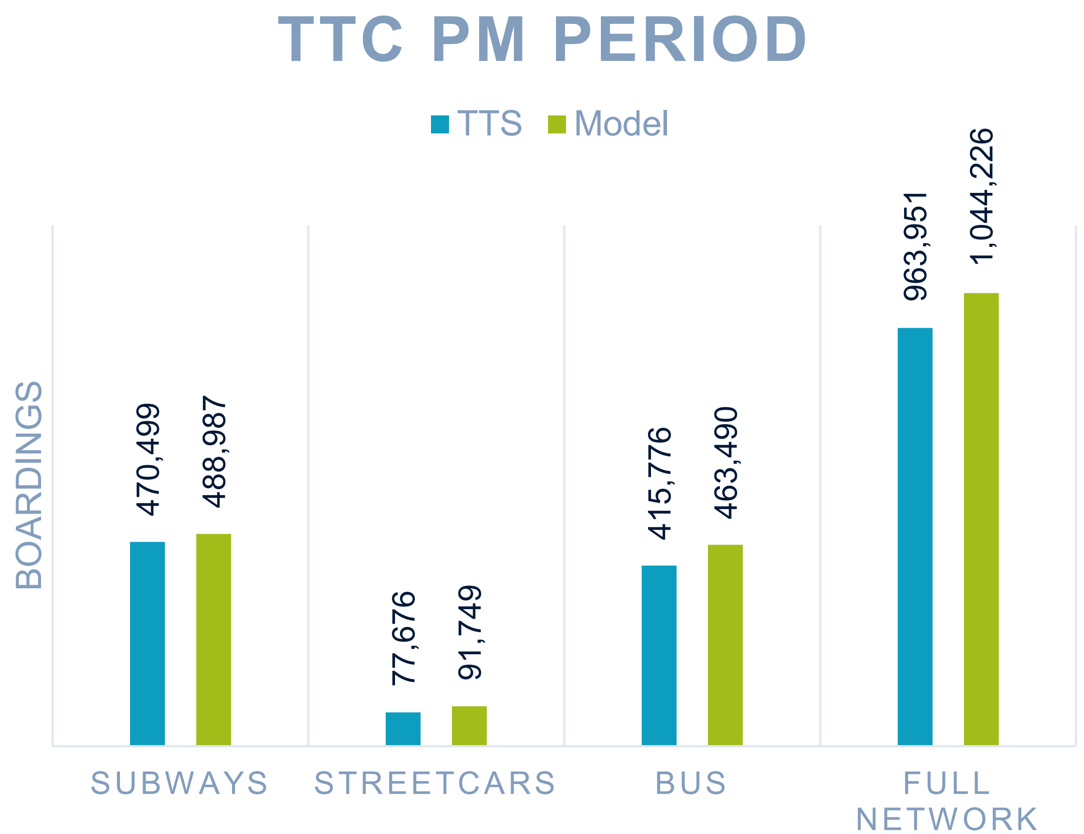
TTC AM		
Mode	**Difference in Trips**	**% Diff**
Subway	32,802	9%
Streetcar	12,271	22%
Bus	51,752	16%
Full Network	96,825	13%



Trip Assignment: Transit Boardings

- Validating the Model's ability to assign trips to the correct transit modes

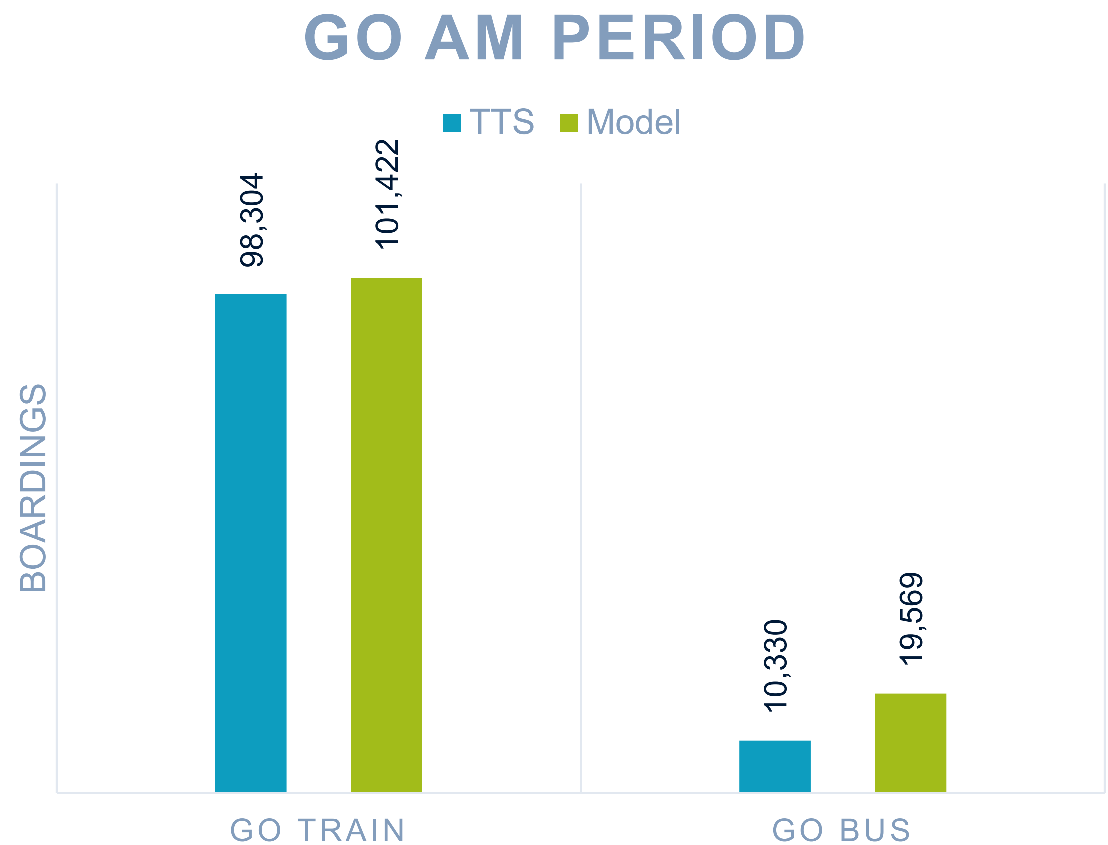
TTC PM		
Mode	**Difference in Trips**	**% Diff**
Subway	18,488	4%
Streetcar	14,073	18%
Bus	47,714	11%
Full Network	80,275	8%



Trip Assignment: Transit Boardings

- Validating the Model's ability to assign trips to the correct transit modes

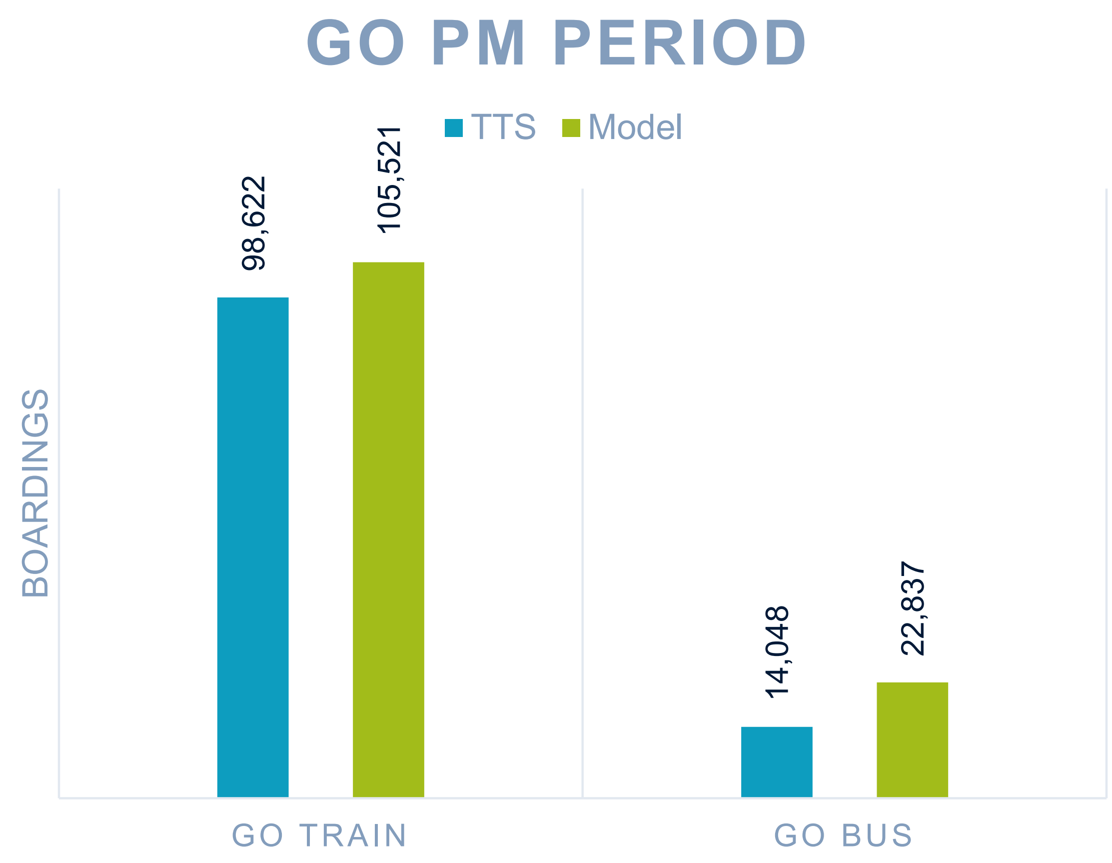
GO AM		
Mode	**Difference in Trips**	**% Diff**
GO Train	3,118	3.2%
GO Bus	9,239	89%
Full GO Network	12,357	11%



Trip Assignment: Transit Boardings

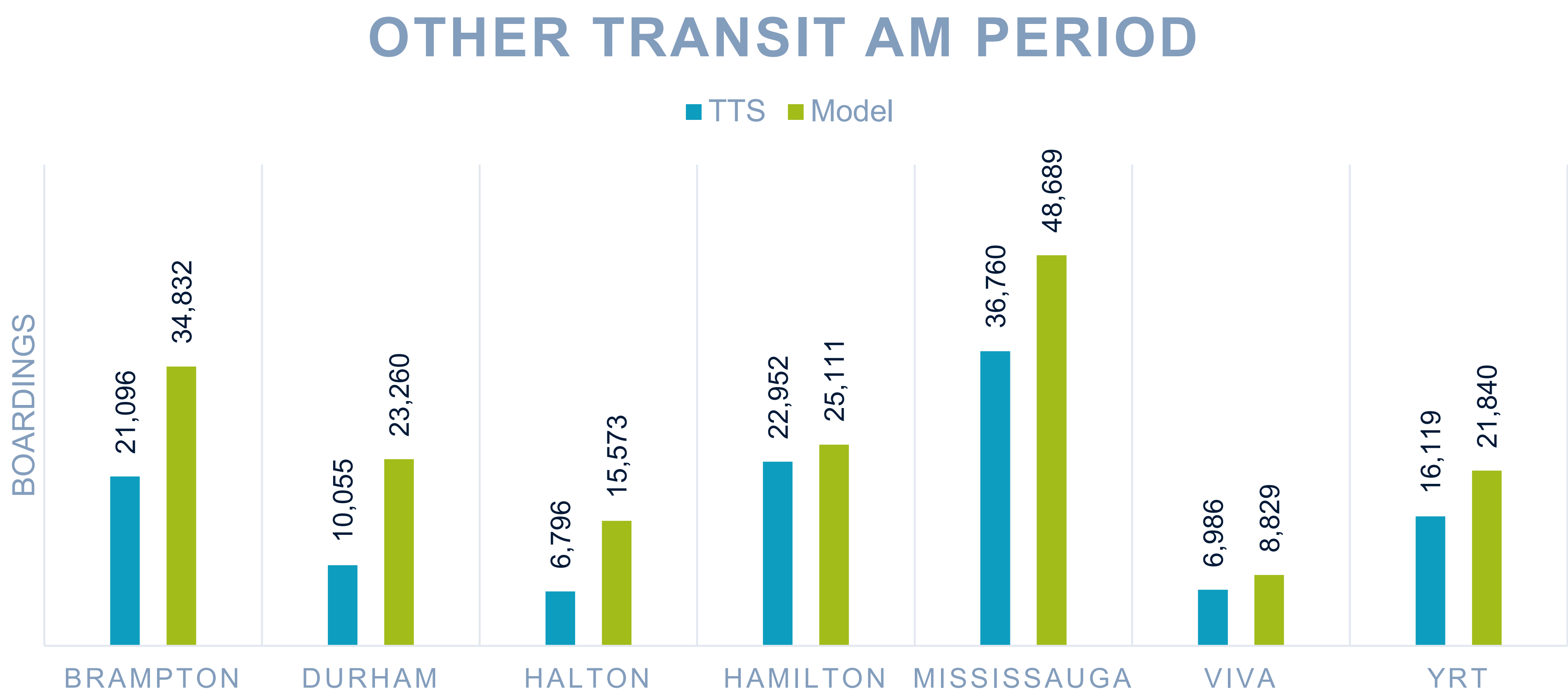
- Validating the Model's ability to assign trips to the correct transit modes

GO PM		
Mode	**Difference in Trips**	**% Diff**
GO Train	6,899	7%
GO Bus	8,790	63%
Full Network	15,689	14%



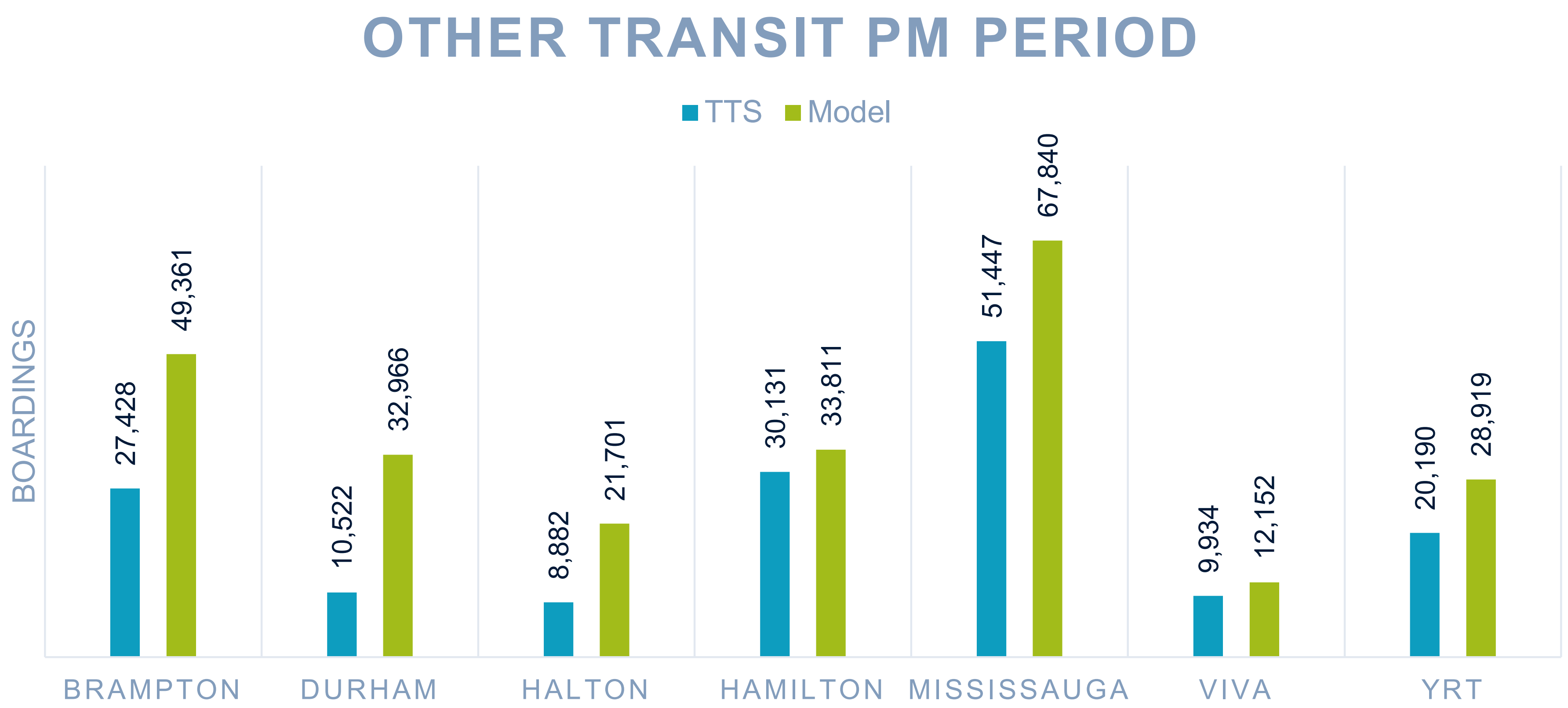
Trip Assignment: Transit Boardings

- Validating the Model's ability to assign trips to the correct transit modes



Trip Assignment: Transit Boardings

- Validating the Model's ability to assign trips to the correct transit modes



Trip Assignment: Transfers

- Validating the Model's ability to produce the correct distribution of transfers between different transit modes

AM Transfer Matrix

	-	B	D	GB	GT	H	W	MS	TTC S	TTC M	TTC B	VIVA	YRT
-	32,411	7,149	8,224	3,322	- 10,551	5,048	2,856	5,651	8,409	6,137	20,868	- 65	3,382
B	6,231	4,720	-	1,023	1,076	-	-	286	-	-	434	- 12	- 21
D	5,645	-	4,065	587	2,852	-	-	-	-	-	56	-	-
GB	3,366	407	- 119	677	567	139	431	429	6	1,570	1,351	236	179
GT	- 26,549	318	982	1,142	2,056	2,138	- 44	1,249	294	17,156	4,388	- 8	- 2
H	4,796	-	-	252	2,344	896	318	171	-	-	-	-	-
W	1,409	-	-	245	1,584	323	- 1,401	-	-	-	-	-	-
MS	5,526	386	-	842	1,984	233	-	2,034	86	139	682	-	18
TTC S	8,237	-	-	20	67	-	-	53	- 344	5,304	- 1,066	-	-
TTC M	21,927	-	-	135	749	-	-	1,279	4,571	- 5,179	8,210	693	415
TTC B	27,862	661	54	210	722	-	-	769	- 751	6,414	15,456	50	306
VIVA	103	11	-	248	- 119	-	-	-	-	561	130	194	715
YRT	1,878	84	-	538	- 213	-	-	8	-	700	1,243	754	730

Trip Assignment: Transfers

- Validating the Model's ability to produce the correct distribution of transfers between different transit modes

PM Transfer Matrix

	-	B	D	GB	GT	H	W	MS	TTC S	TTC M	TTC B	VIVA	YRT
-	46,647	9,626	11,901	- 3	- 29,916	7,617	463	8,317	7,003	5,582	34,936	- 1,041	4,046
B	11,590	7,936	-	1,136	496	-	-	331	-	-	356	41	46
D	13,781	-	7,093	6	1,534	-	-	-	-	-	30	-	-
GB	1,832	965	585	1,454	1,531	259	1,123	580	12	- 47	- 211	188	558
GT	- 11,684	2,473	2,872	1,085	3,571	2,910	2,333	2,271	113	949	1,021	- 10	77
H	8,126	-	-	255	2,528	1,472	359	79	-	-	-	-	-
W	2,911	-	-	905	50	414	- 599	-	-	-	-	-	-
MS	8,104	322	-	726	1,883	147	-	3,902	- 42	1,187	127	-	35
TTC S	10,042	-	-	5	568	-	-	55	- 1,331	5,796	- 1,045	-	-
TTC M	3,710	-	-	523	19,164	-	-	- 266	9,062	- 15,272	51	1,129	450
TTC B	5,751	565	- 7	1,758	5,472	-	-	1,077	- 744	19,431	12,876	369	1,179
VIVA	180	1	-	419	- 38	-	-	-	-	570	- 343	399	1,031
YRT	5,403	45	-	521	57	-	-	45	-	293	- 85	1,144	1,307

Trip Assignment: Transit Ridership

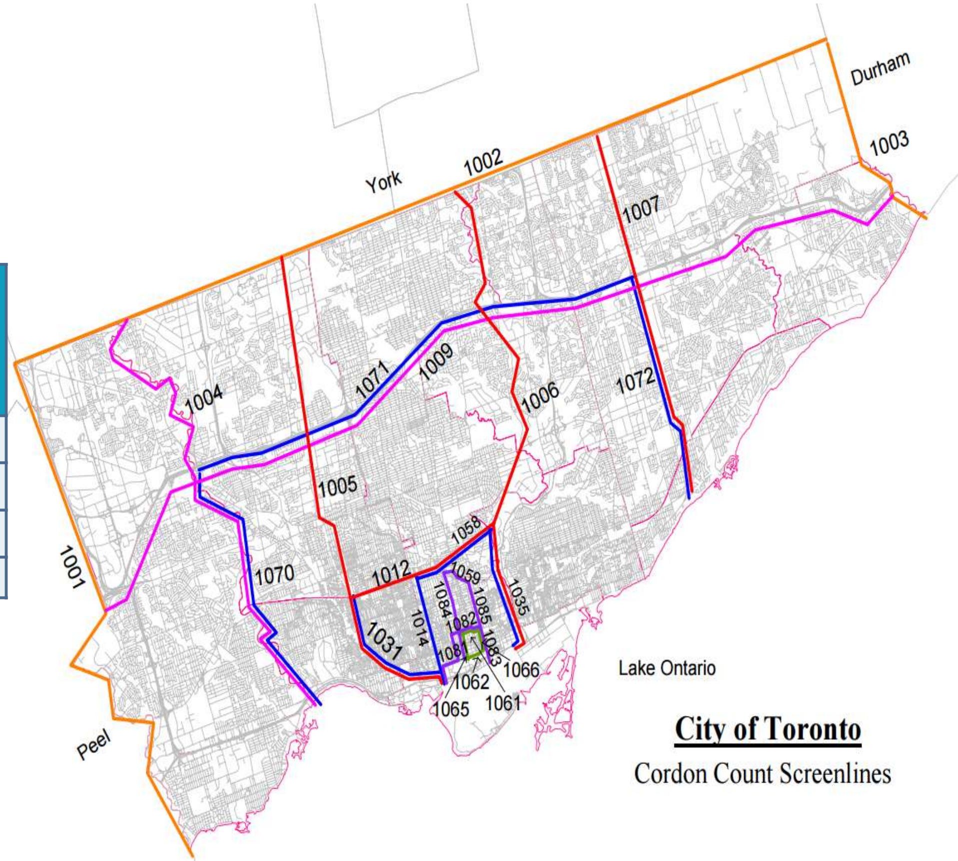
- Validating the Model's ability to produce the correct ridership on the different operators

Operator	Mode	Time Period	Model Ridership	TTS Ridership	Difference	% Difference
TTC	Subway	AM	293,163	273,329	-19,834	-7%
TTC	Streetcar	AM	66,250	55,066	-11,184	-20%
TTC	Bus	AM	274,088	225,551	-48,537	-22%
GO	Train	AM	98,313	91,427	-6,887	-8%
GO	Bus	AM	18,319	12,257	-6,062	-49%
TTC	Subway	PM	363,496	340,647	-22,849	-7%
TTC	Streetcar	PM	87,853	71,859	-15,994	-22%
TTC	Bus	PM	345,623	287,189	-58,434	-20%
GO	Train	PM	100,458	98,144	-2,314	-2%
GO	Bus	PM	20,800	13,155	-7,646	-58%

Trip Assignment: Streetcar Screenlines - AM

- Validating the Model's ability to produce the correct distribution of Streetcar trips on the network

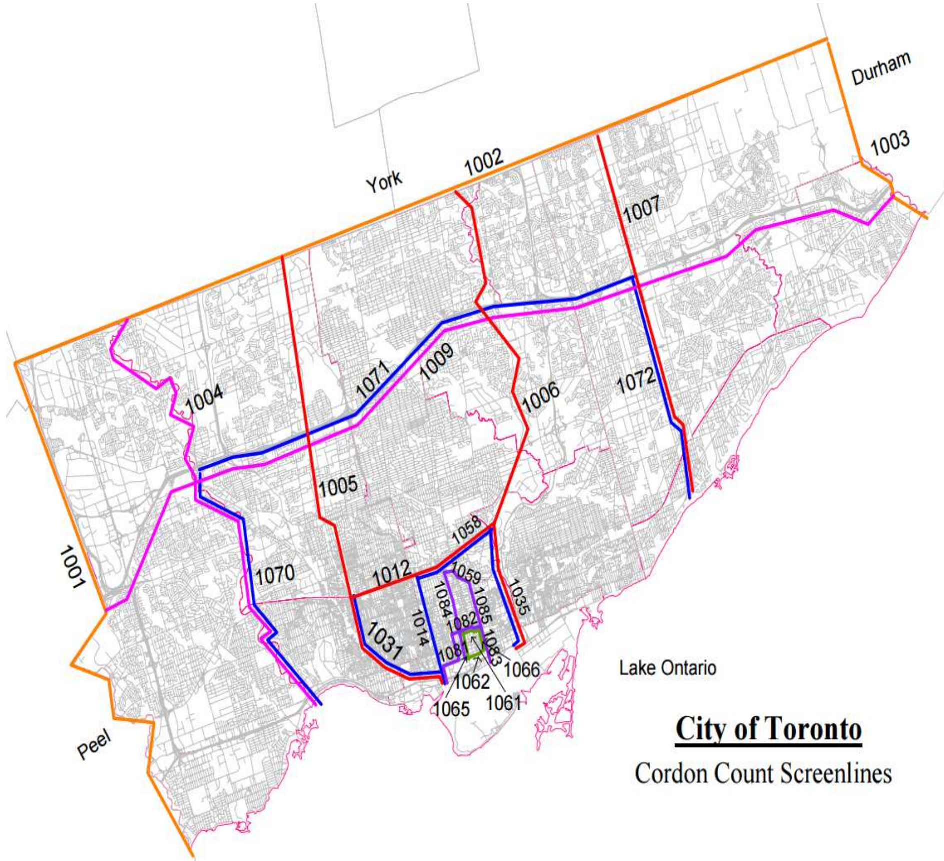
SL	DIR	CCDRS	TTS	Model	Difference vs CCDRS	Difference vs TTS
T1014	IN	6,071	11,261	13,338	7,267	2,077
T1014	OUT	4,557	3,568	3,594	-963	26
T1035	IN	6,516	4,650	6,156	-360	1,506
T1035	OUT	3,000	1,701	1,931	-1,069	230



Trip Assignment: GO Bus Screenlines - AM

- Validating the Model's ability to produce the correct distribution of GO Bus trips on the network

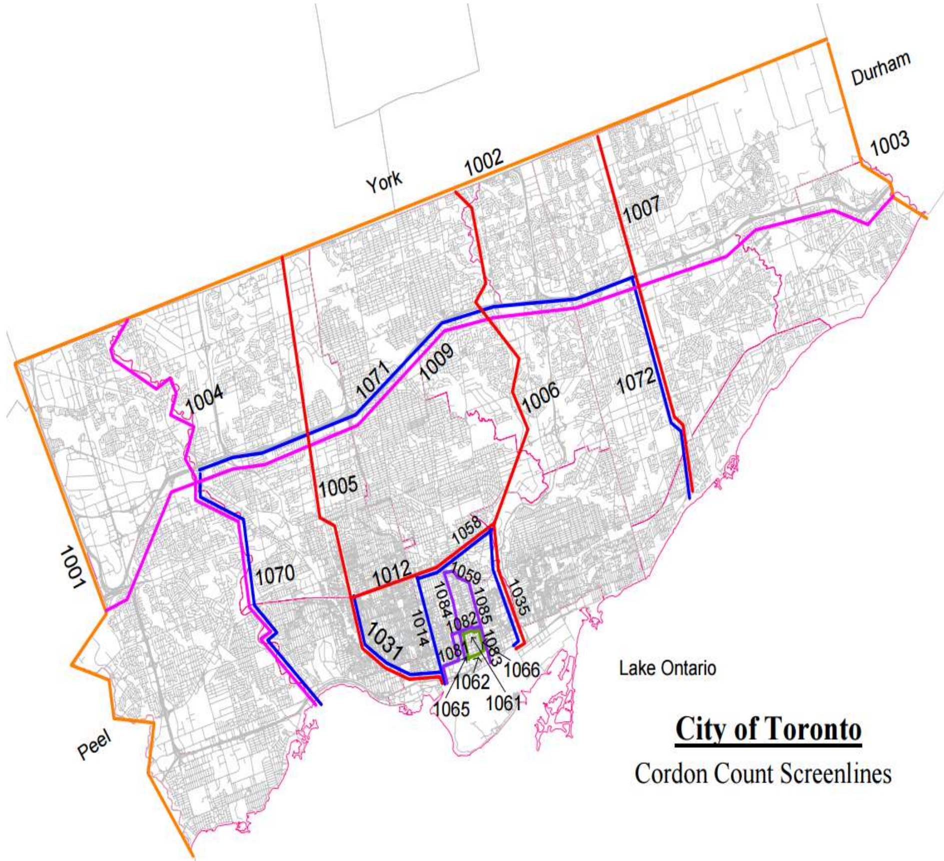
SL	DIR	CCDRS	TTS	Model	Difference vs CCDRS	Difference vs TTS
T1001	IN	639	2,452	3,305	2,666	853
T1001	OUT	1,120	511	1,083	-37	572
T1002	IN	944	4,987	5,542	4,598	555
T1002	OUT	197	473	631	434	158
T1003	IN	630	804	2,386	1,756	1582
T1003	OUT	152	319	500	348	181



Trip Assignment: TTC Bus Screenlines - AM

- Validating the Model's ability to produce the correct distribution of TTC Bus trips on the network

SL	DIR	CCDRS	TTS	Model	Difference vs CCDRS	Difference vs TTS
T1001	IN	455	891	1,466	1,011	575
T1001	OUT	734	1,025	2,300	1,566	1,275
T1002	IN	2783	3,024	4,135	1,352	1,111
T1002	OUT	3454	2,341	3,724	270	1,383
T1014	IN	766	180	299	-467	119
T1014	OUT	393	21	20	-373	-1
T1058	IN	808	365	413	-395	48
T1058	OUT	167	0	4	-163	4
T1035	IN	380	12	38	-342	26
T1035	OUT	226	16	209	-17	193



Trip Assignment: AM Counts at GO Stations

- Validating the Model's ability to produce the correct number of boardings and alightings at various GO Station locations

GO Station	Metrolinx Boardings	Model Boardings	Difference in Boardings	Metrolinx Alightings	Model Alightings	Difference in Alightings
Union (GO)	1314	1883	569	70843	69863	-980
Ajax	3624	4818	1194	116	467	351
Whitby	3966	4360	394	140	283	143
Bramalea	2349	3841	1492	78	729	651
Clarkson	3526	4522	996	238	1002	764
Streetsville	2756	3452	696	9	93	84
Mount Joy	1091	1553	462	2	91	89
Milton	1731	1793	62	0	0	0
Richmond Hill	2794	4084	1290	0	0	0

Trip Assignment: Transit Volumes

- To validate the Model's ability to produce the correct transit volume in the AM period, we have extracted a couple of key transit locations in the network

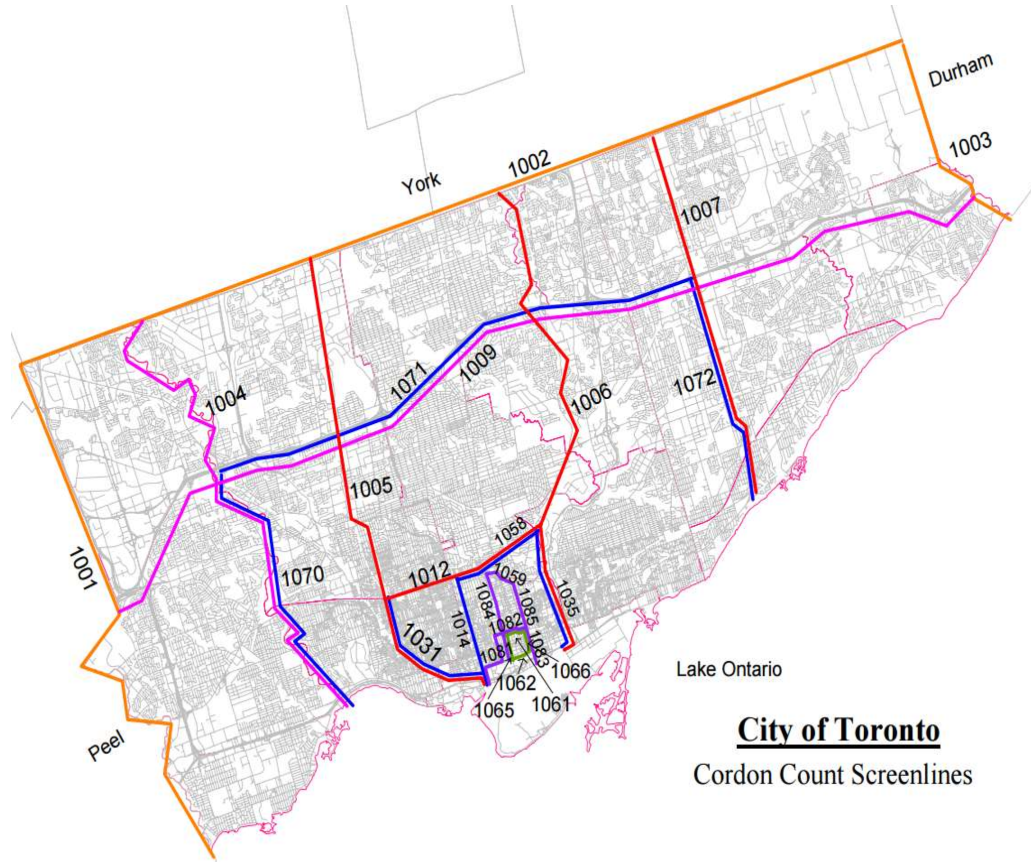
Key Location	Model Peak Hour Volume	Observed Peak Hour Volume	Difference	% Difference
South of Bloor (SB)	27,527	27,105	422	1.6%
South of St. George (SB)	23,223	20,994	2,229	10.6%

Key Location	Model: Total Volume	Observed: Total Volume	Difference	% Difference
Union Station (Inbound from the West)	45,884	42,314	3,570	8.4%
Union Station (Inbound from the East)	23,979	28,529	-4,550	-16%

Trip Assignment: Auto Screenlines – AM

- Validating the Model's ability to produce the correct distribution of Auto trips on the network

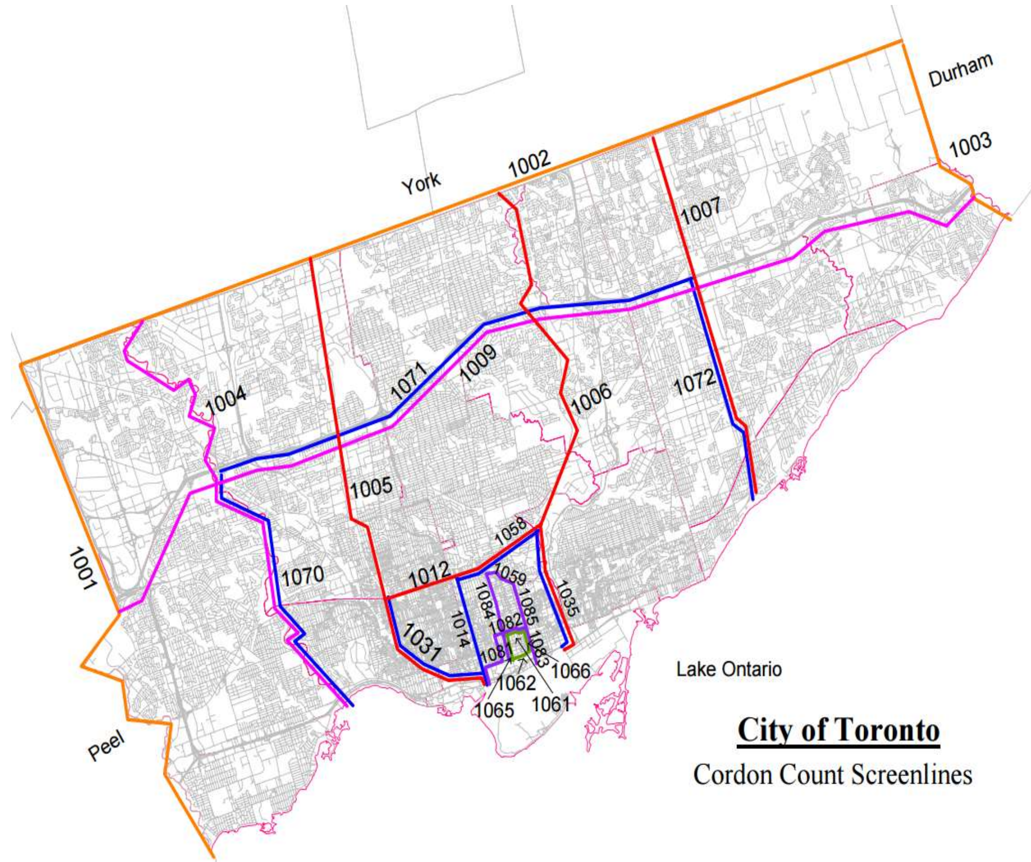
SL	DIR	CCDRS	TTS	Model	Difference vs CCDRs	Difference vs TTS
T1001	IN	40,759	39,878	37,895	-2,864	-1,983
T1001	OUT	34,014	32,085	29,923	-4,091	-2,162
T1002	IN	60,257	56,870	50,407	-9,850	-6,464
T1002	OUT	40,130	33,910	28,785	-11,345	-5,125
T1003	IN	16,228	18,560	16,400	172	-2,160
T1003	OUT	6,075	5,577	4,217	-1,858	-1,360
T1014	IN	17,323	17,388	18,546	1,223	1,158
T1014	OUT	11,375	7,625	8,640	-2,735	1,015
T1058	IN	7,879	6,376	6,643	-1,236	267
T1058	OUT	4,336	2,427	4,111	-225	1,684
T1035	IN	16,831	16,175	16,053	-778	-122
T1035	OUT	12,208	6,820	6,559	-5,649	-261



Trip Assignment: Auto Screenlines – PM

- Validating the Model's ability to produce the correct distribution of Auto trips on the network

SL	DIR	CCDRS	TTS	Model	Difference vs CCDRs	Difference vs TTS
T1001	IN	37,474	34,592	40,541	-2,864	5948
T1001	OUT	45,987	45,019	47,662	-4,091	2644
T1002	IN	49,879	40,482	40,733	-9,850	251
T1002	OUT	61,834	61,542	52,449	-11,345	-9093
T1003	IN	7,124	8,025	8,118	172	93
T1003	OUT	15,887	19,890	15,832	-1,858	-4057
T1014	IN	15,627	11,442	13,268	1,223	1825
T1014	OUT	15,984	20,204	19,608	-2,735	-596
T1058	IN	4,881	4,347	5,551	-1,236	1204
T1058	OUT	7,699	7,800	6,953	-225	-846
T1035	IN	13,687	9,669	10,404	-778	735
T1035	OUT	17,556	20,297	17,627	-5,649	-2669



Trip Assignment: Auto VKTs

- Validating the Model's ability to produce the correct number of vehicle kilometers travelled

Time Period	Model VKTs	TTS VKTs	Difference	% Difference
AM	28,156,990	32,391,048	- 4,234,058	-13%
MD	23,809,360	28,908,162	- 5,098,802	-18%
PM	36,109,580	43,018,177	- 6,908,597	-16%
EV	17,667,470	16,545,937	1,121,533	7%

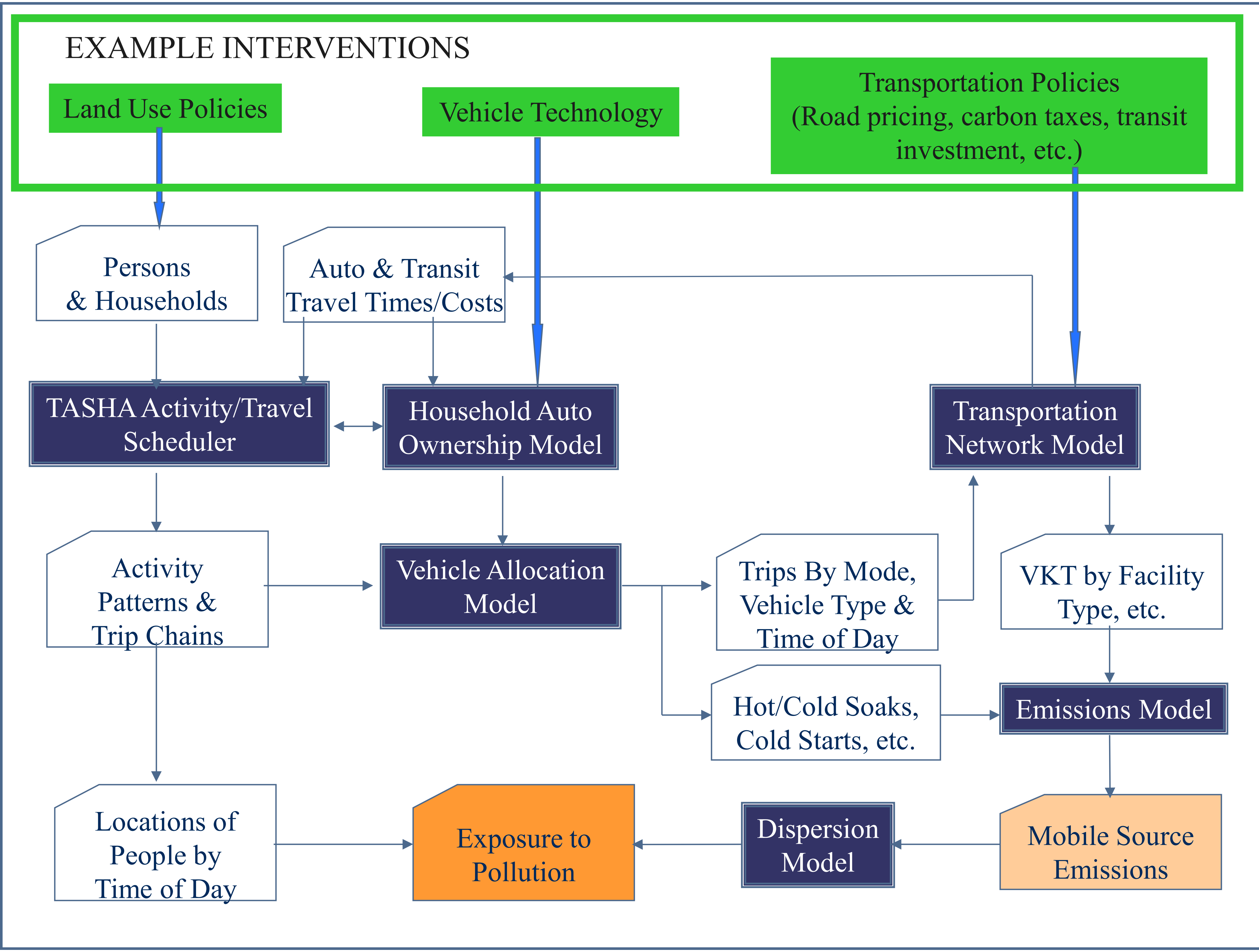
Example Applications

1. Environmental modelling.
2. COVID-19 modelling.
3. Economic benefits of transit.

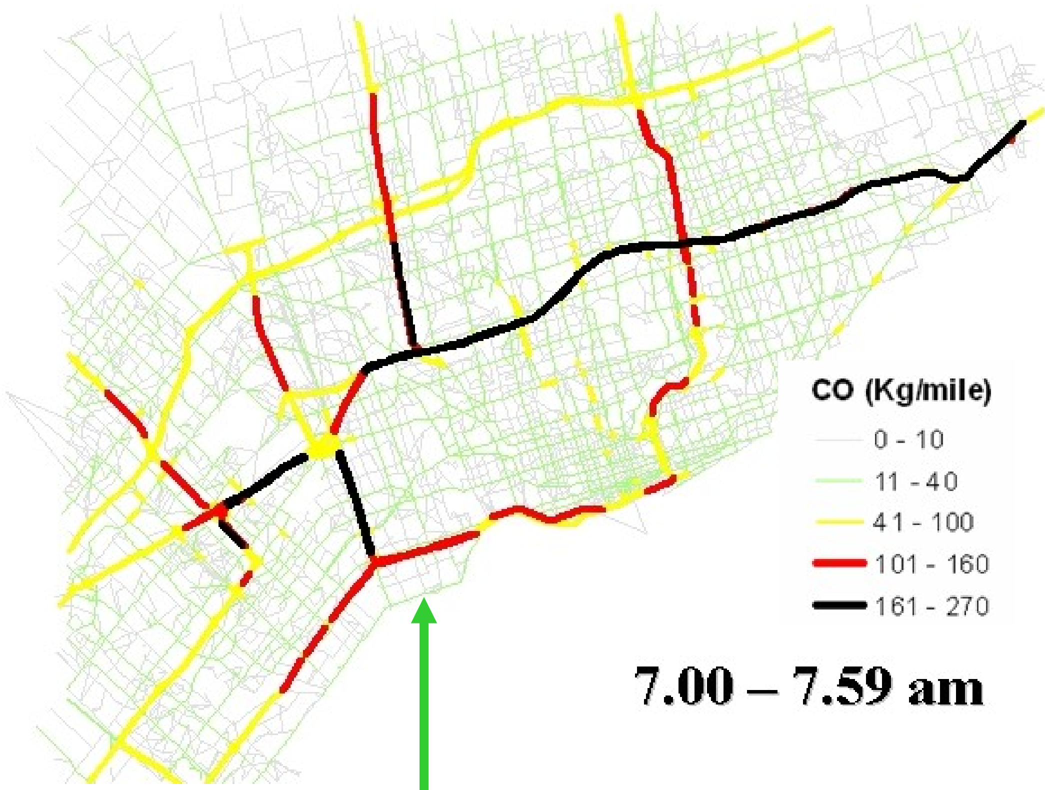
Example 1: Environmental Modelling

- GTAModel outputs of road link speeds & volumes lined with:
- MOBILE6.2C emissions model (link emissions by type by link by time of day)
- CALMET meteorological model
- CALPUFF dispersion model (pollutant concentrations by zone by time of day)

→ **Dynamic population exposure to pollution by zone by time of day!!**

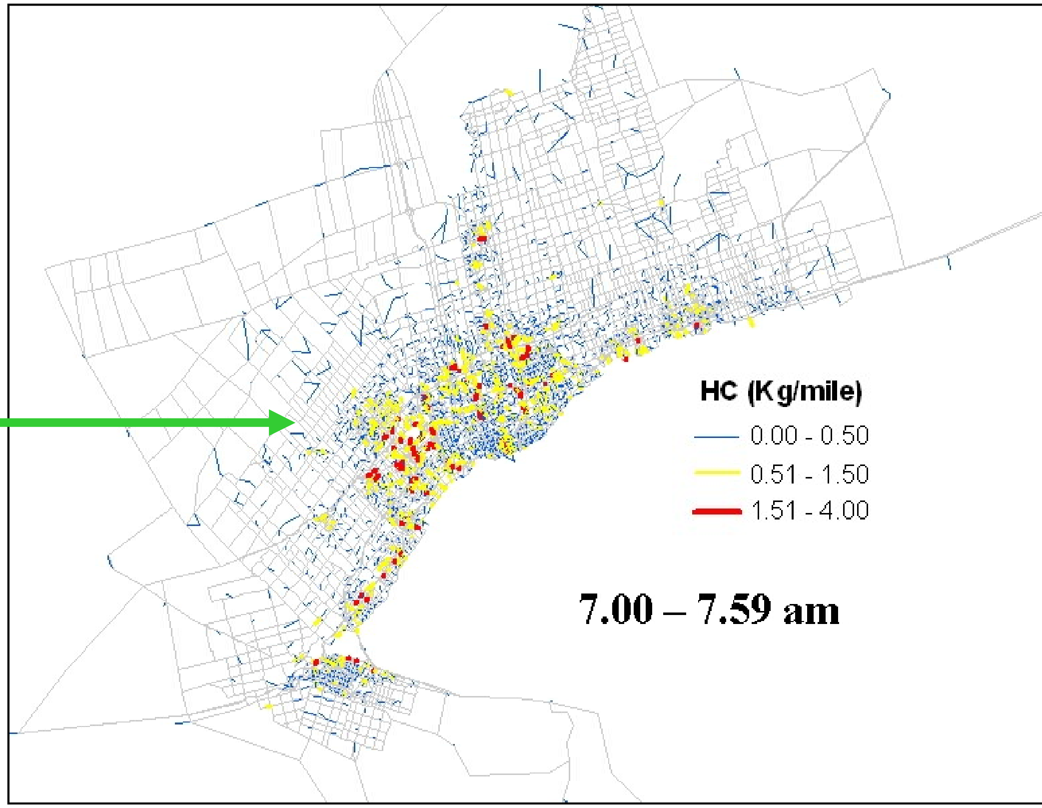

EXAMPLE INTERVENTIONS
Land Use Policies
Vehicle Technology
Transportation Policies (Road pricing, carbon taxes, transit investment, etc.)
Persons & Households
Auto & Transit Travel Times/Costs
TASHA Activity/Travel Scheduler
Household Auto Ownership Model
Transportation Network Model
Activity Patterns & Trip Chains
Vehicle Allocation Model
Trips By Mode, Vehicle Type & Time of Day
VKT by Facility Type, etc.
Hot/Cold Soaks, Cold Starts, etc.
Emissions Model
Locations of People by Time of Day
Exposure to Pollution
Dispersion Model
Mobile Source Emissions

Auto Emissions by location and time of day

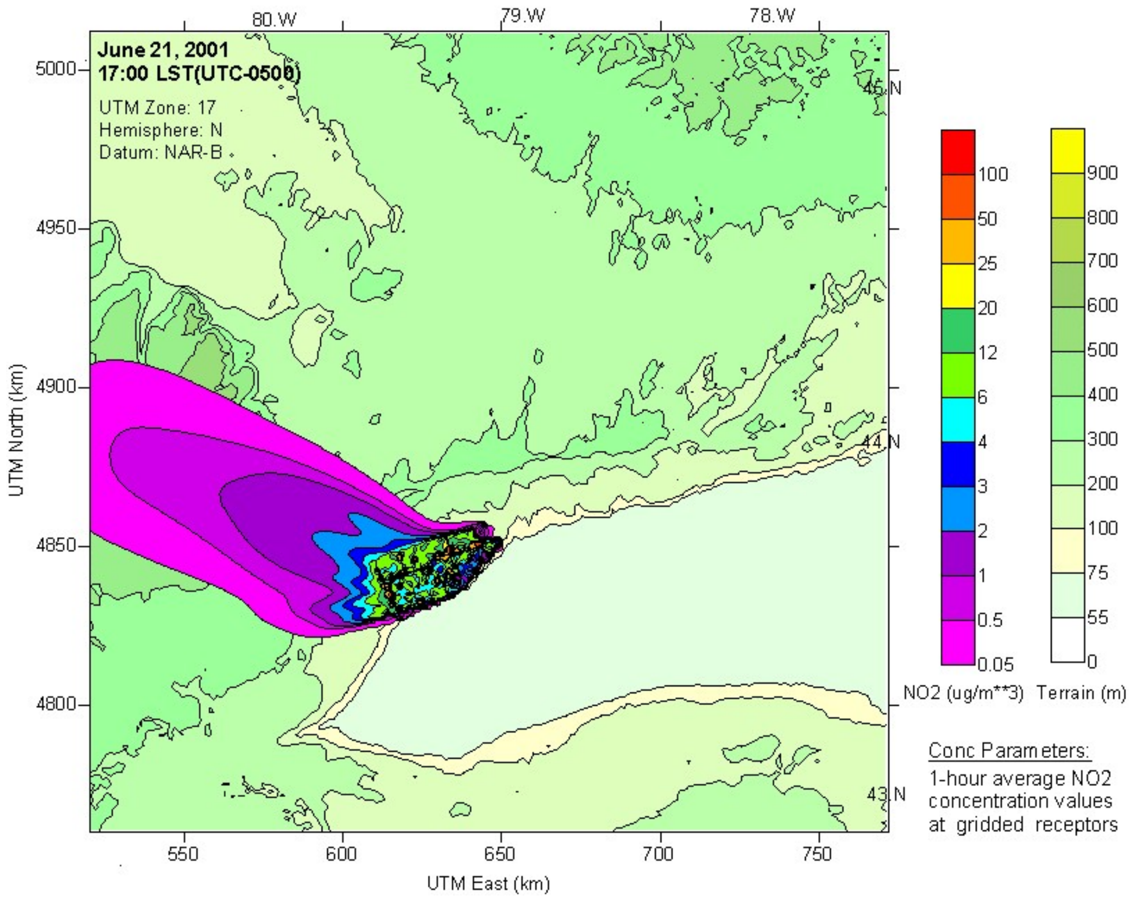


Link-based running emissions by time of day

Zone-based soak emissions by time of day

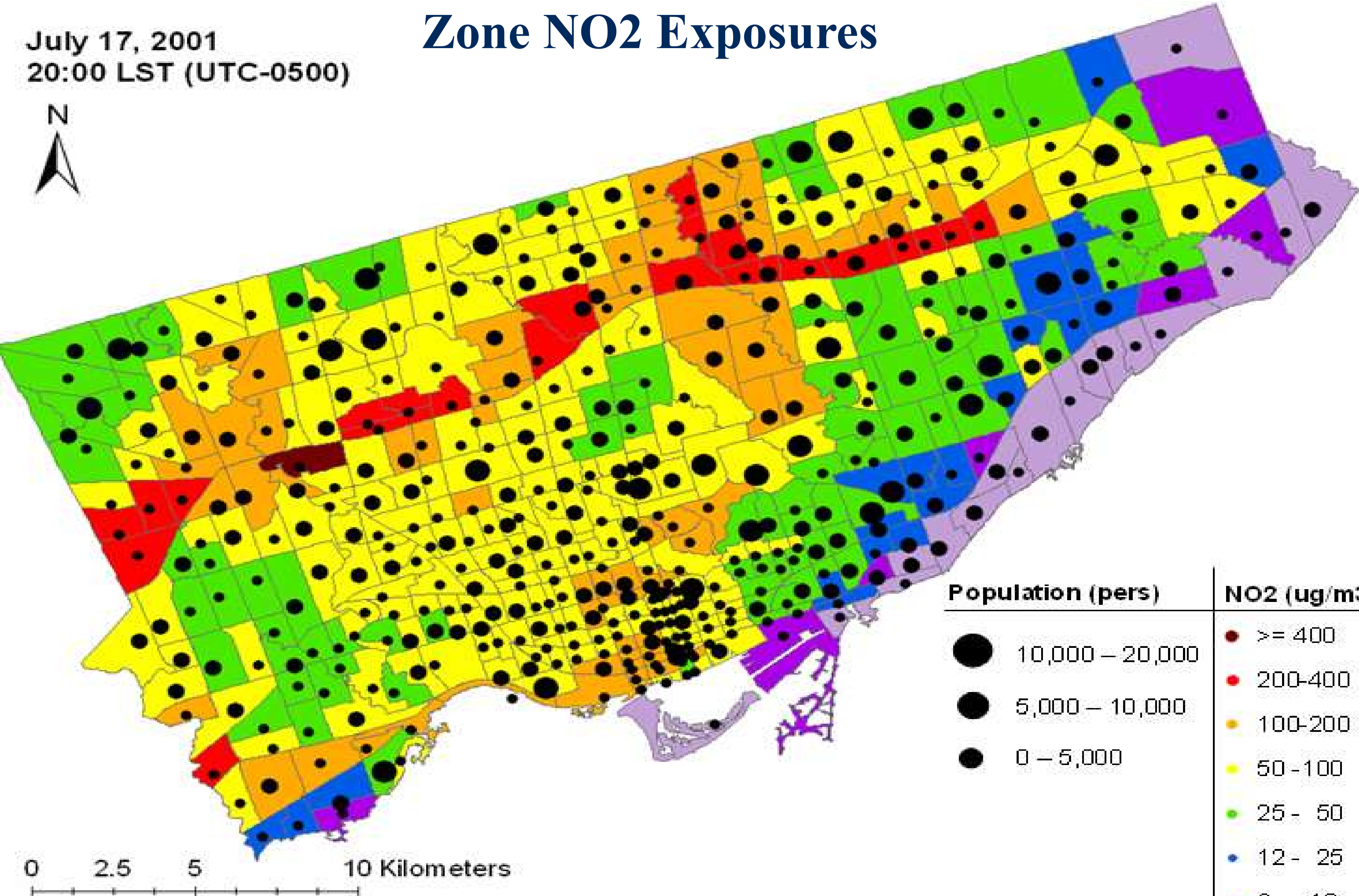


Dispersion of Emission Concentrations



Zone NO2 Exposures

July 17, 2001
20:00 LST (UTC-0500)



Population (pers)	NO2 (ug/m3)	% pop
10,000 – 20,000	>= 400	0.2
5,000 – 10,000	200-400	4.2
0 – 5,000	100-200	15.2
	50 - 100	48.0
	25 - 50	22.0
	12 - 25	5.4
	6 - 12	1.3
	0 - 6	3.6

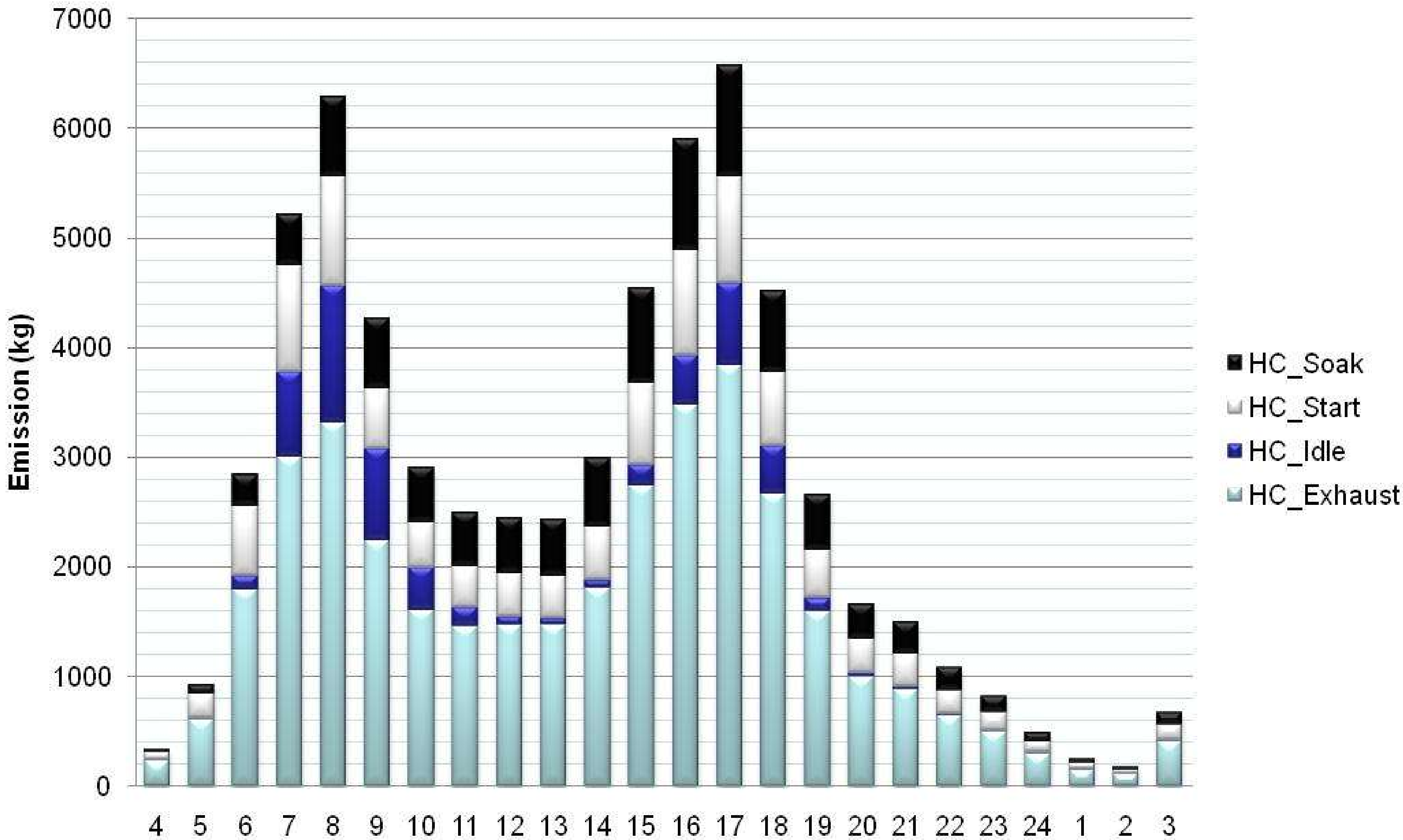
TASHA-MATSIM

More recently TASHA has been linked with MATSIM, an agent-based micro/meso-scopic network simulator.

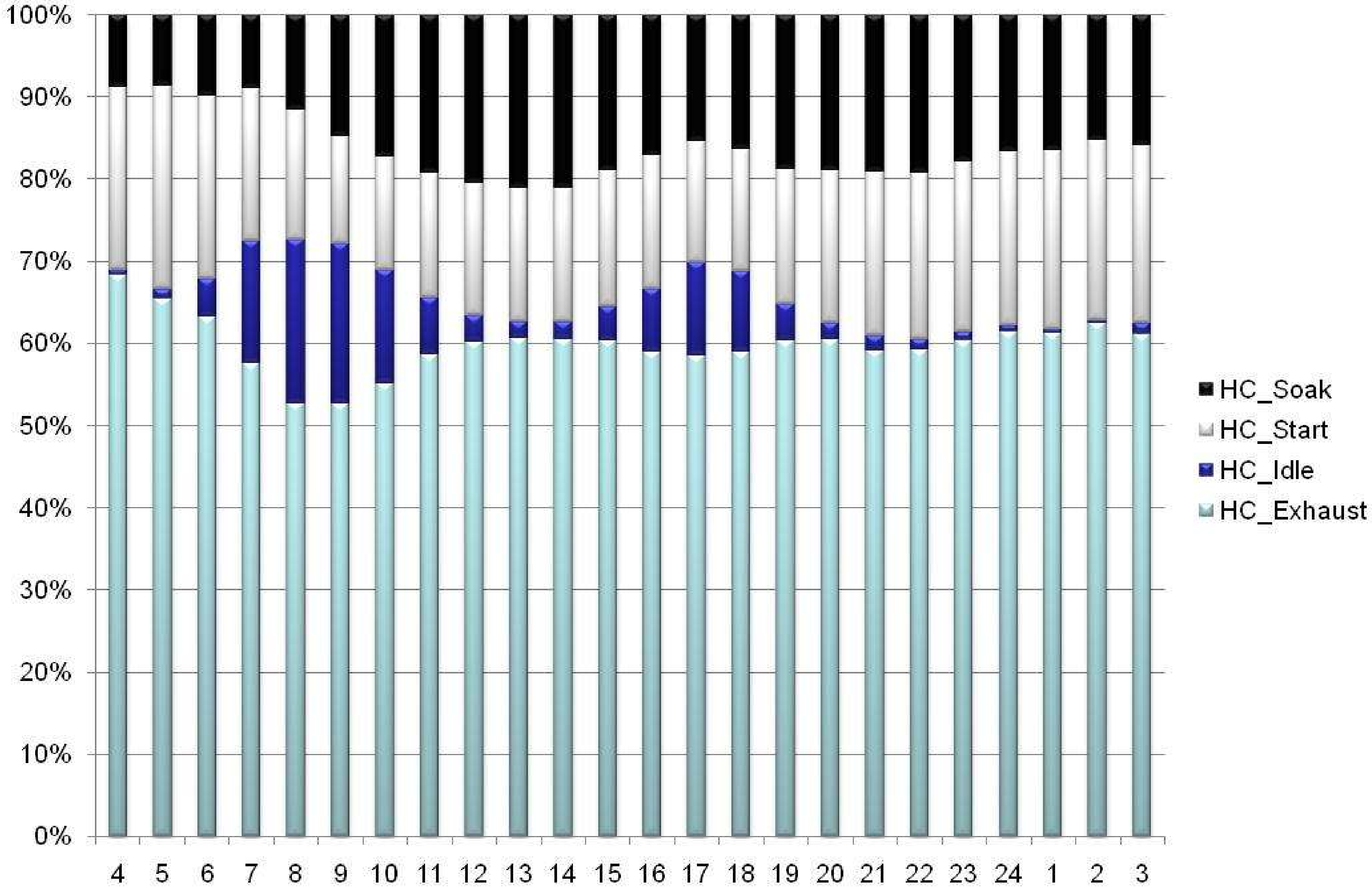
MATSIM allows us to keep track of individual agents as they travel through the network so we can accumulate their emissions (and, eventually, their exposure to pollutants).

It also provides us with rudimentary vehicle dynamics, allowing a more detailed calculation of vehicle emissions.

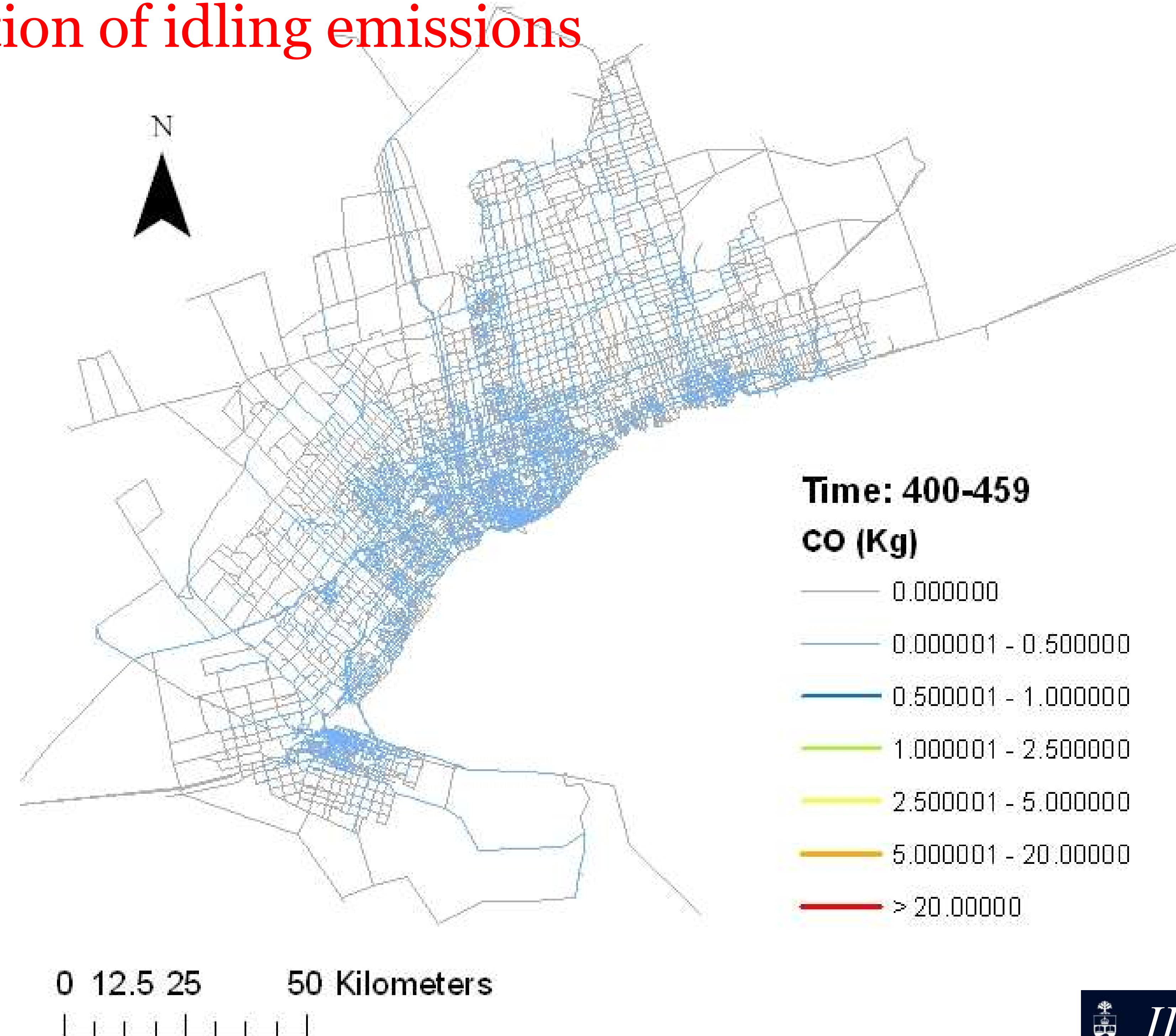
Emissions by hour



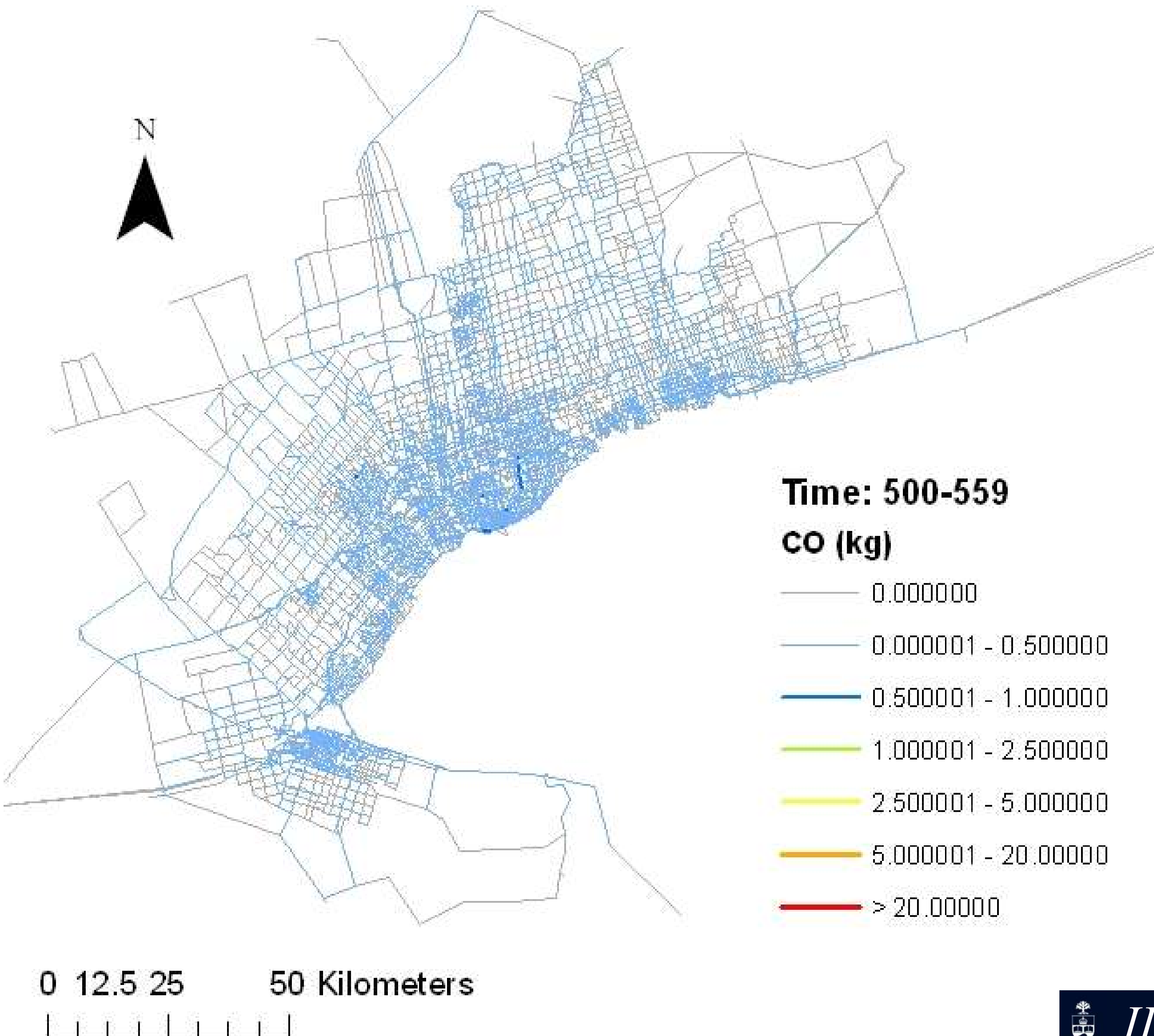
Emissions by hour



Evolution of idling emissions

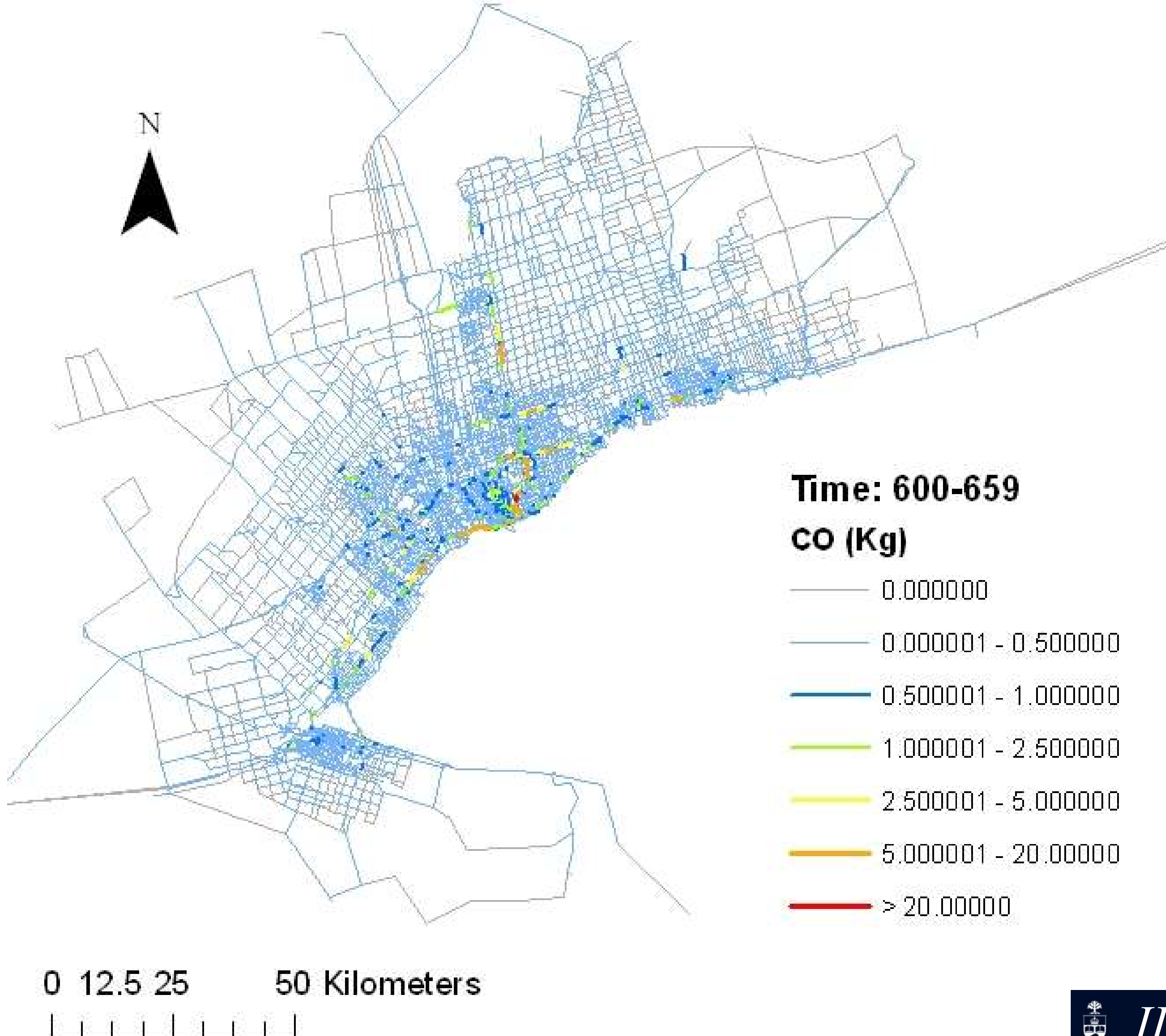


ILUTE

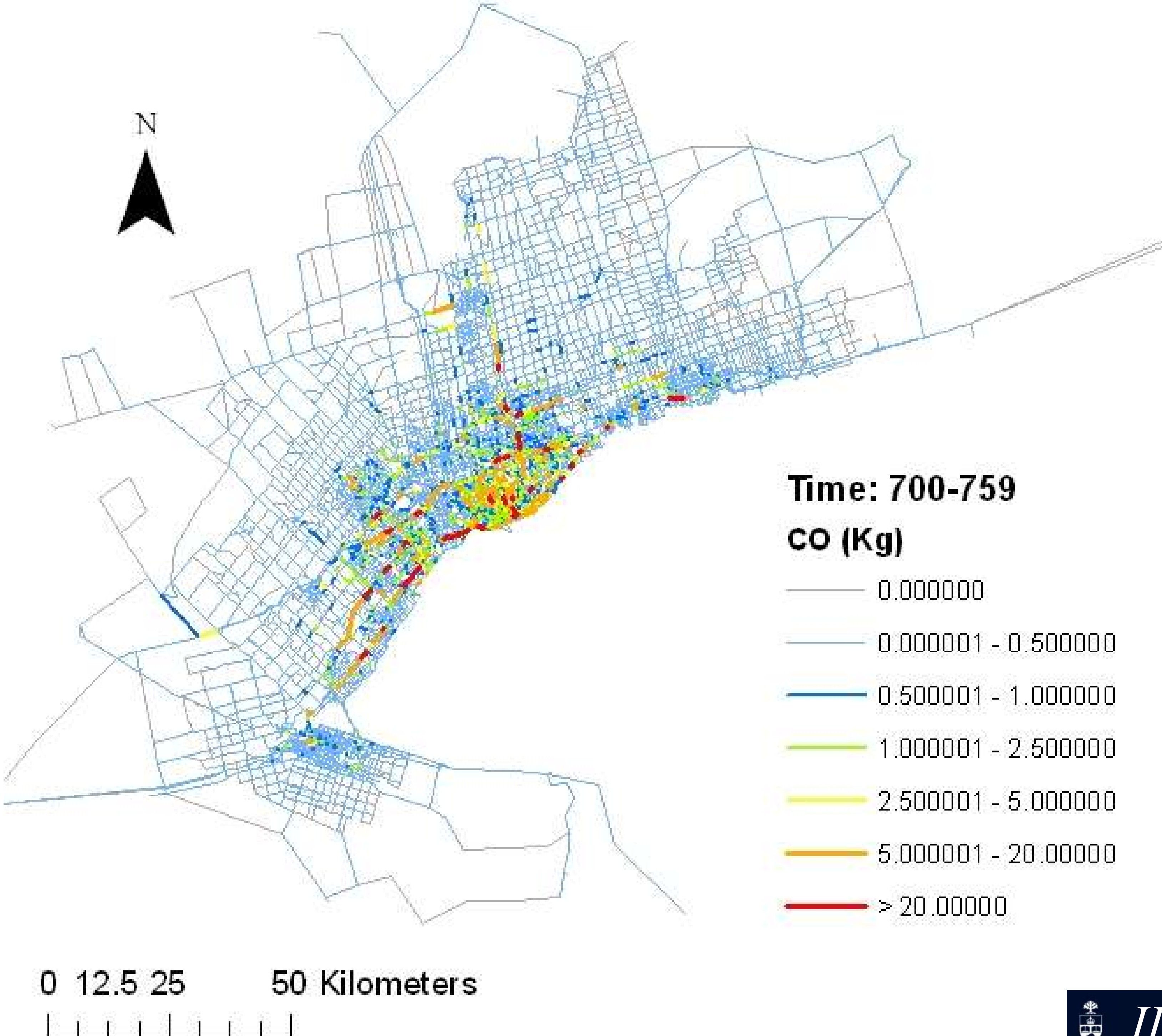


N
Time: 500-559
CO (kg)
0.000000
0.000001 - 0.500000
0.500001 - 1.000000
1.000001 - 2.500000
2.500001 - 5.000000
5.000001 - 20.00000
> 20.00000
0 12.5 25 50 Kilometers

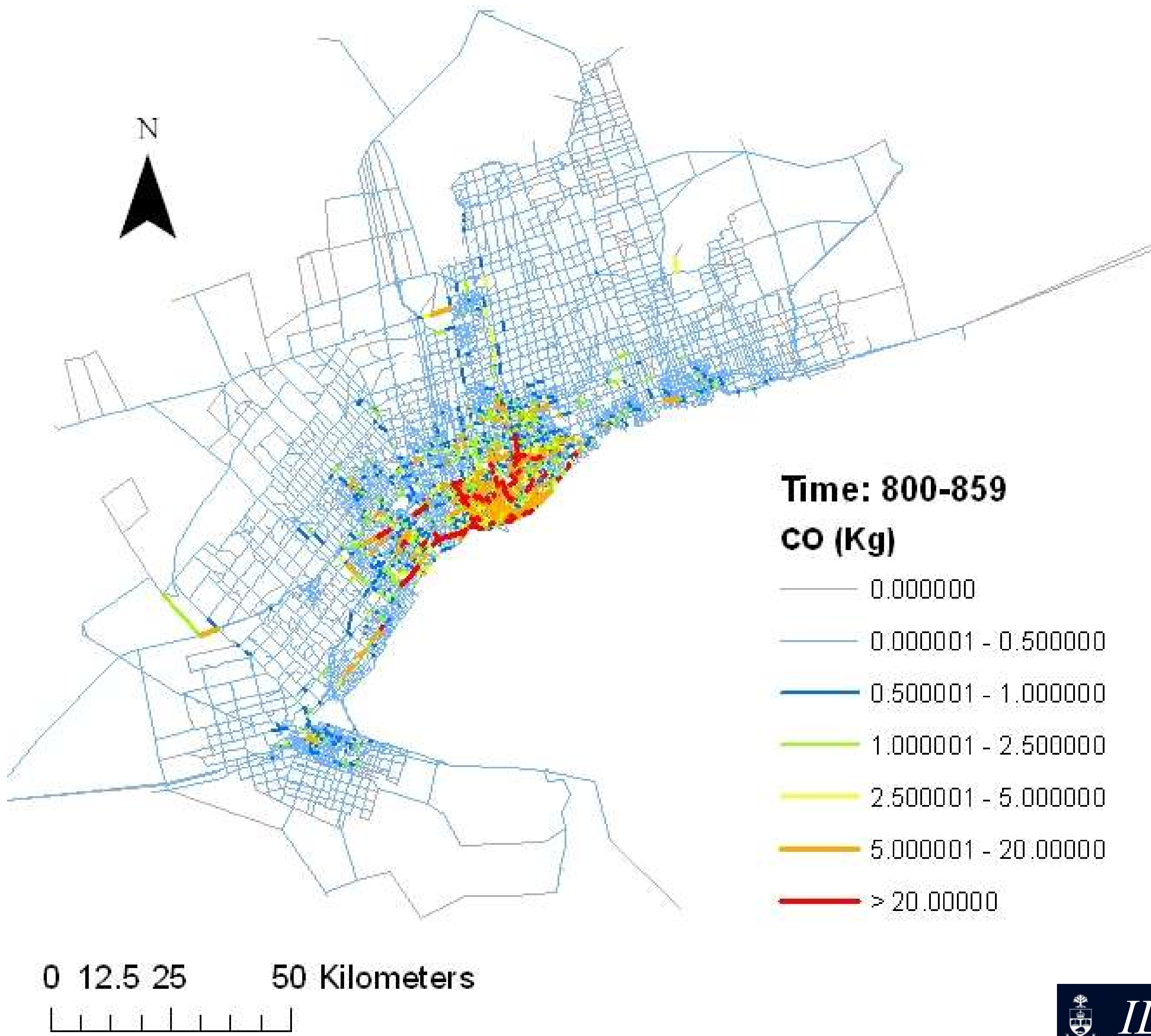
ILUTE


N
Time: 600-659
CO (Kg)
0.000000
0.000001 - 0.500000
0.500001 - 1.000000
1.000001 - 2.500000
2.500001 - 5.000000
5.000001 - 20.00000
> 20.00000
0 12.5 25 50 Kilometers

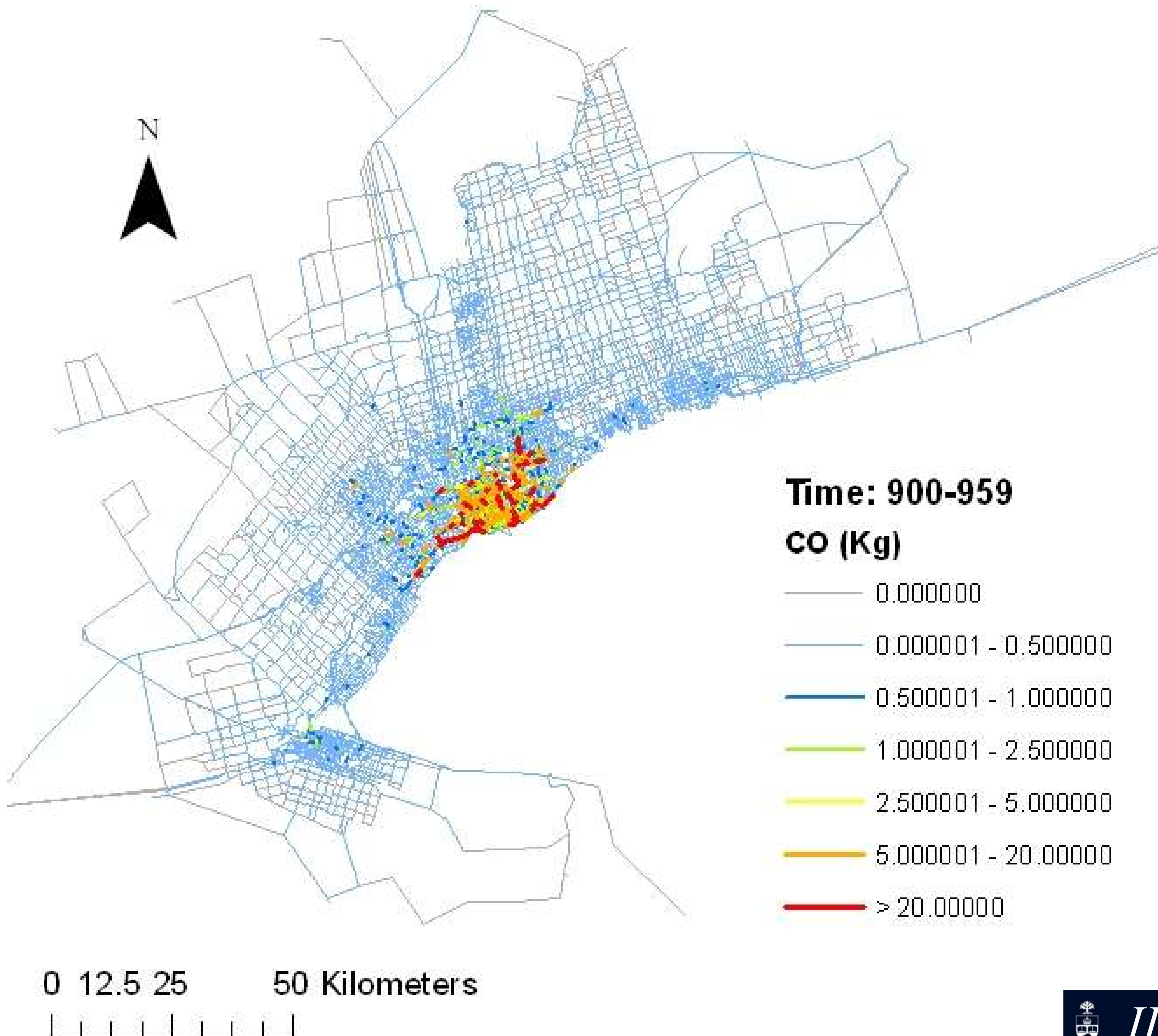
ILUTE


N
Time: 700-759
CO (Kg)
0.000000
0.000001 - 0.500000
0.500001 - 1.000000
1.000001 - 2.500000
2.500001 - 5.000000
5.000001 - 20.00000
> 20.00000
0 12.5 25 50 Kilometers

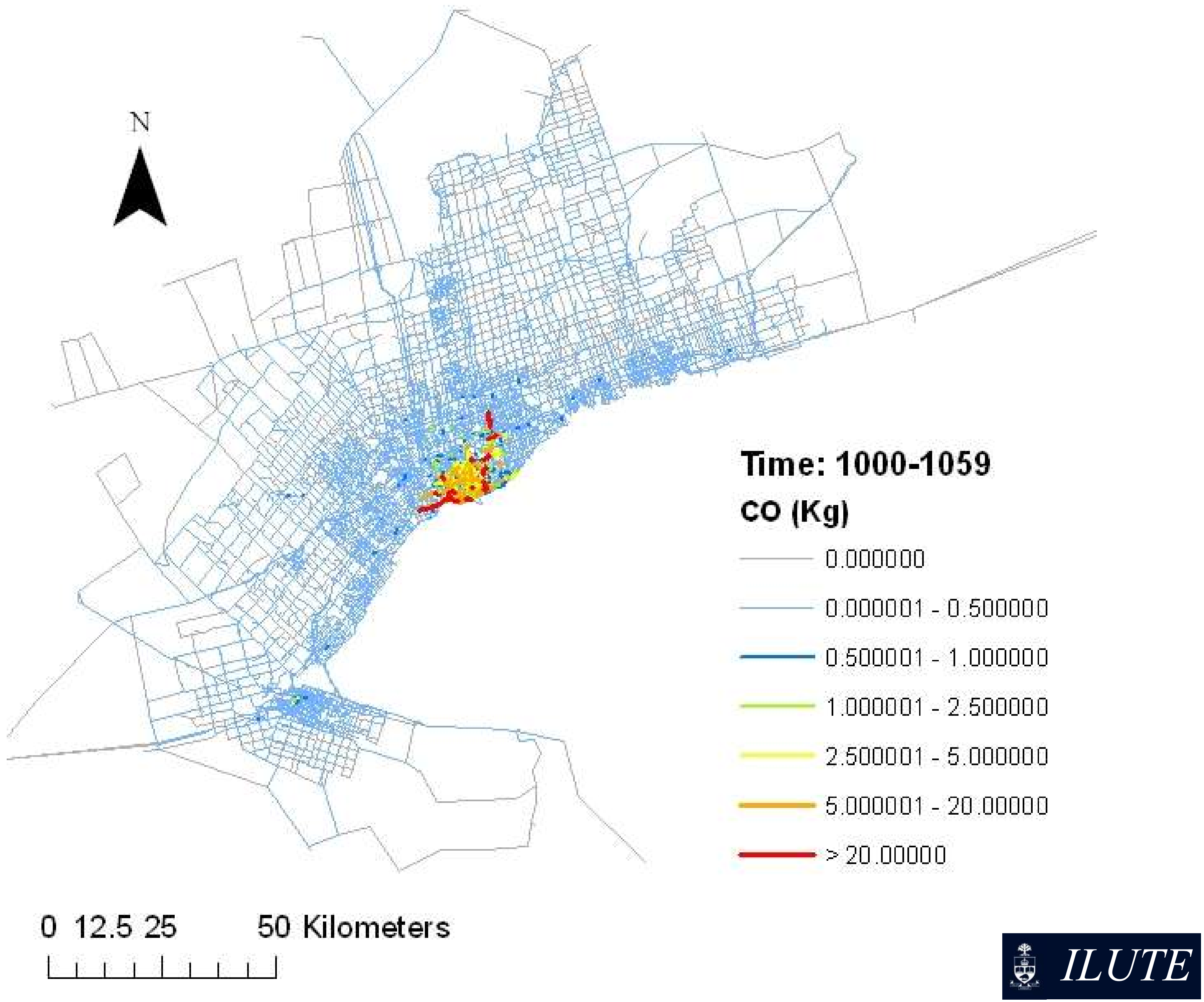
ILUTE

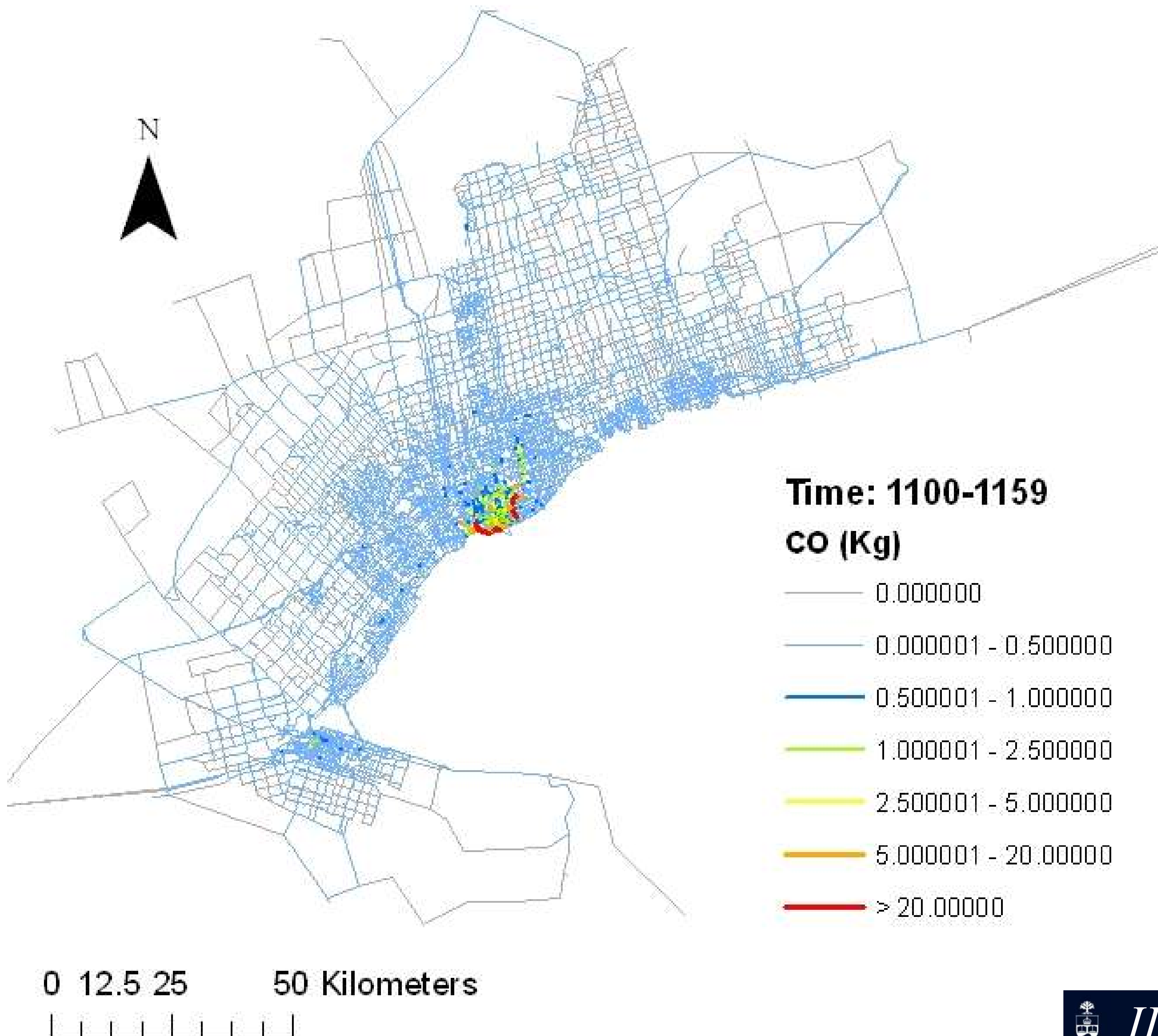

N
Time: 800-859
CO (Kg)
0.000000
0.000001 - 0.500000
0.500001 - 1.000000
1.000001 - 2.500000
2.500001 - 5.000000
5.000001 - 20.00000
> 20.00000
0 12.5 25 50 Kilometers

ILUTE

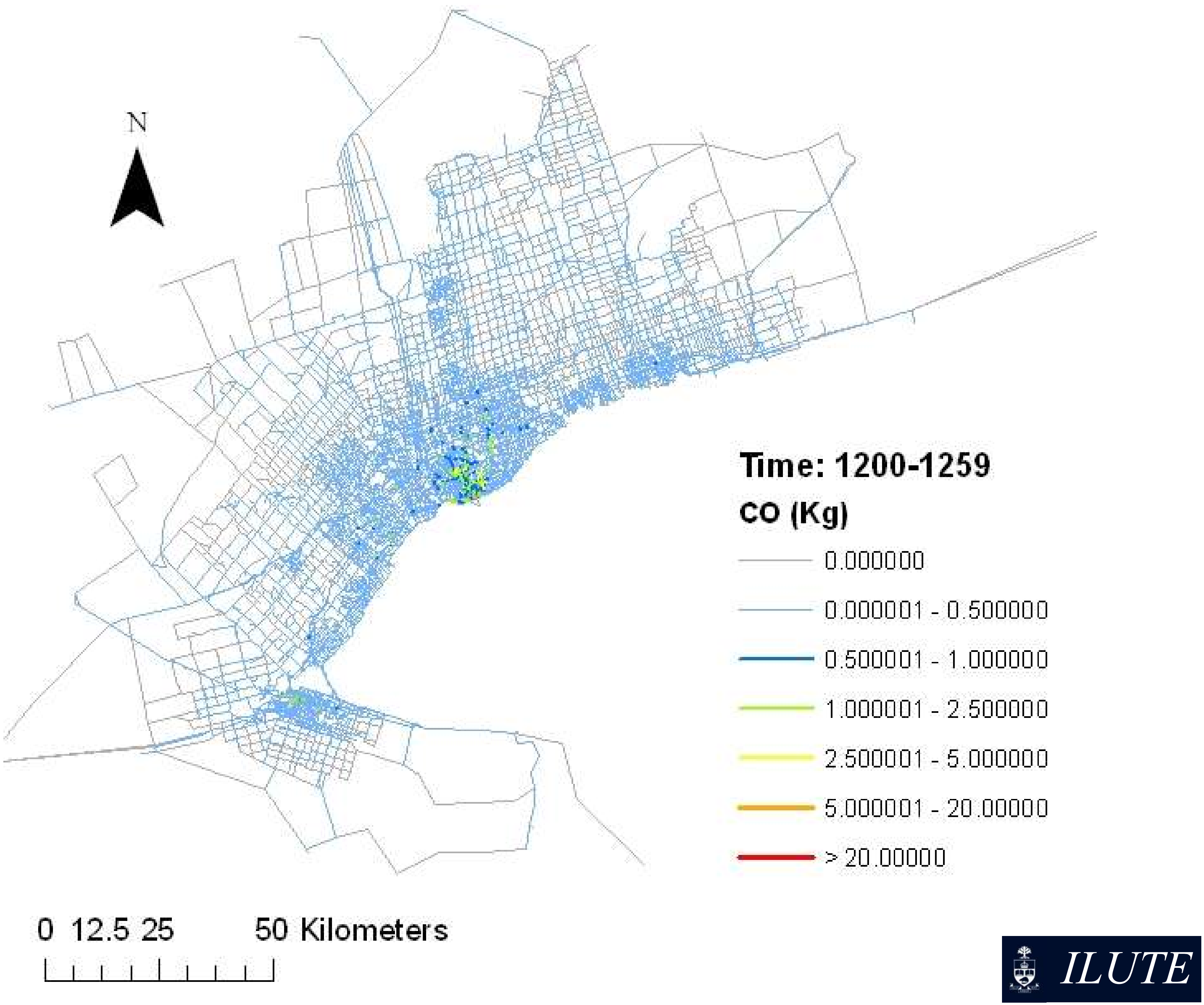

N
Time: 900-959
CO (Kg)
0.000000
0.000001 - 0.500000
0.500001 - 1.000000
1.000001 - 2.500000
2.500001 - 5.000000
5.000001 - 20.00000
> 20.00000
0 12.5 25 50 Kilometers

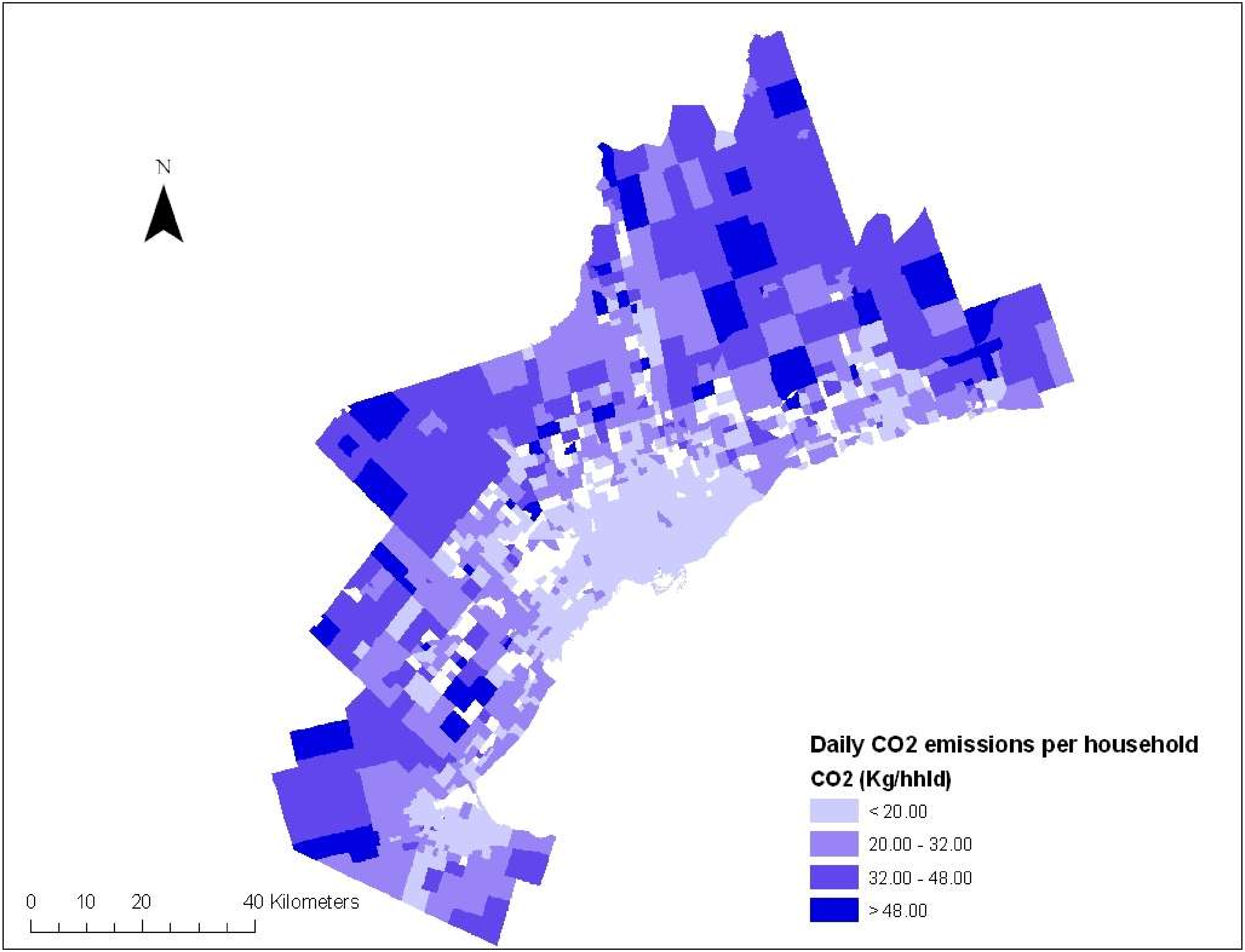
ILUTE


N
Time: 1000-1059
CO (Kg)
0.000000
0.000001 - 0.500000
0.500001 - 1.000000
1.000001 - 2.500000
2.500001 - 5.000000
5.000001 - 20.00000
> 20.00000
0 12.5 25 50 Kilometers
ILUTE

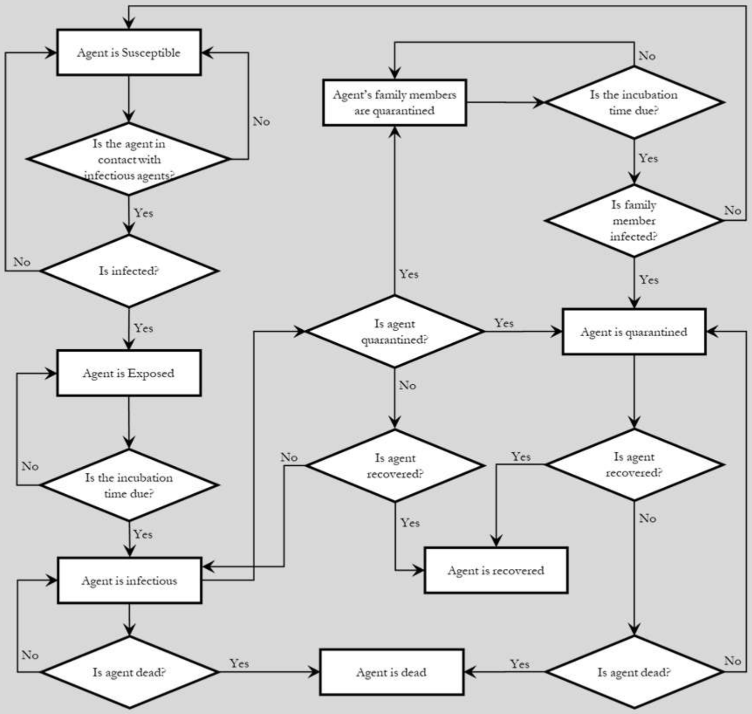

N
Time: 1100-1159
CO (Kg)
0.000000
0.000001 - 0.500000
0.500001 - 1.000000
1.000001 - 2.500000
2.500001 - 5.000000
5.000001 - 20.00000
> 20.00000
0 12.5 25 50 Kilometers

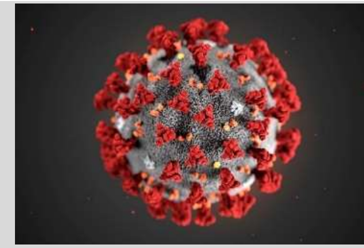
ILUTE

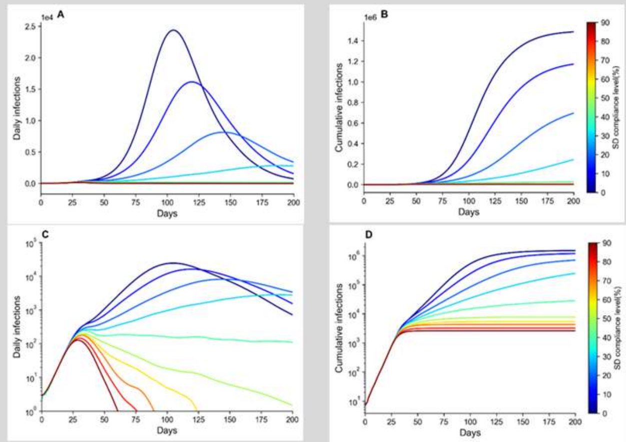

N
Time: 1200-1259
CO (Kg)
0.000000
0.000001 - 0.500000
0.500001 - 1.000000
1.000001 - 2.500000
2.500001 - 5.000000
5.000001 - 20.00000
> 20.00000
0 12.5 25 50 Kilometers
ILUTE


N
0 10 20 40 Kilometers
Daily CO2 emissions per household
CO2 (Kg/hhld)
< 20.00
20.00 - 32.00
32.00 - 48.00
> 48.00

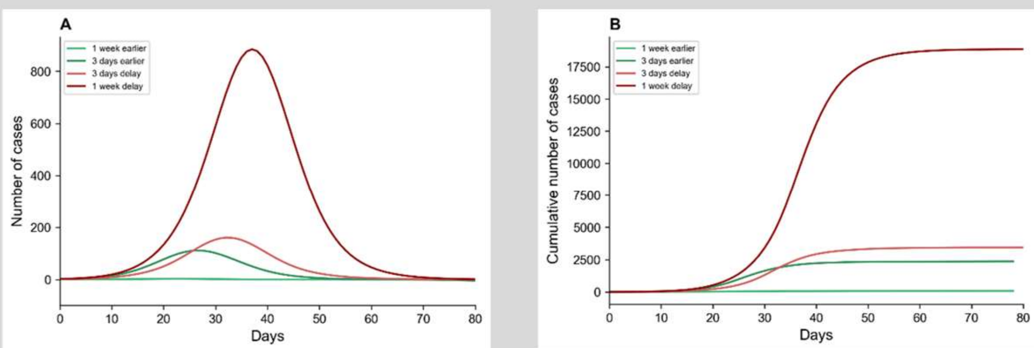
Example 2: ABM Modelling of COVID-19 Spread in Sydney



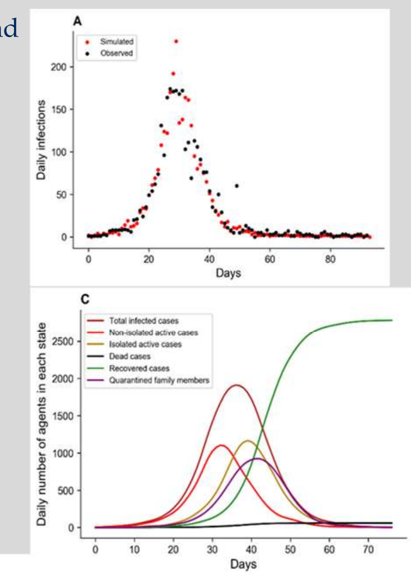


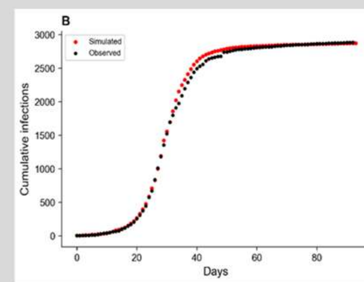


A comparison of different Social Distancing compliance levels.
(a) daily number of cases (linear),
(b) cumulative cases (linear),
(c) daily number of cases (logarithmic), and
(d) cumulative cases (logarithmic).



A comparison between the influence of implementing the lockdown earlier (in greenish) and later (in reddish) while all the strategies are in place as in the base case scenario. (A) Daily number of cases, and (B) Cumulative number of cases.





Performance of the calibrated SydneyGMA -based disease spreadi model in reproducing the daily number of cases (A), the cumulat number of cases (B) and the number of cases at each state of t pandemic modelling (C) in the base-case scenario.

Example 3: Economic Benefits of Transit Investment

Every $1 invested in TTC yields approx. $7 in benefits

	Operating (Return to 100% Service [2019 Proxy])		Capital (Line 2 Shut Down)		Average Benefit / $1
	Benefits in $ (Millions)	Per / $1	Disbenefits in $ (Millions)	Per / $1	
Economic & Regional Development					
GDP (Added Value)	$17.7	$0.57	$415.0	$1.02	**$0.80**
Quality of Life					
Transit Travel Time Savings	$436.8	$4.55	$1,694.4	$4.16	**$4.36**
Auto Operating & Ownership Cost Savings	$203.2	$2.12	$247.2	$0.61	**$1.36**
Auto Travel Time Savings	$24.0	$0.25	$19.2	$0.05	**$0.15**
Road Accident Reductions	$17.3	$0.18	$20.2	$0.05	**$0.11**
Health Outcome Improvements	$7.4	$0.08	$32.5	$0.08	**$0.08**
GHG Reduction	$2.3	$0.02	$7.3	$0.02	**$0.02**
Sub-Total Quality of Life Benefits	**$690.9**	**$7.20**	**$2,020.8**	**$4.97**	**$6.08**
Total Benefits	**$708.6**	**$7.77**	**$2,435.8**	**$5.99**	**$6.88**

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