

# Experiments in Using Agent-Based Microsimulation to Model COVID-19 & Other Urban Disruptions



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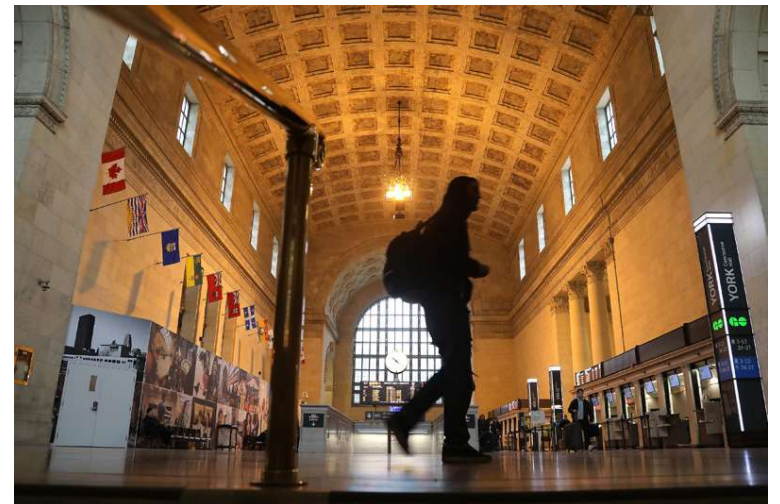


UNIVERSITY OF TORONTO  
FACULTY OF APPLIED SCIENCE & ENGINEERING  
Transportation Research Institute

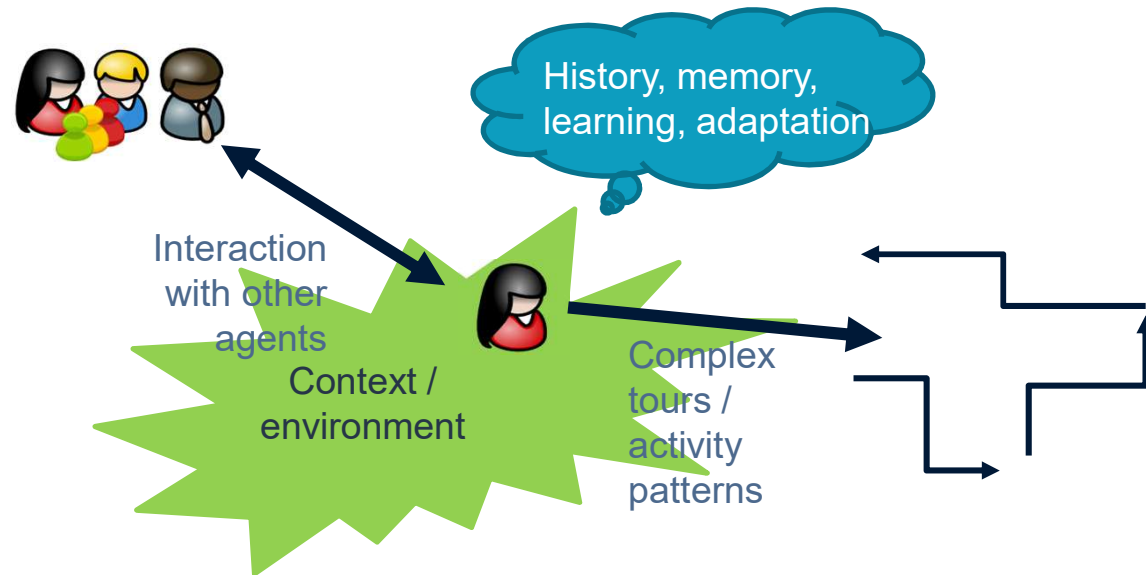
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# Presentation Outline

- TASHA & GTAModel V4.
- Application 1: Testing COVID-19 control strategies in Sydney
- Application 2: Testing transferability to other cities/countries.
- Application 3: GTAModel C19



# TASHA: Travel/Activity Scheduler for Household Agents



TASHA is an agent-based microsimulation model of daily activity & travel generation & scheduling.

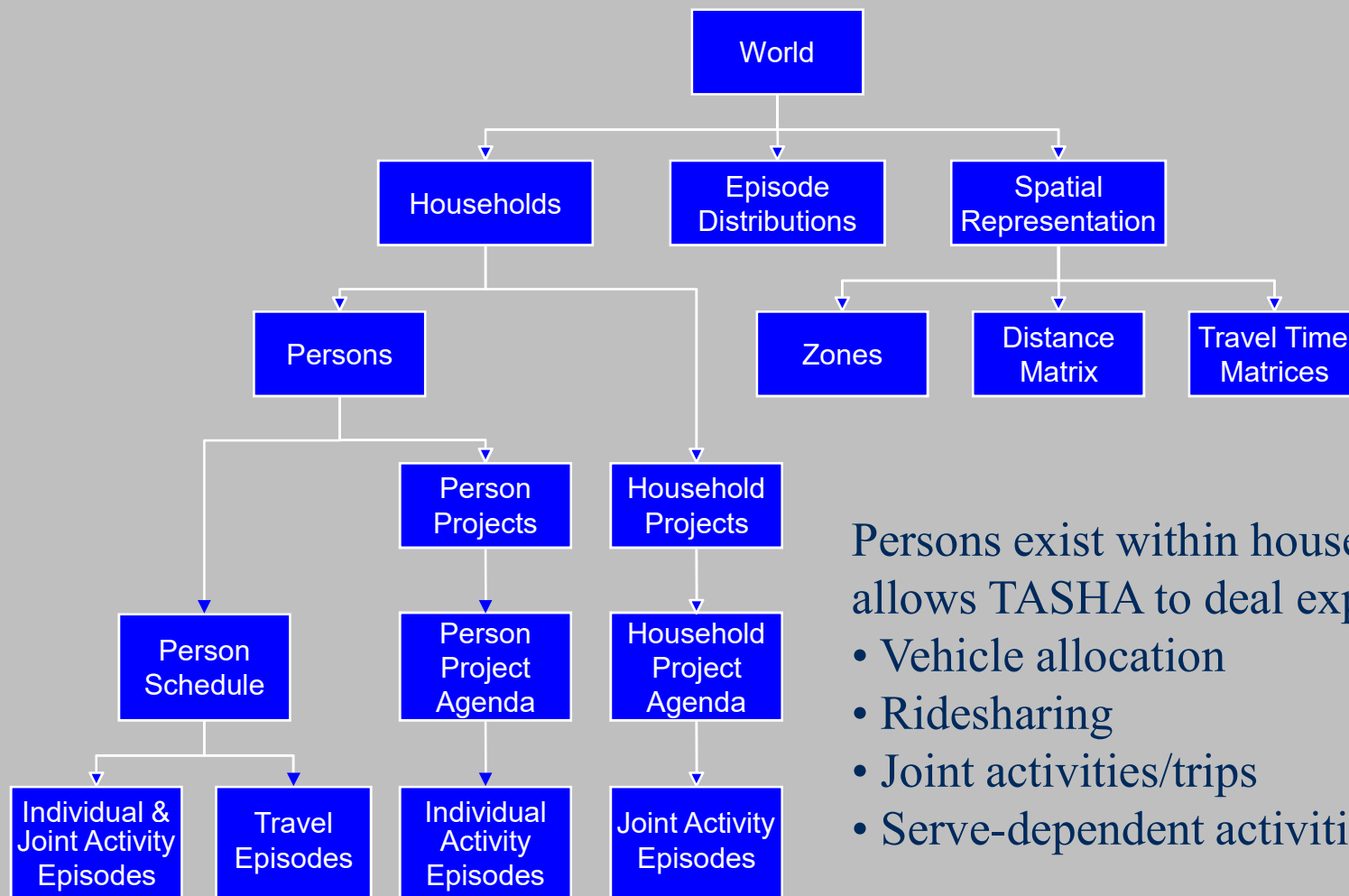


# Key TASHA Features

- **Activity-based:**
  - Travel is a “derived demand”. If we are to predict travel behaviour, we need to understand **why** people are travelling, **what** the activities are in which they need to participate, **where**, **when**.
- **Tour-based:**
  - We organize our day around the pattern of activities in which we need to engage. Within-tour constraints need to be recognized. In TASHA, arbitrarily complex tours can be parsimoniously & efficiently modelled.
- **Household-based.**
  - Household constraints & interactions are critical in determining individual persons’ travel.
- **Continuous time (over a typical 24-hour weekday).**
  - All trips modelled, by time of day.
  - Peaking & peak-spreading emerge naturally within the model.
- **Computationally efficient.**
  - A model run only takes 1-3 hours (depending on the computer). Rapid turnaround means many scenarios, alternatives, “permutations on a theme” can be explored.



# TASHA Class Structure

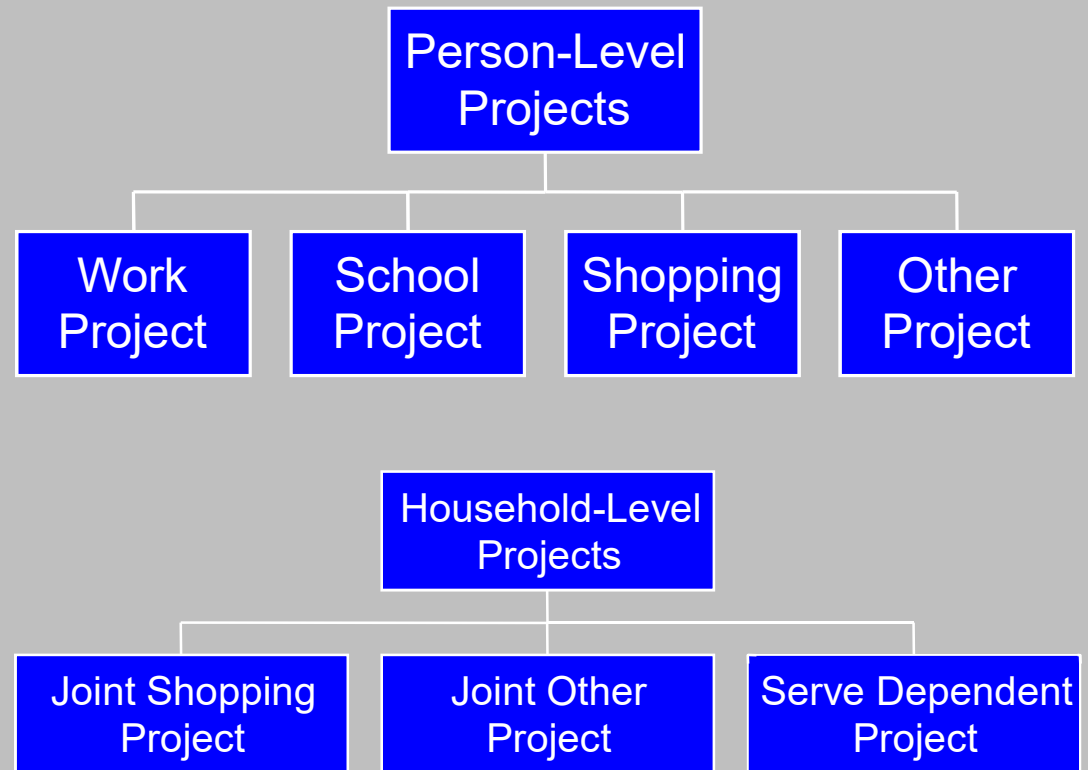


Persons exist within households. This allows TASHA to deal explicitly with:

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

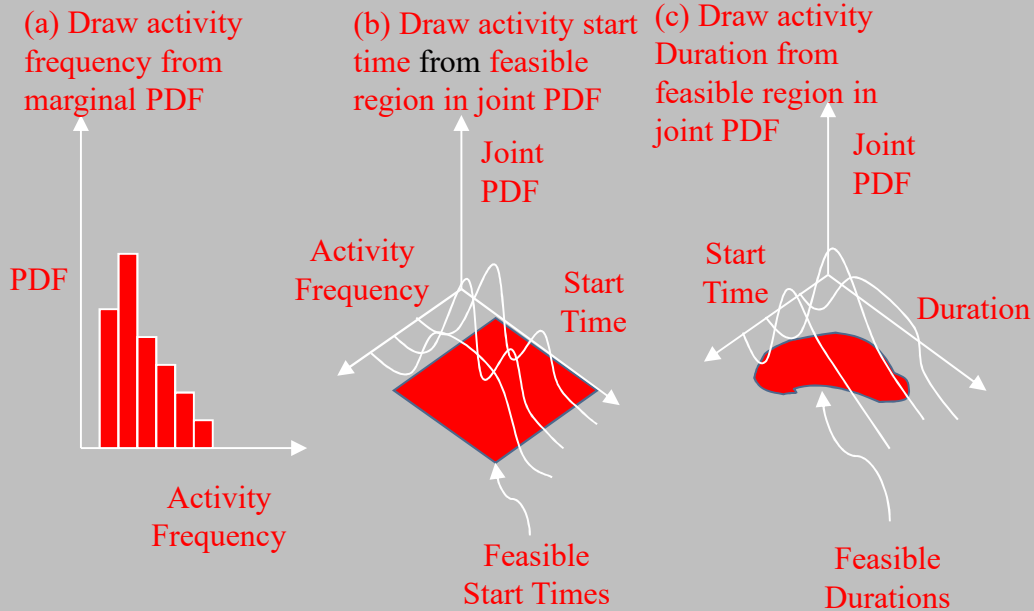
# Projects

- 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.*

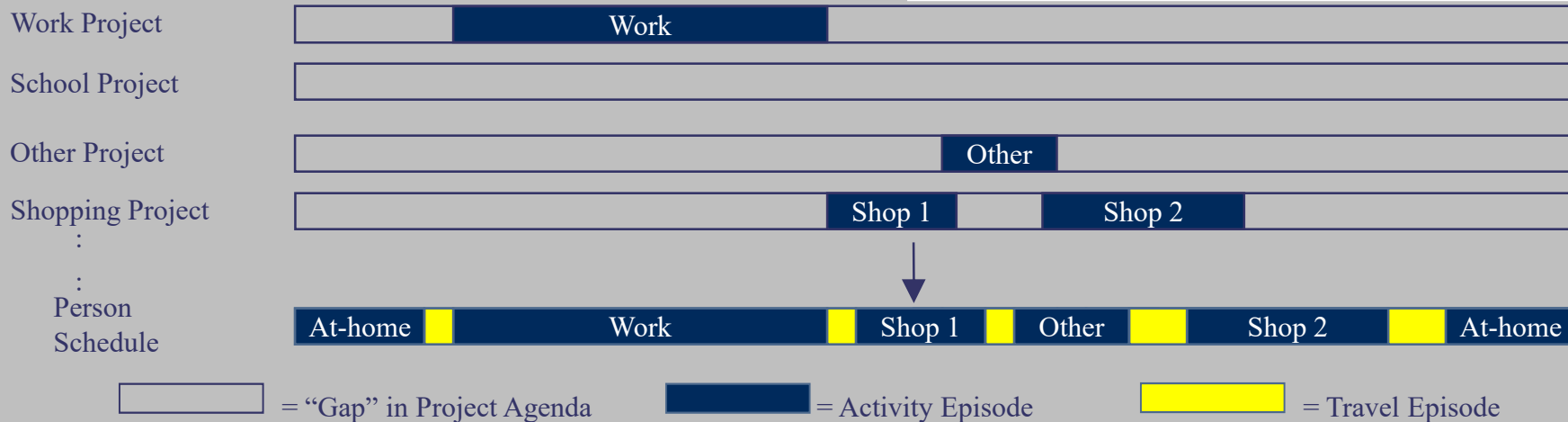
## Activity Episode Frequency, Start Time and Duration Generation



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

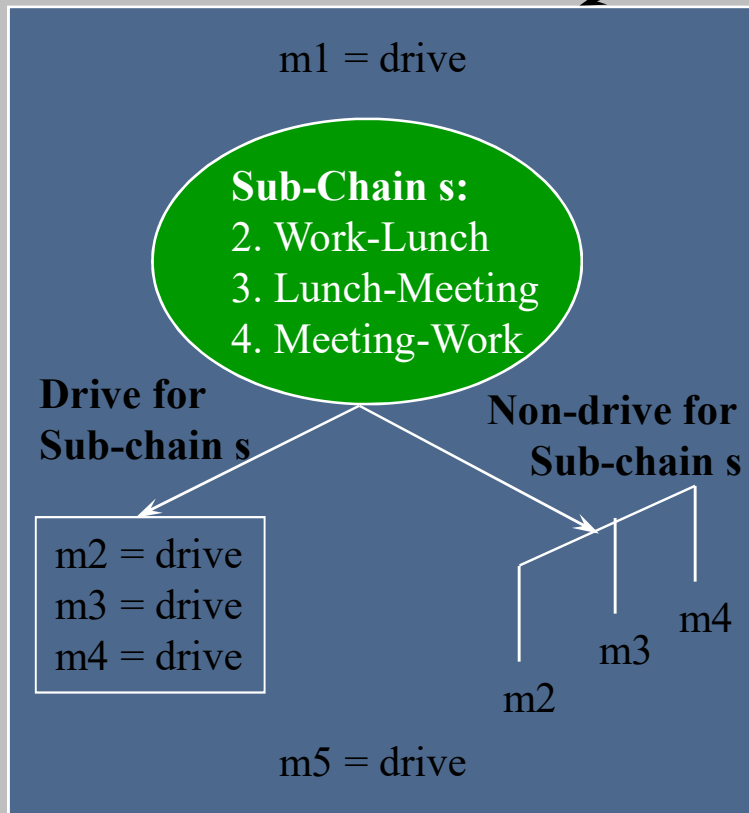
## Chain c:

1. Home-Work
2. Work-Lunch
3. Lunch-Meeting
4. Meeting-Work
5. Work-Home

$mN$  = mode chosen for trip N

Drive Option for Chain c

Non-drive option for Chain c



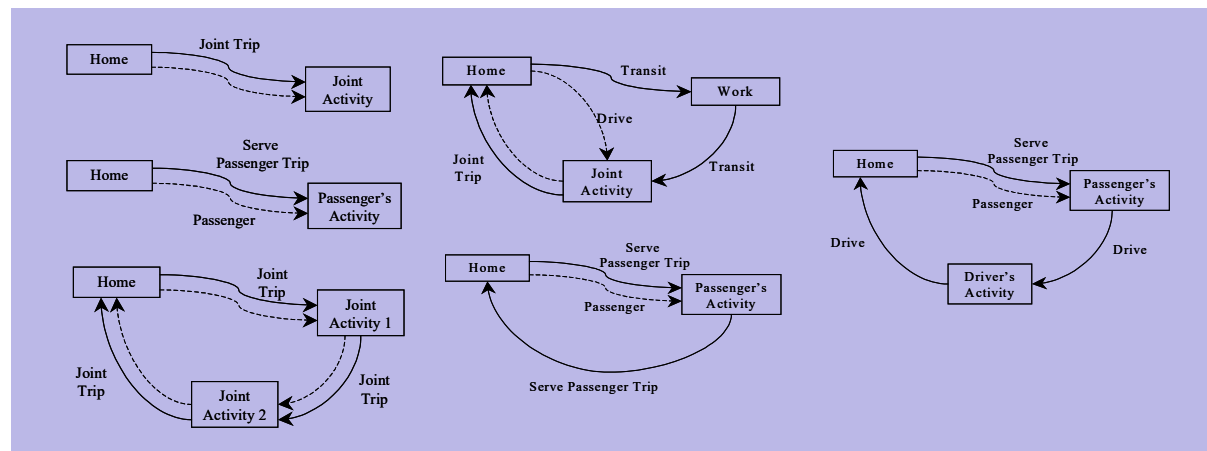
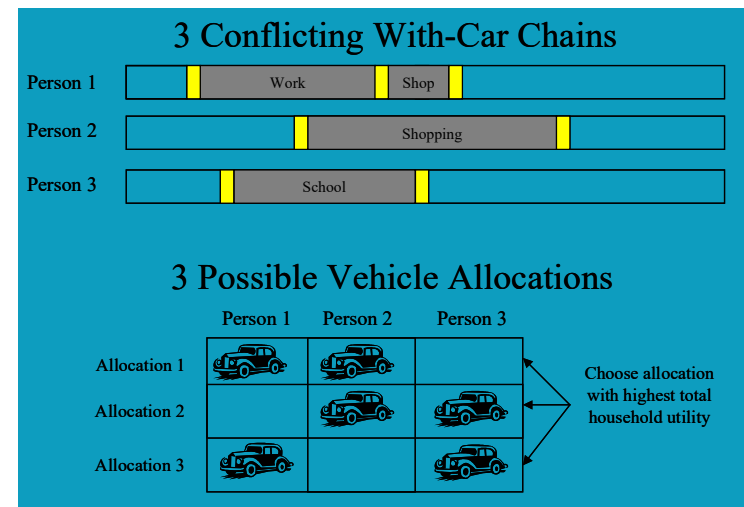
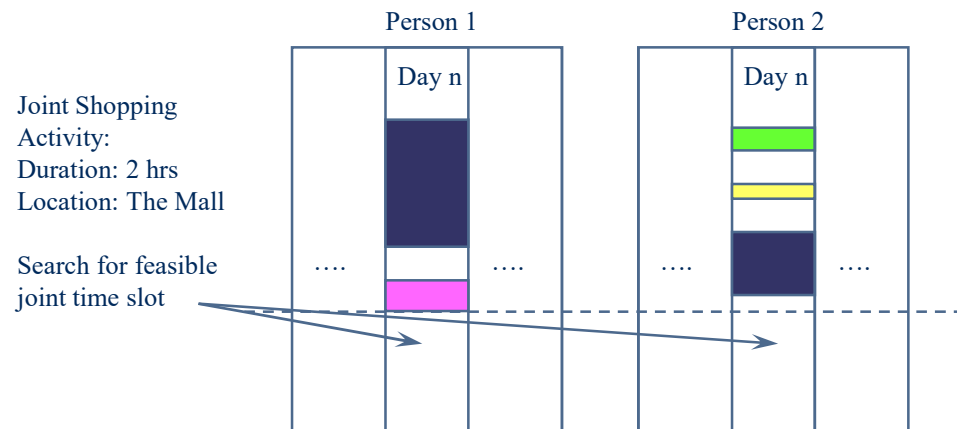
TASHA's tour-based mode choice model:

- 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.



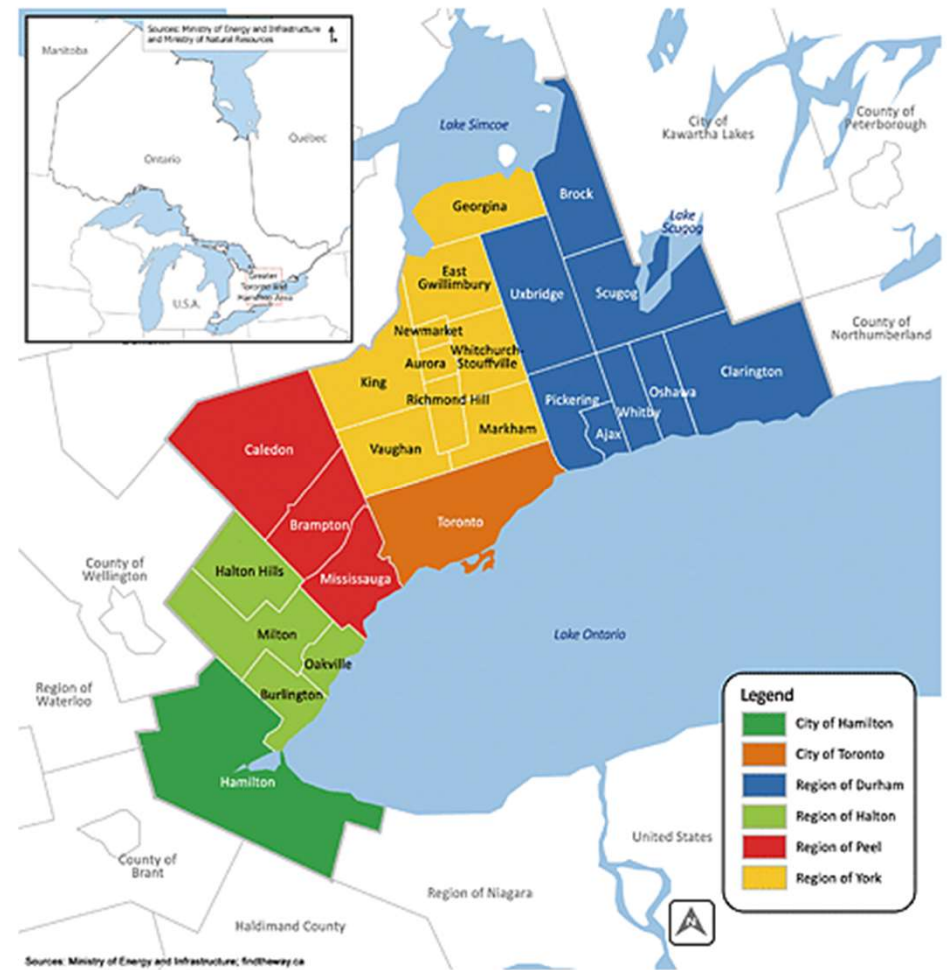
# Household-Level Interactions

- Joint activity episodes.
- Car allocation.
- Within household interactions

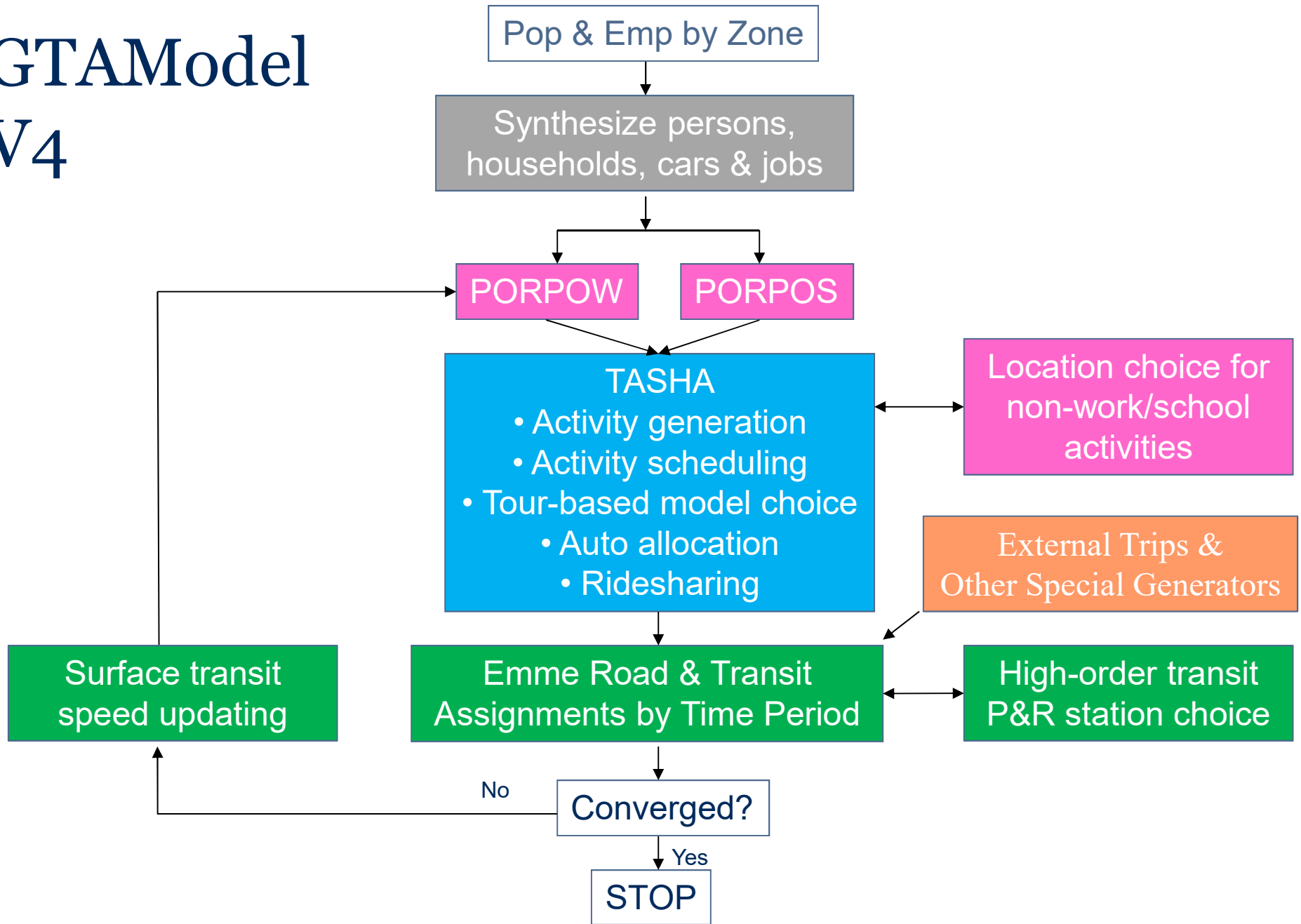


# GTA Implementation: GTAModel V4

- 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.
- Currently in operational use in the Greater Toronto Area (GTA)

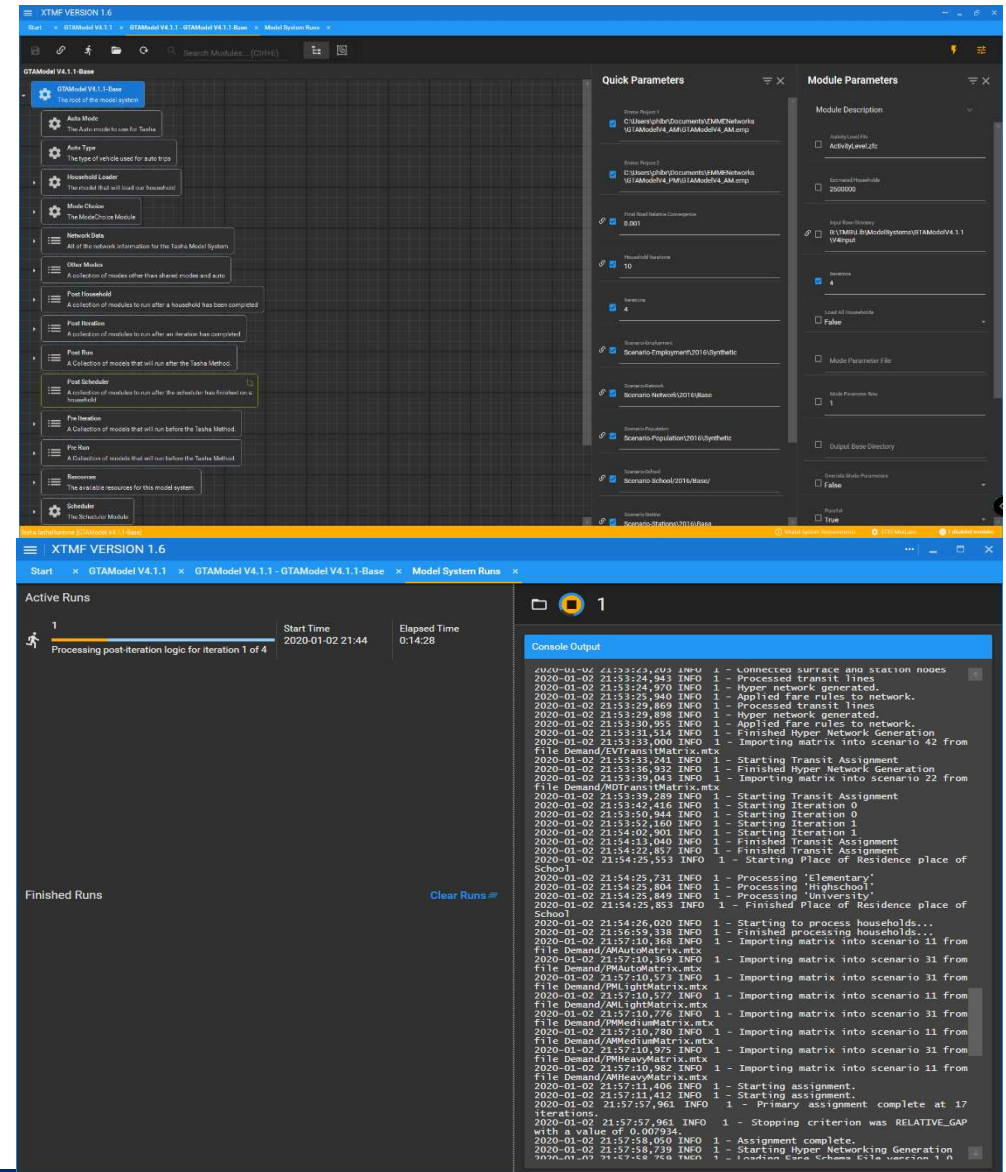


# GTAModel V4



# eXtensible Travel Modelling Framework (XTMF)

- TASHA & GTAModel are implemented in XTMF, custom software developed to support rapid, flexible, extensible development of model systems.
- Written in C# under .net.
- XTMF supports a full interface with Emme through the TMG Emme Toolbox (also MATSim & Aimsun).
- Modular design means can develop new applications quickly.
- Both XTMF & the Toolbox are open source (GPLv3) & available on GitHub.



# Computational Efficiency



- Emphasis has been placed on maximizing computational efficiency.
  - Parallelization.
  - GPU computations.
  - Keeping algorithms simple.
- Currently doing 100% population runs for the 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.**



# Application #1: Sydney & COVID-19 Control Strategies

- Colleagues @ UNSW have applied TASHA to the Sydney GMA, combined it with a custom SIR model that they have calibrated, and used it to test various COVID-19 control strategies.



# Introduction

- Different control strategies are implemented worldwide for slowing down COVID-19 infection spread.
- On one hand, the intense quarantine and full lockdown come with huge human and economic cost.
- On the other hand, relaxing the restrictions can worsen the strain on the health care systems and threaten societies by resurgence of infection.
- Governments are looking for best policies for easing or lifting control strategies.
- The extent to which restrictions can be lifted so that the disease remains under control and economies do not suffer significant damage is a critical question.



# Modelling Disease Spread

The diagram shows the SIR model equations:  $\frac{dI}{dt} = \beta IS - \gamma I$  and  $\frac{dR}{dt} = \gamma I$ . A blue curved arrow labeled "feedback" points from the  $I$  term in the second equation back to the  $\beta IS$  term in the first equation. Two arrows labeled "Control parameters" point from the text above to the  $\beta$  and  $\gamma$  terms in the equations.

$S$  = "Susceptible"

$I$  = "Infectives"

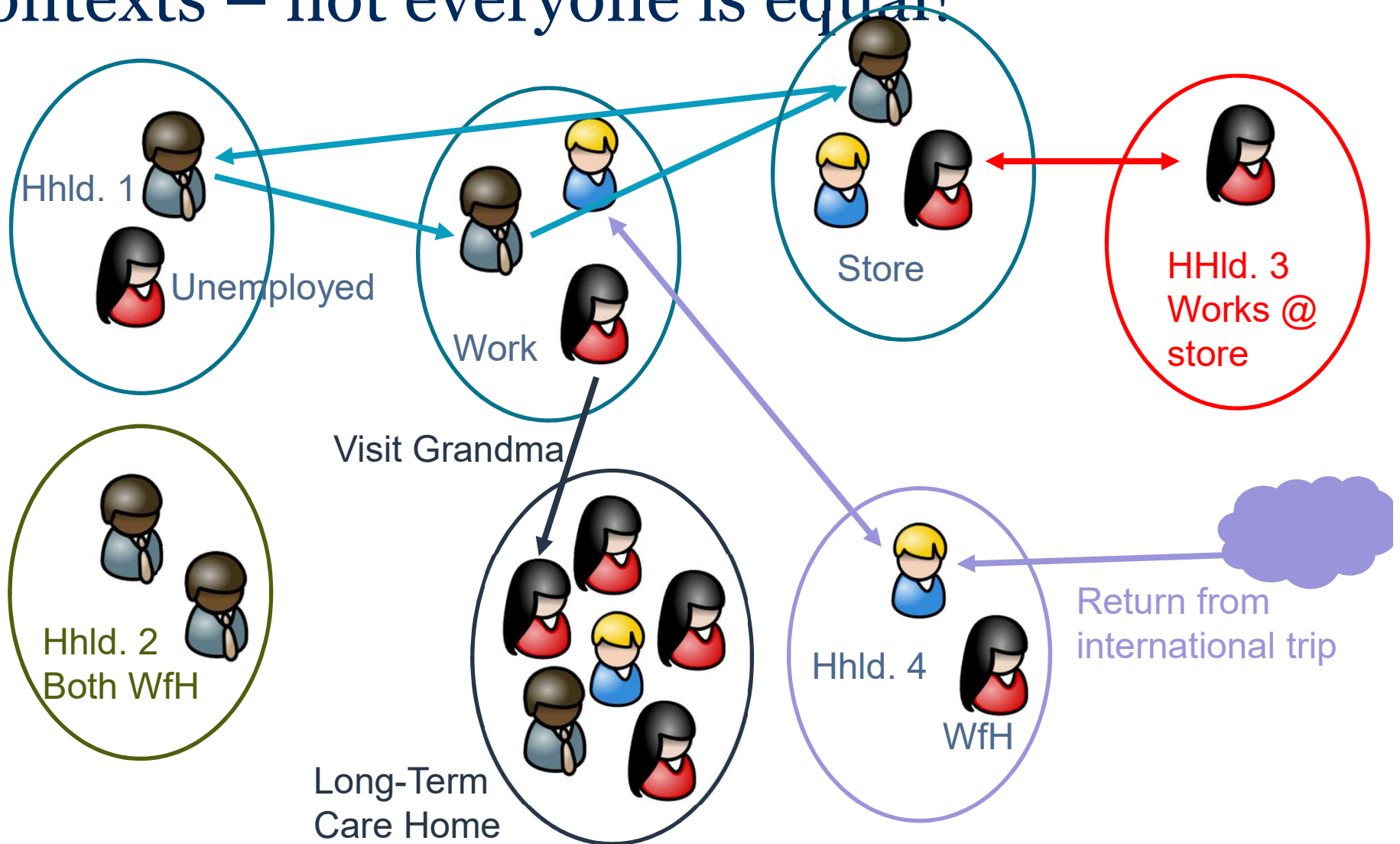
$R$  = "Removed"

- Typical "SIR" (Susceptible; Infected; Removed) models of disease spread are extremely aggregate:
  - No spatial component.
  - No socio-demographics/economics.
  - No households (or other "social networks")
    - Workplaces.
    - Hospitals & long-term care residences,
    - ...
- Role exists for agent-based microsimulation (ABM) activity/travel models to improve upon these models.





# Exposure & risk vary by personal & spatial contexts – not everyone is equal!



# SydneyGMA



## *Specifications*

- SydneyGMA based on GTAModel & TASHA.
- Interactions between household members including their individual or joint trips, their modes of transport, and their daily activities are captured. These characteristics play key roles in disease transmission modelling.
- Since out-of-home locations of all persons are modelled by time of day, the probability of infected individuals encountering susceptible individuals can be modelled at the level of the traffic zone.

## *Limitations*

- Most of the GTAModel parameters were naively transferred to Sydney.
- It is not able to explicitly model out-of-home interactions among agents at a micro “face-to-face” level.
- Does not model “super-spreader events” such as weddings, funerals, etc., nor chronic “hot spots” such as long-term care homes.
- Does not model fundamental changes in activity/travel parameters (e.g., aversion to taking transit).



# The integrated model

- The disease spread model iteratively interacts with SydneyGMA model once per day and scrutinises the itinerary of each agent in the system.
- It updates the disease state of each agent. In particular, the changes each day between agents' disease states affect their travel behaviour and activity participation (and their family members itineraries) in subsequent days of the simulation.



# Model system parameters

There are several factors that affect the movement rates (probabilities) among the different disease states. The factors can be categorised into:

- 1) travel behaviour-specific parameters (held constant)
- 2) disease-specific parameters (calibrated for Sydney)
- 3) policy-specific parameters (scenario inputs)



# Model System Parameter Calibration

- The parameters of the integrated activity/travel-SIR model were calibrated from Sydney data using procedures developed by Dr. Ali Najmi in his PhD thesis (working with TASHA) to calibrate parameters in large-scale model systems.
- Response surface methodology (RSM) is used to systematically & efficiently calibrate the model while considering the interactions of its constituent parameters. By optimally calibrating parameters, their unbiased impacts on disease spread can be captured.

Najmi, A., T.H. Rashidi, J. Vaughan and E.J. Miller, “Calibration of Large-Scale Transportation Planning Models: A Systematic Approach”, *Transportation*, 2019. DOI: 10.1007/s11116-019-10018-6.

Najmi, A., E.J. Miller and T.H. Rashidi, “A Novel Approach for Systematically Calibrating Transport Planning Model Systems”, *Transportation*, 46(5), 1915-1950, 2019, 1-36. DOI: 10.1007/s11116-018-9911-6.



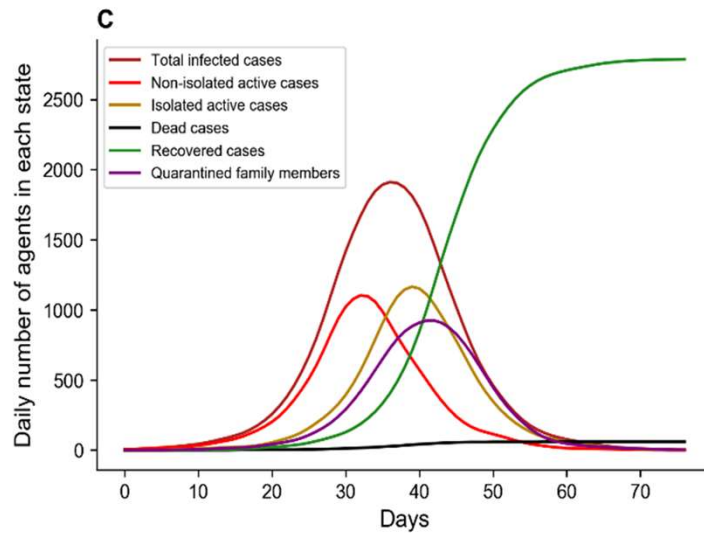
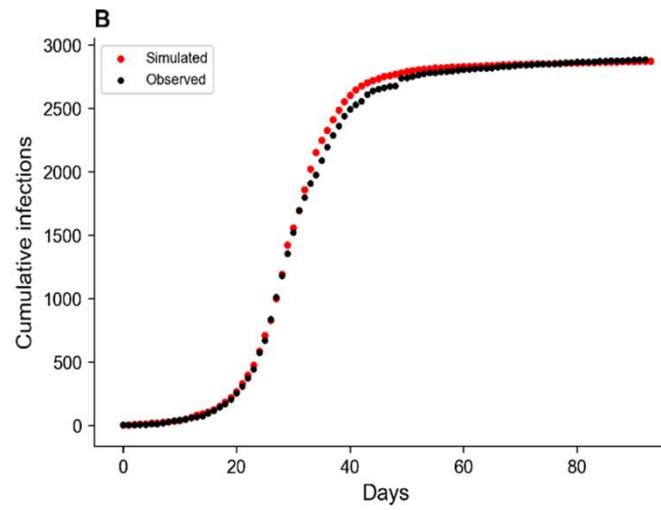
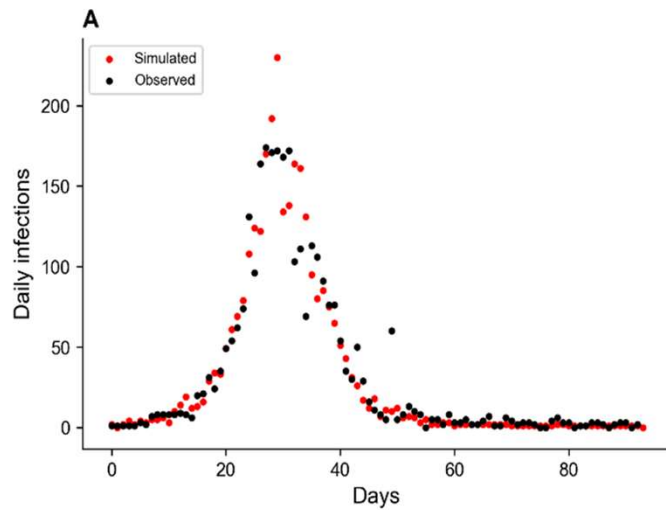
# Calibrated agent-based disease transmission model parameters

## Calibrated parameters

| Parameters  | Lower bound | Upper bound | Calibrated value |
|---|-------------|-------------|------------------|
| Infection probability (per trip)  | 0.03        | 0.05        | 0.044            |
| Infection probability at home (per day per case)  | 0.03        | 0.1         | 0.052            |
| Correction factor of infection probability for M, O and P occupations compared to G and S occupations | 1           | 1.5         | 1.26             |
| Quarantine probability (per day)  | 0.05        | 0.15        | 0.12             |
| SD compliance level after lockdown  | 60%         | 100%        | 85.94%           |
| Base contact number (per trip)  | 1           | 3           | 2                |
| Incubation period   | 3           | 5           | 4.23             |
| Contact number in PT vehicle  | 6           | 14          | 13.85            |



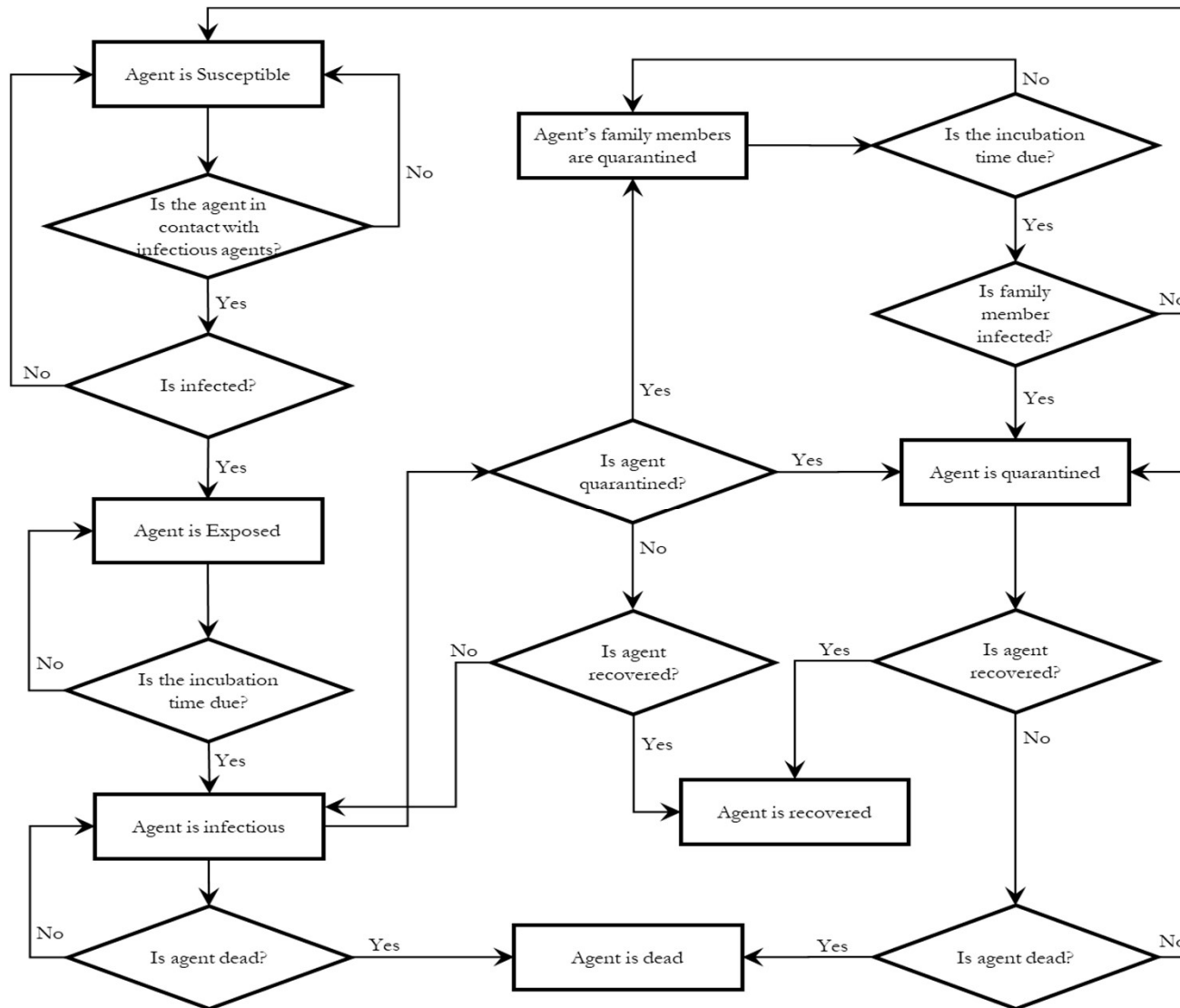
# Calibration fit is excellent



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



# ABM Disease Transmission Model Flowchart

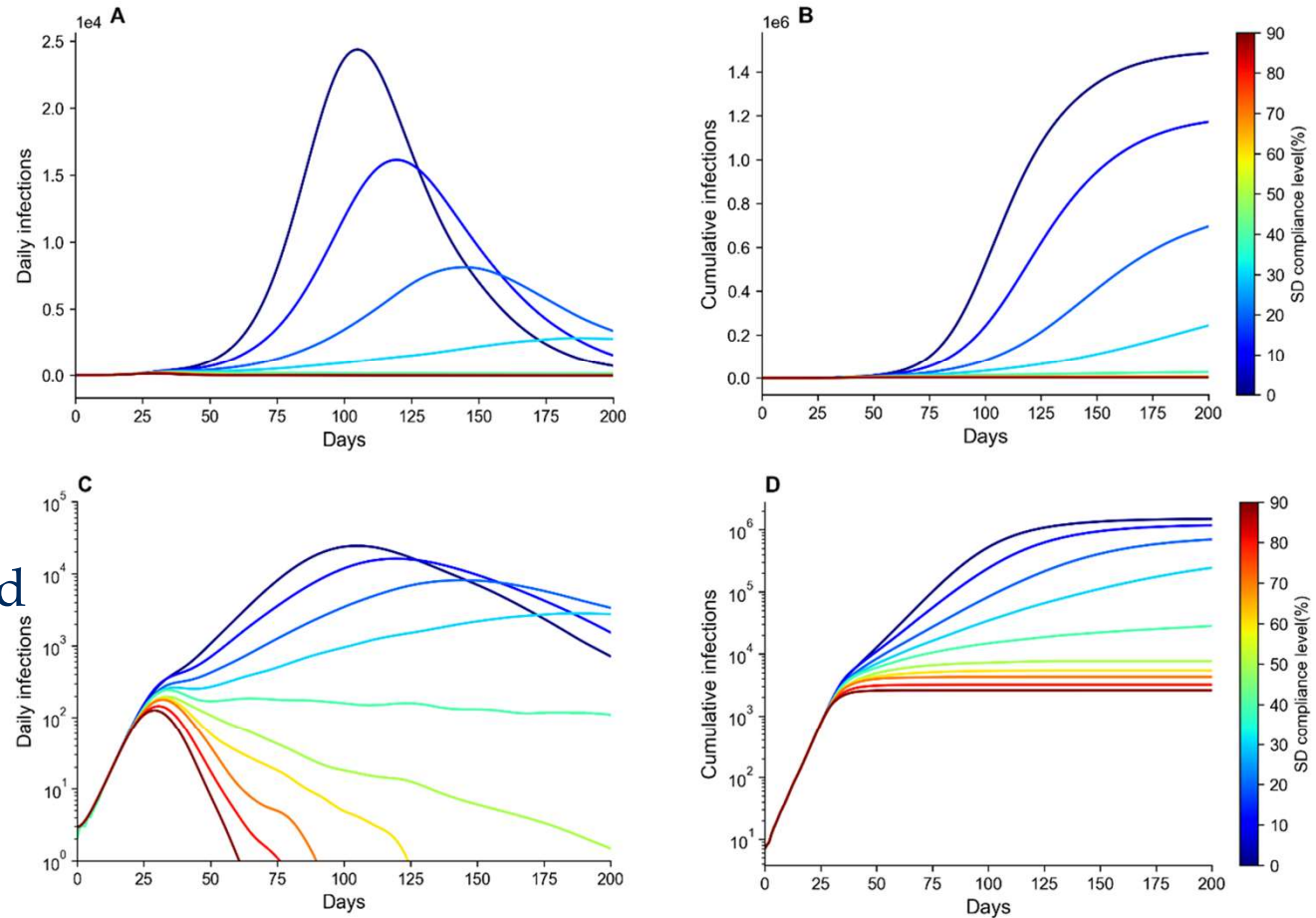




# Social Distancing Compliance Level

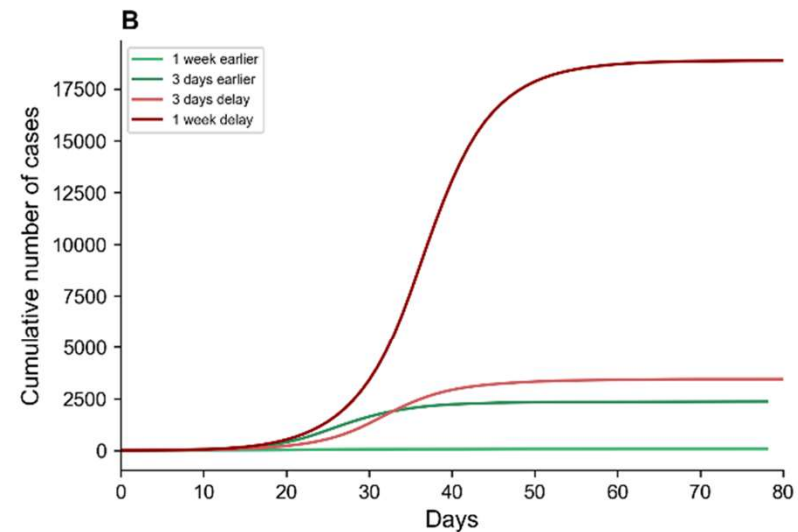
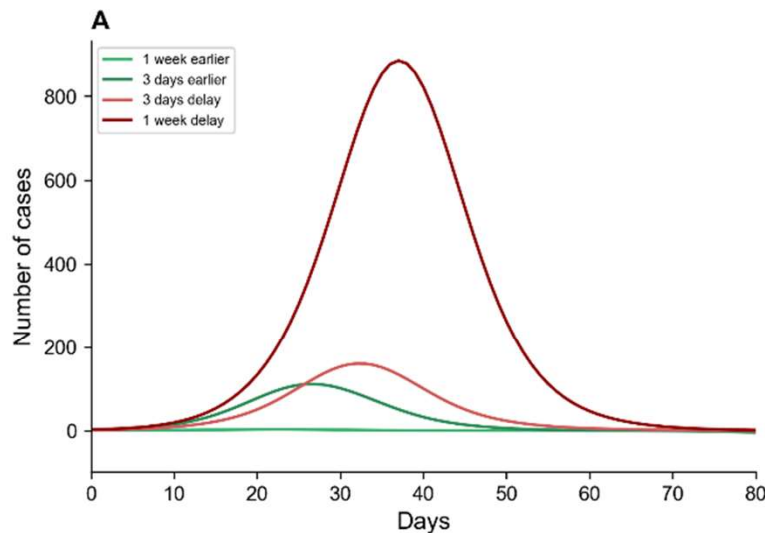
- The estimated compliance level for the Sydney GMA is 85%.
- What would happen if the people had complied with social distancing less?

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



# Speed of implementation of lockdown

- Did the lockdown start at the right time?
- What would happen if the lockdown was started earlier or later?



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.



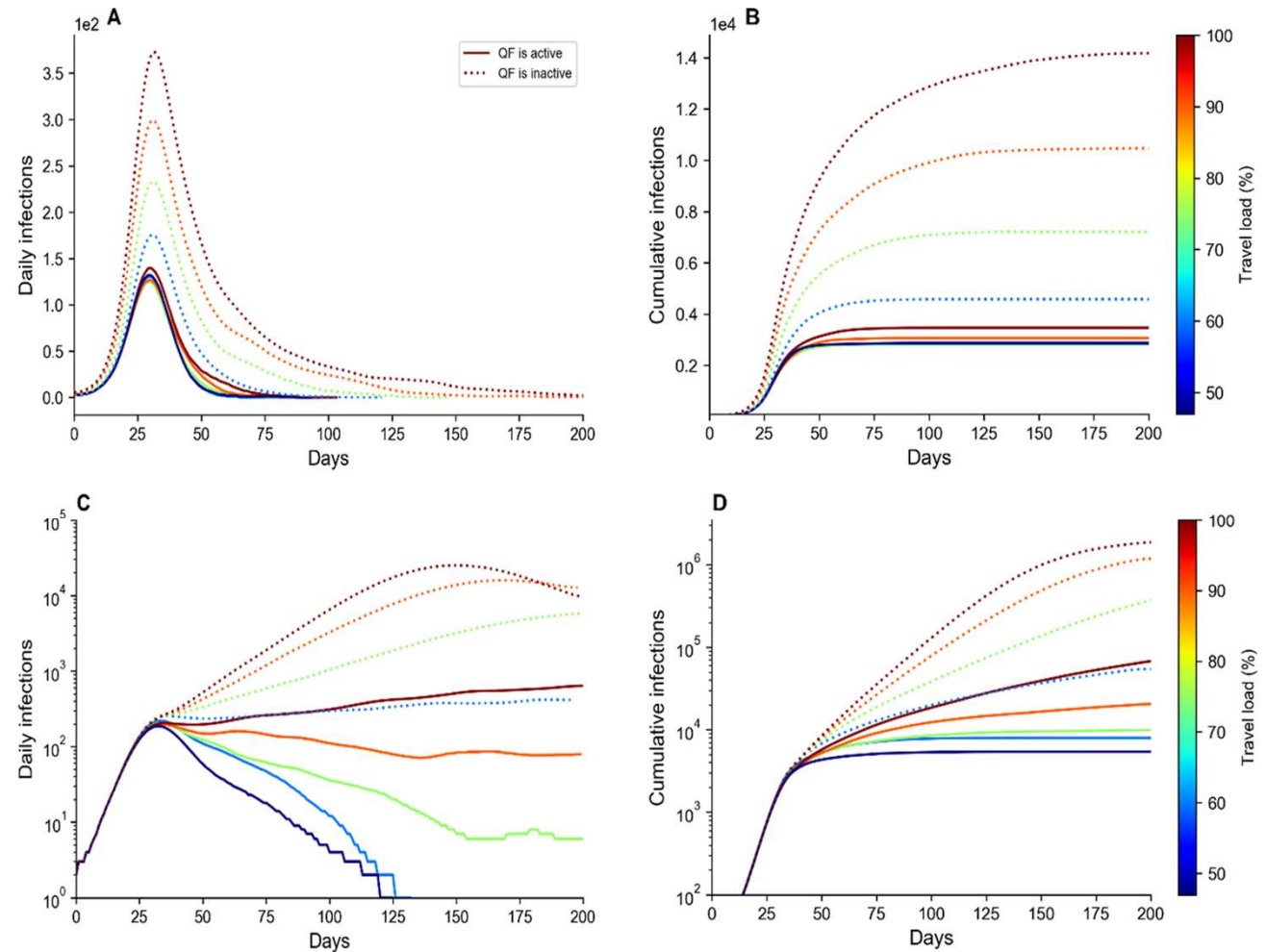
# Demand load and quarantining family members

- What would happen if the home quarantine was not enforced?
- What would happen if the travel restrictions had been enforced less seriously?

A comparison of different travel load and its interaction with home quarantine strategy at two social distance compliance levels of 85.9% and 60%.

(A) daily number of cases (SD compliance levels is 85.9%),  
(B) cumulative cases daily number of cases (SD compliance levels is 85.9%),  
(C) daily number of cases (SD compliance levels is 60%), and  
(D) cumulative cases daily number of cases (SD compliance levels is 60%).

Note: Responding to the skewness of large values, (C) and (D) are plotted in logarithmic scale.



# Summary of Key Findings

- There is little benefit for the social distancing compliance levels of less than 50%.
- The compliance level of 60% and less is not suitable if the decision is to ease the restrictions on businesses and leisure activities.
- Even a one-week delay in enforcing lockdown could increase the cases by about 700%.
- Quarantining the family members of isolated cases plays a key role such that its relaxation remarkably increases the suppressing period of the disease, even if a high compliance level of social distancing is in place.
- Having a high travel load magnifies the spread of the virus unless wearing facemasks is enforced.
- Wearing a mask at home is the least effective control strategy.



# Acknowledgements



**Assoc. Prof. Taha Rashidi**

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Najmi, A., F. Safarighouzhdi, E.J. Miller, R. MacIntyre and T.H. Rashidi, “Easing or tightening control strategies: Determination of COVID-19 parameters for an agent-based model”, submitted to *PLOS One*, 2020.

Najmi, A., F. Safarighouzhdi, R. MacIntyre, E.J. Miller, and T.H. Rashidi, “Facemask and social distancing, pillars of opening up economies”, submitted to *The Lancet Infectious Diseases*, 2020.



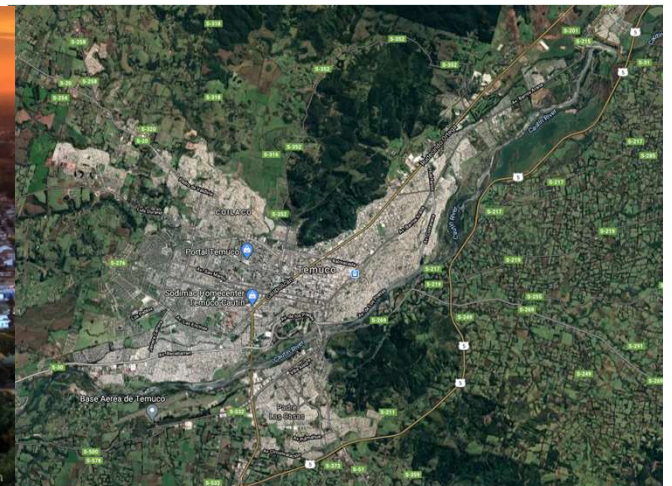
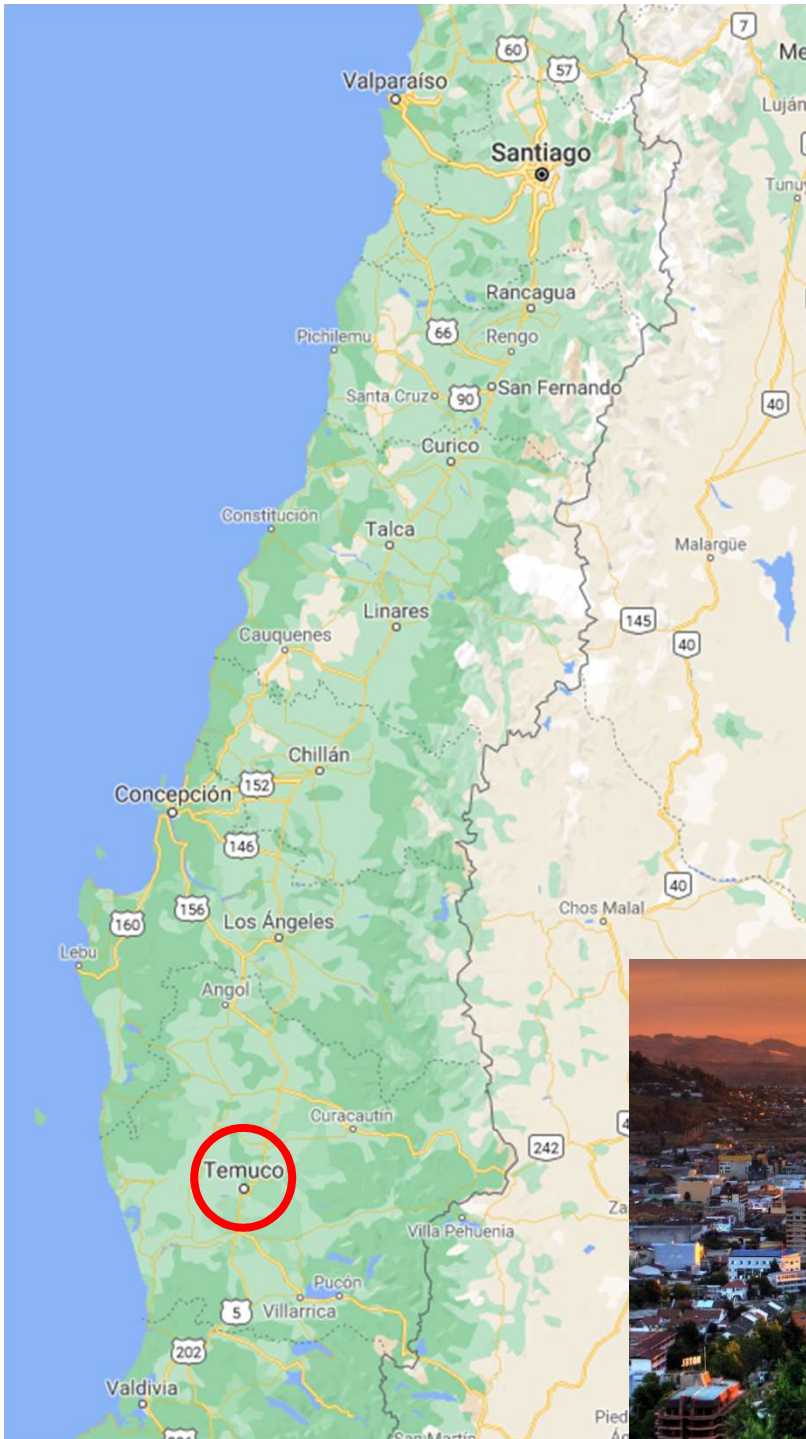
# Case Study #2: Model Transferability

- Various other experiments in testing the transferability of TASHA are underway:
    - Helsinki (Oulu University)
    - Melbourne (Monash University)
    - Temuco, Chile (U. de Concepción)
- } Both involve connecting TASHA to MATSim.

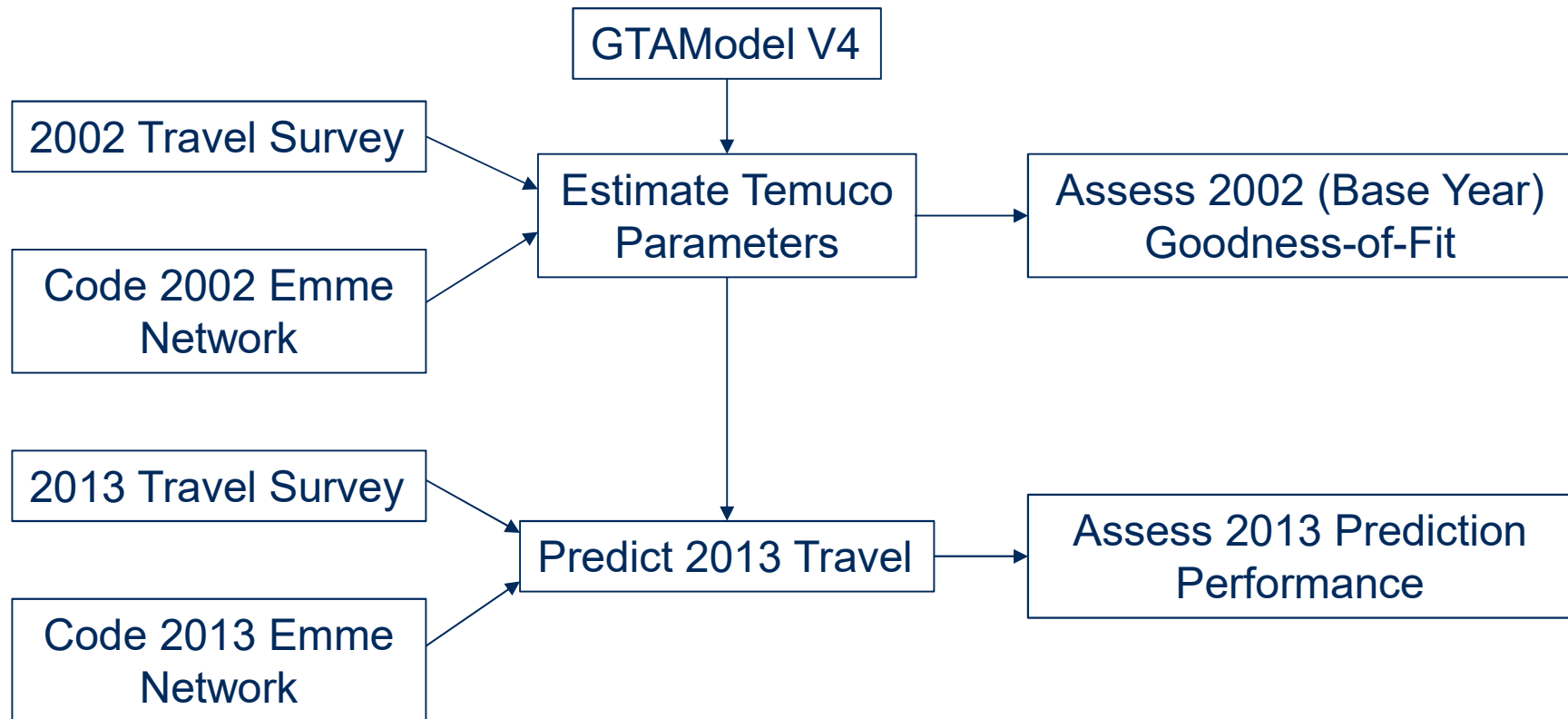


# Temuco, Chile

- Temuco is a medium-sized city (approx. 220,000 pop.) located 680km south of Santiago.
- Objective: test spatial & temporal transferability

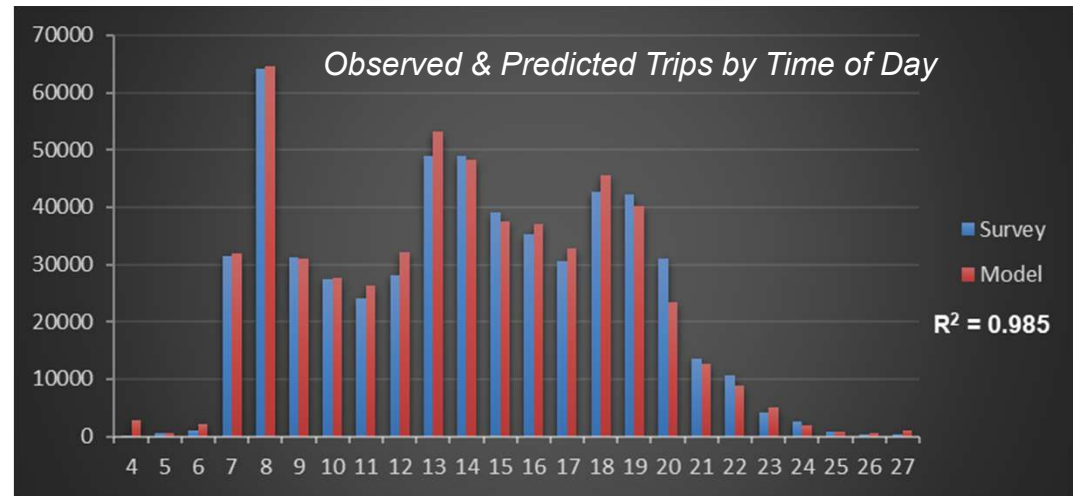
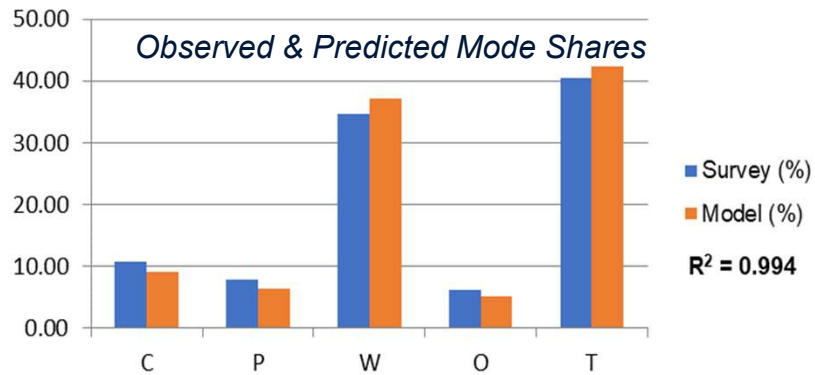


# Transferability test plan

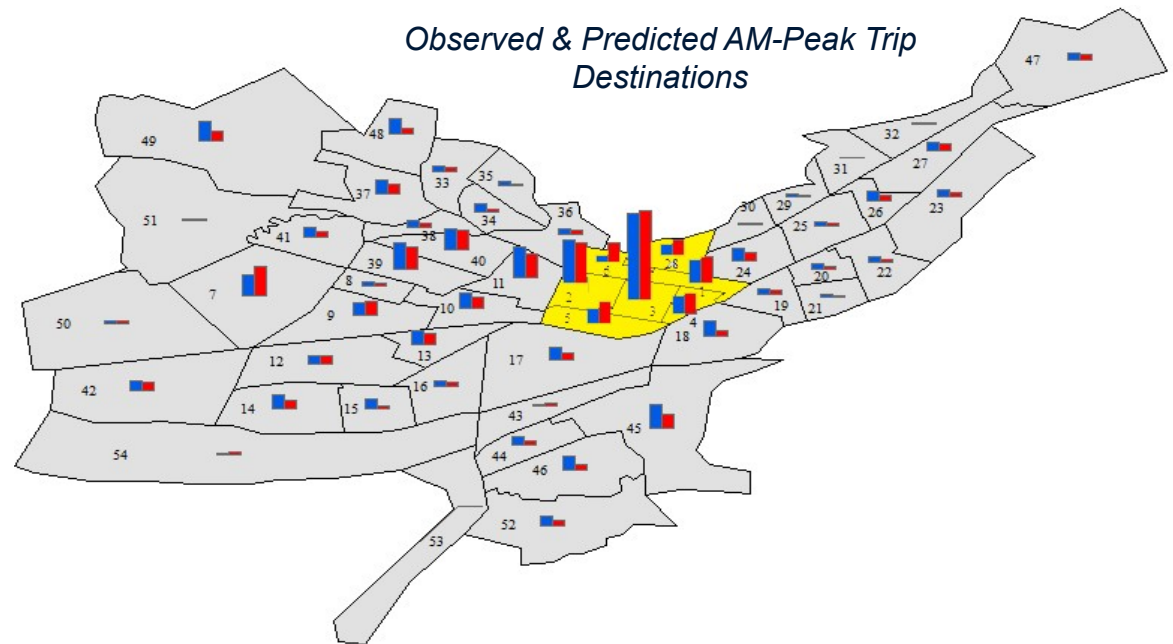




# Sample 2002 Results



- Base year estimation & calibration results generally look good.



# 2013 Validation

- 2013 forecast results are still in progress.
- Significant changes in standard work & school hours occurred between 2002 & 2013 – difficult for the model to capture!
- Some issues exist with Place of Residence – Place of work (PoRPoW) linkage predictions.



# A few preliminary observations

- As with trip-based models, activity generation is still very statistically-based:
  - Difficult to capture contextual changes.
  - COVID-19 impact implications.
- Spatial location choice is typically the weakest link in the modelling chain.
  - Adequacy of available “attraction” variables.
  - Stochasticity.
- Overall model structure transfers well, but local data to develop local parameters remains critical.

Allendes, V., J.A. Carrasco & E.J. Miller, “Spatial and temporal transferability of microsimulation activity-based models: An application of TASHA in Chile”, (draft manuscript)

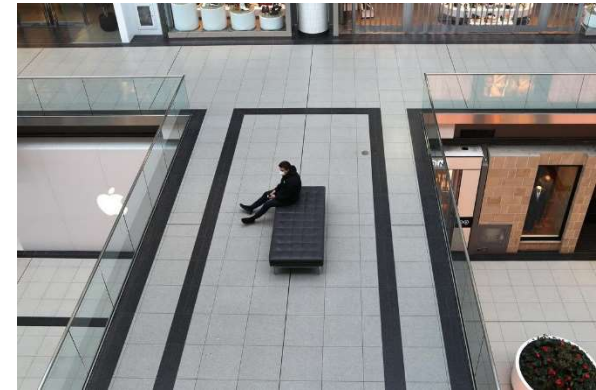


Returning to Toronto ...



# Application #3: COVID-19 & Modelling in the GTHA

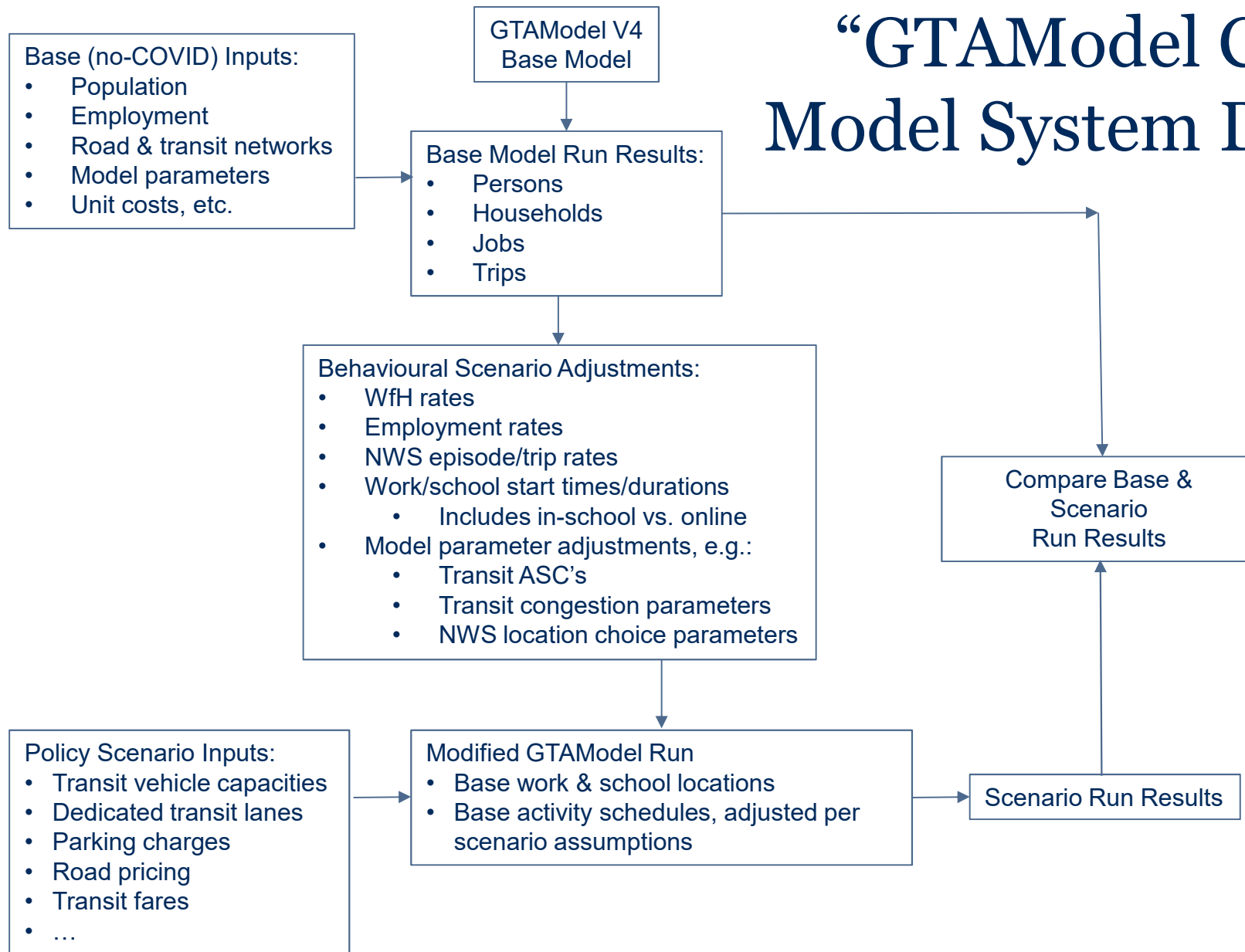
- The City of Toronto has asked for a modified GTAModel model system that would allow various components of a “base run” to be held constant to test various COVID-19 scenarios to be tested.
- Examples:
  - Hold PoR<sub>PoW</sub> fixed, but change percentage of persons working from home.
  - Change labour force participation rates (LFPR).
  - Adjust transit mode choice constants to reflect altered perceptions of public transit.
  - Adjust non-work/school activity rates.
  - Adjust school trip-making rates.
  - ...?

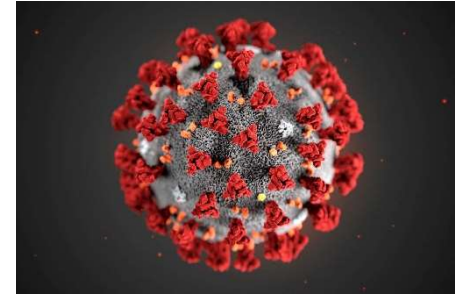


- Note that such a model system would permit other types of (non-COVID-19) scenarios to be tested as well.



# “GTAModel C19” Model System Design



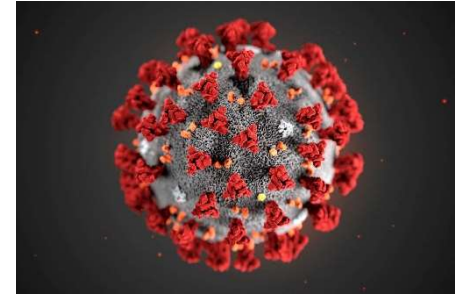


# Two-Phase Approach

- Phase 1, fall 2020 / early winter 2021:
  - Develop proposed modified model system.
  - Test various recovery scenarios.
- Phase 2, winter / early spring 2021:
  - Once COVHITS survey data are available for fall, 2020 conditions:
    - Undertake a more extensive re-estimation/calibration of the modified system.
    - Update scenario assumptions.
    - Re-analyze scenarios.
  - The model system can continue to be updated / improved as additional survey data become available.
    - Continue to update scenarios & assumptions about the eventual steady-state “new normal”.
    - Eventually the base and modified model systems may converge into a single “new normal” model system?



# Phase 1 Work Plan



- Gather road & transit counts for 2019 (pre-COVID) and 2020 (COVID) conditions.
- Code 2020 road & transit networks.
- Estimate 2020 population & employment distributions.
- Design & code the modified scenario testing model system.
- Attempt to calibrate key parameters to reproduce “total lockdown” conditions (circa April-May, 2020).
  - WfH & employment rates.
  - NWS rates.
  - Transit parameters.
  - ...?
- Base (no-COVID) & “total lockdown” runs define upper & lower bounds for any “recovery pathway”.
- Develop & test various “recovery scenarios”.





The ILUTE  
research team  
throughout the  
years & in  
happier times.

May we see  
these days  
again!

Thank you.

Any questions?

