A Comprehensive Utility maximizing System of Travel Option Modelling (CUSTOM): Modelling Daily Passenger Travel Demand in the Way it Should Be!

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Polytechnique Montréal
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Outline

- Introduction
- Trip-based modelling
- Activity-based modelling
- Formulations of CUSTOM: Comprehensive Utility maximizing System of Travel Option Modelling
- Empirical applications of CUSTOM
- On-going research

Introduction

- Transportation engineers deal with
  - ✓ Planning/Developing new system (component)
  - ✓ Optimize efficiency of existing system

- Understanding travel demand is the first step of all transportation engineering practice
  - ✓ Short-term (e.g. single corridor of the road network)
  - ✓ Medium-term (e.g. Small portion of network)
  - ✓ Long-term (e.g. road/transit network of a region)

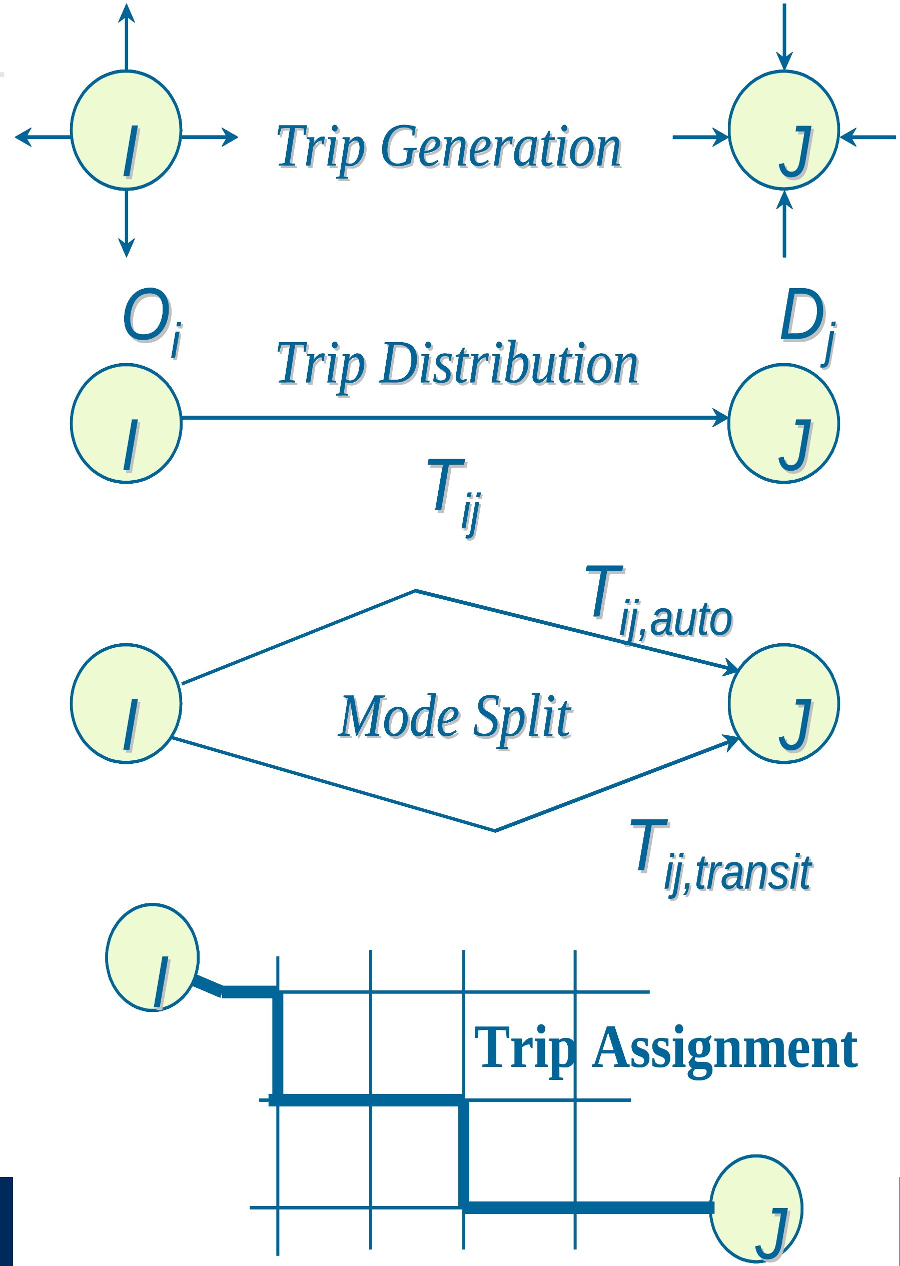
- Miss-match between travel demand and supply (transportation system performance)
  - ✓ Traffic congestion: delays, disruption in economic activities, air pollution (SO_x ,NO_x ,etc.), GHG emission

Demand Prediction

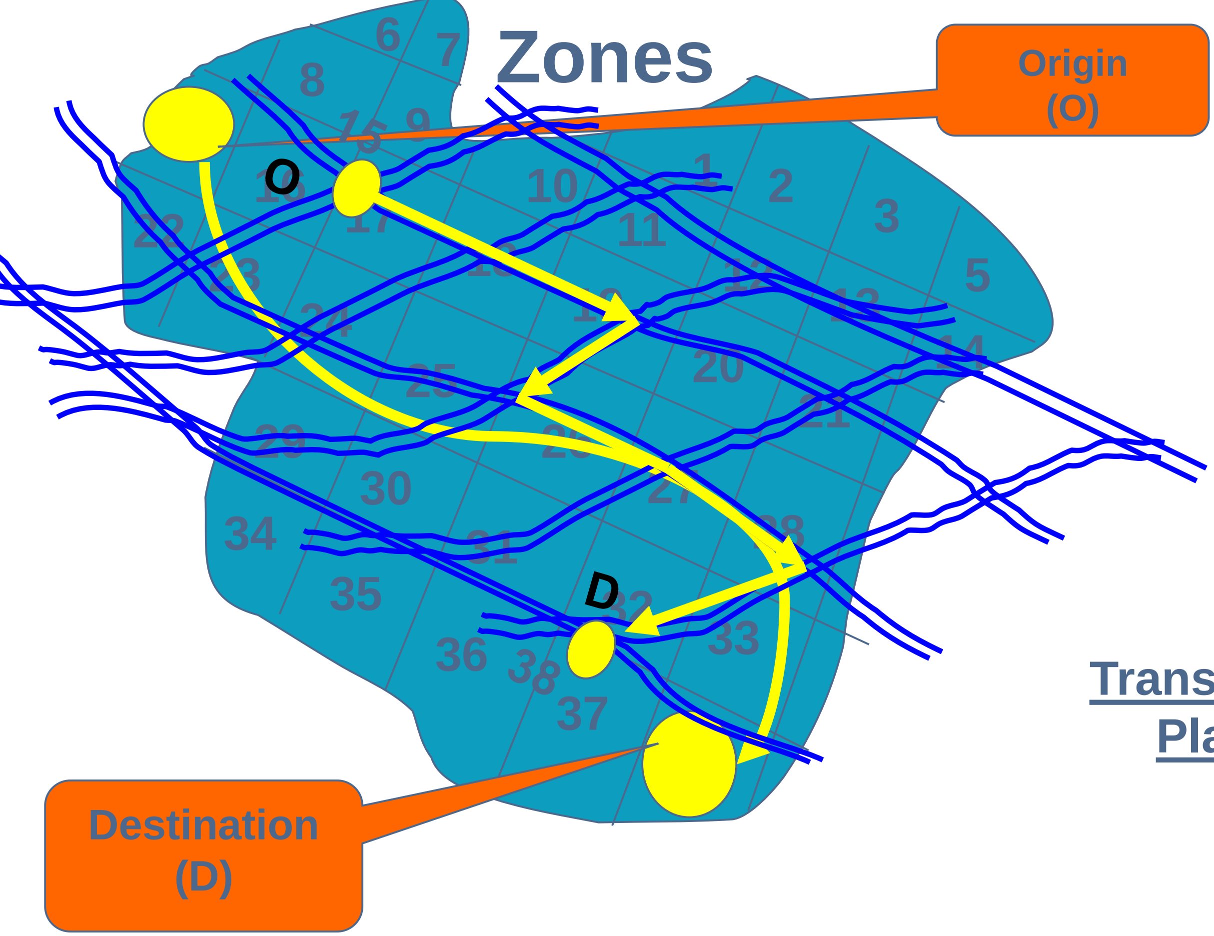
- Demand for transportation & performance of the transportation system

- Predicting/determining/quantifying demand for travel
  - ✓ Travel demand model

- Conventional approach
  - ✓ 4-stage approximation



4-Stage Model



Trip Generation

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Trip Distribution

↓

Mode Choice

↓

OD Matrix

↓

Route Choice / Traffic Assignment

Transportation Planning ↑

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↓ **Traffic Flow** ↓

Traffic Engineering

Shortcomings of Conventional Method

1) Crude conceptualization of travel demand

   ✓ Considering trip as direct demand

   ✓ Aggregation

2) Forcing the behavioural process to comply with physical analogy: Gravity theory

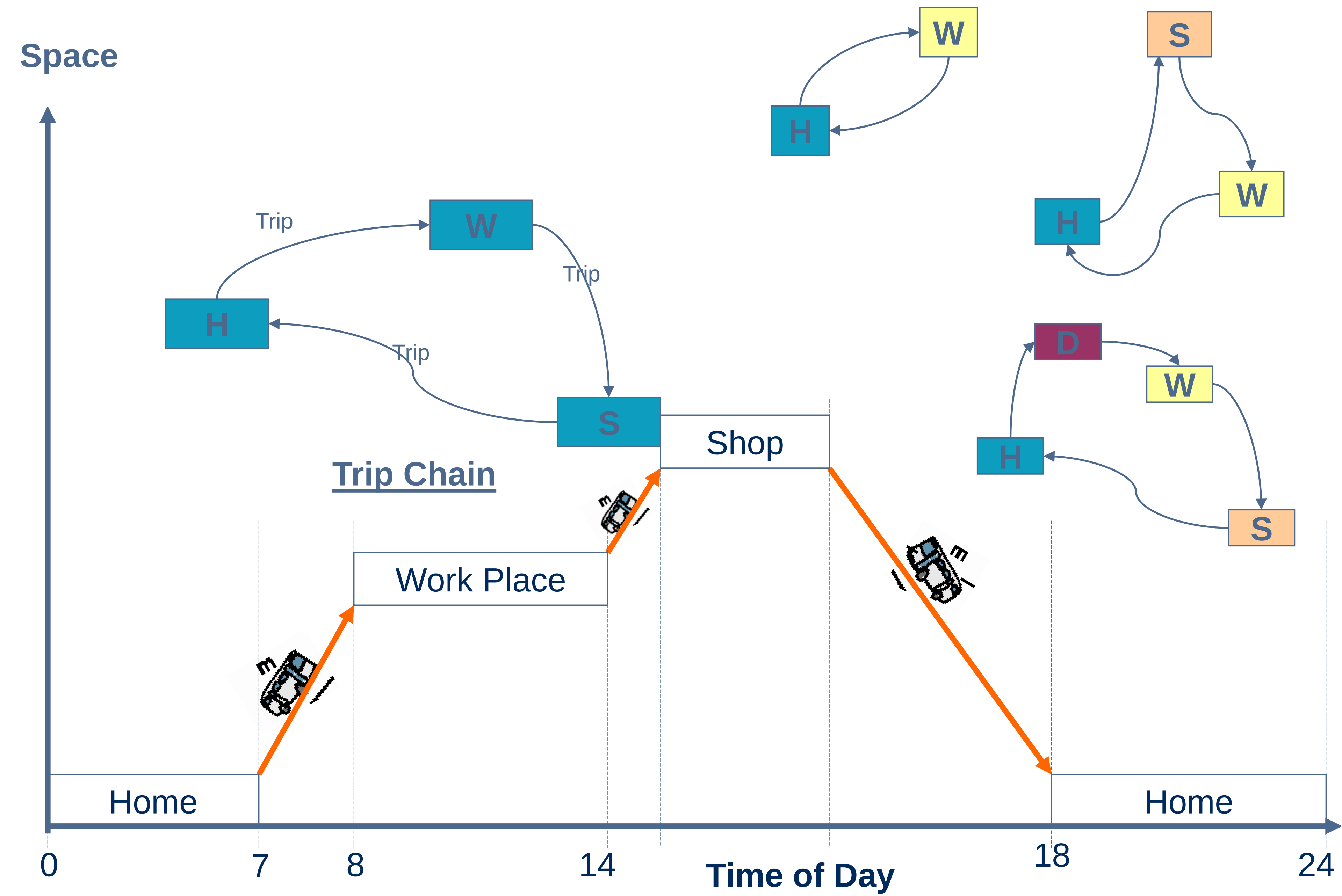
   ✓ Using simplified mathematical techniques

3) Considering each trip as an isolated event: Missing behavioural constraints

4) Ignoring the demand-supply dynamics

Addressing the Cause

- ➢Travel is a derived demand
- ➢We need to travel to participate in different activities at different locations on the space
- ➢ Activities emerges from basic needs (biological, economic and social)
- ➢ Constraints: limited time (24 hours a day), limited resources, personal constraints, etc.
- ➢ Opportunity: scope of travel, accessibility, etc.
- ➢ Time-space prism (Hägerstrand, 1976)


Space
W
H
S
W
H
Trip
W
Trip
H
Trip
S
D
W
H
S
Shop
Trip Chain
Work Place
Home
Home
0
7
8
14
18
24
Time of Day

Travel Behaviour

- **Individual's activities influences all others**
  - Externalities (congestions, delays, emissions)
- **Short-term** (daily activity-travel) decisions are influenced by the **Medium-term** (e.g. auto ownership) as well as **Long-term** (e.g. home and work location) decisions
- **Dynamics of multiple scales**
  - Intra-household (e.g. Ride share, car allocation, task allocation)
  - Inter-household (social network)
  - With the surrounding environment

Advancing Demand Modelling

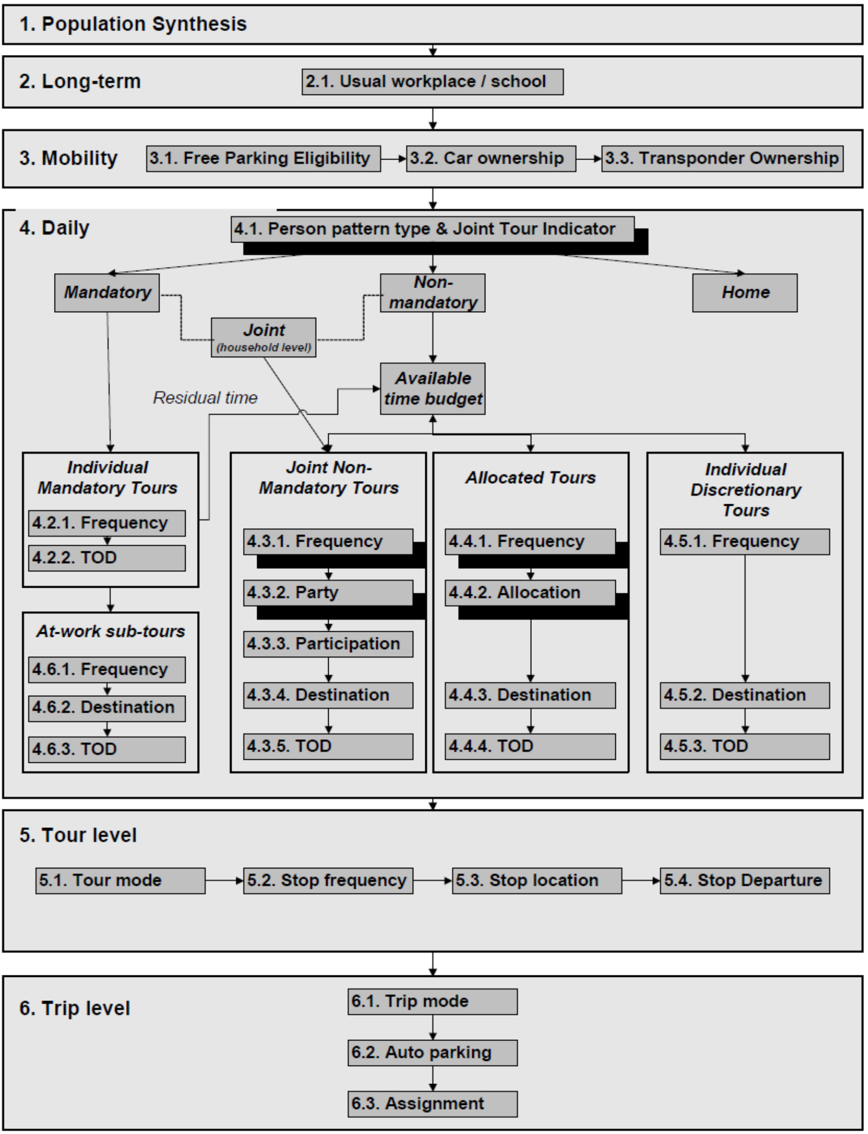
- **Tour-based model**:
  - ✓ Travel-Activity Pattern Choice. Apply discrete choice models to predicting daily patterns of trips
- **Activity-based model: Pure Rule-based**
  - ✓ Use (if-then-else) type of rules to sequentially develop daily activity schedules.
  - ✓ Rules may be skimmed from observed patterns
- **Activity-based model: Loosely bound econometrics**
  - ✓ Use econometric models to predict different decisions. Then use arbitrary rules to form scheduling patterns
- **Activity-based model: Hybrid rules and econometrics**
  - ✓ Use a mix of rules and econometric approach to conveniently predict daily activity-travel patterns

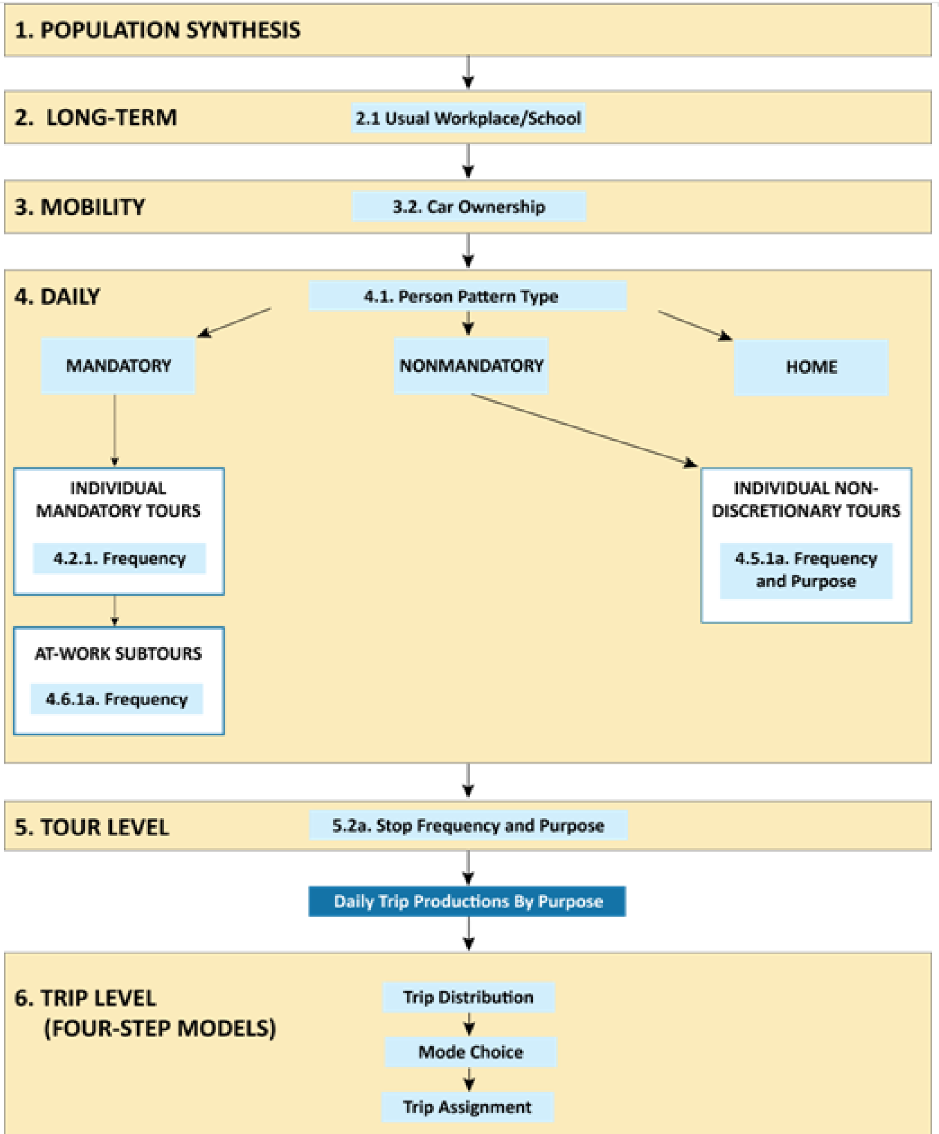
Advancing Travel Demand Modelling: Canadian Examples

- **Tour-based model**:
  - ✓ Greater Golden Horseshoe (GGH) model developed for MTO for the Greater Toronto, Hamilton and Surrounding Area
  - ✓ It is a tour-based approach of activity-based model.

- **Rule-based model**:
  - ✓ Greater Toronto Area Model: GTA Model 4.0
  - ✓ It uses a rule based approach (TASHA) to develop activity-based approach

GGH Model: Activity patterns





GGH Model: Mode choice

GGH model is called activity-based model even though:

- ✓ It is unclear how the tour choices are modelled
- ✓ For chosen tour types: stop frequency and stop type choices are modelled as regression models
- ✓ Tour generation model is individual-based, but destination choices are modelled as zone-based gravity/entropy-based model
- ✓ Tour patterns are modelled, but mode choice is modelled for individual trips considering all modes are feasible for all trips
- ✓ Daily time constraints are not defined explicitly
- ✓ Intra-household interactions are completely overlooked

GTA Model with TASHA

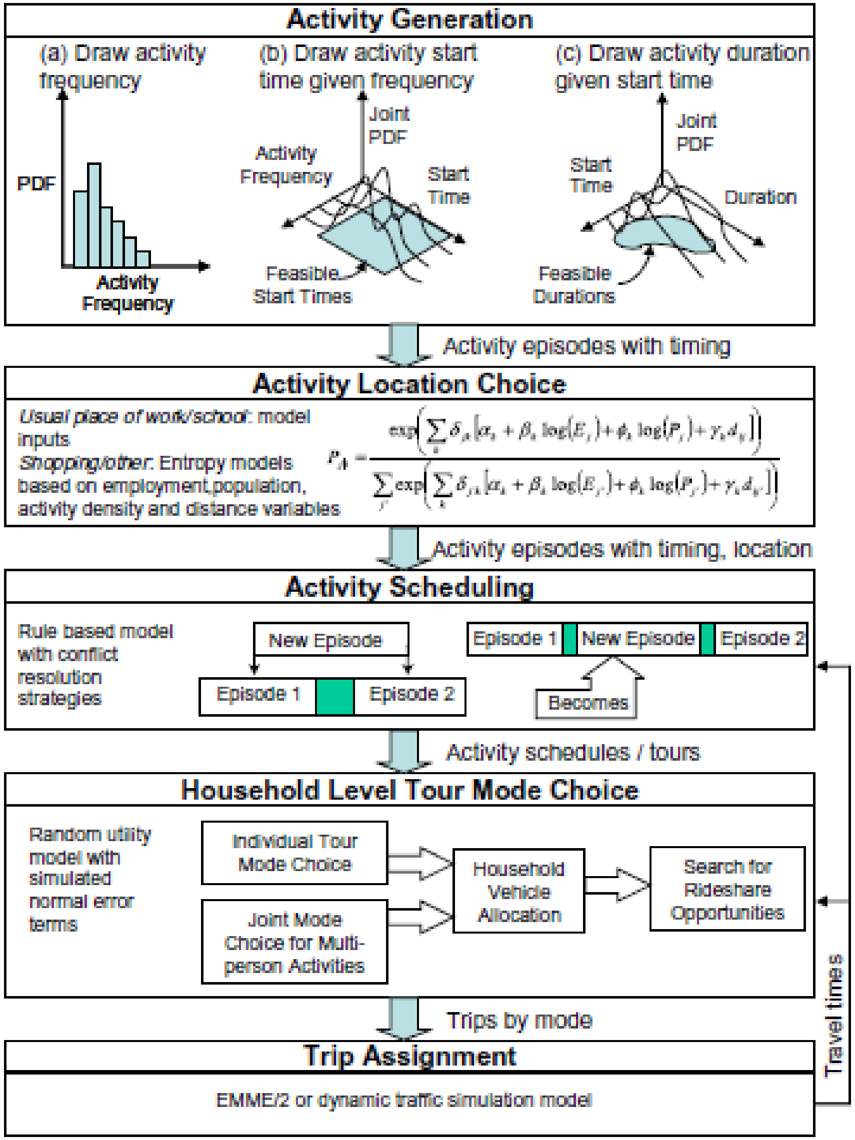
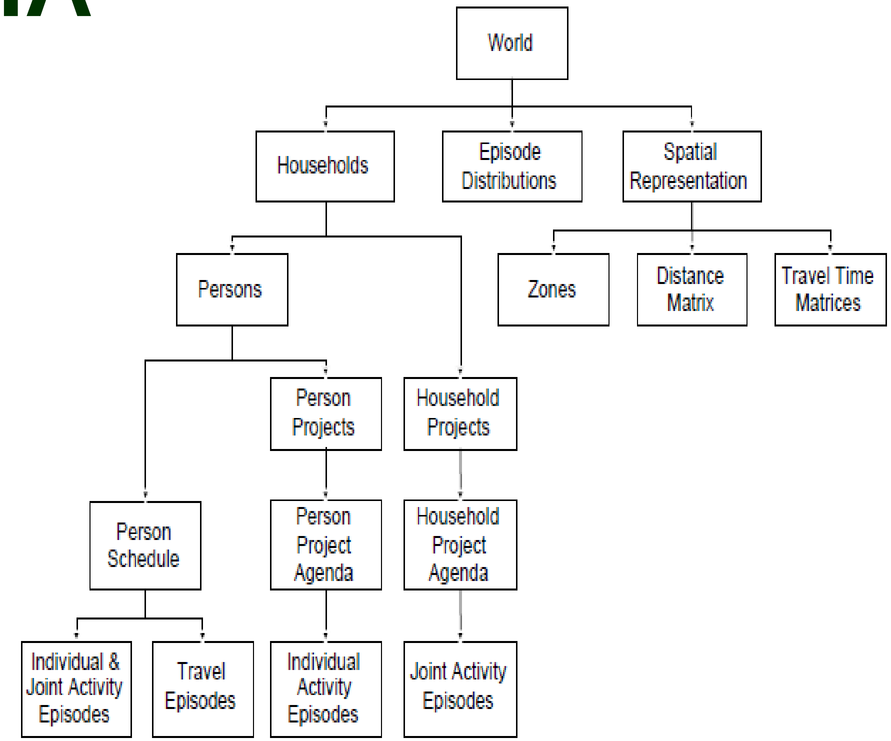


Fig. 1. Conceptual design of TASHA.



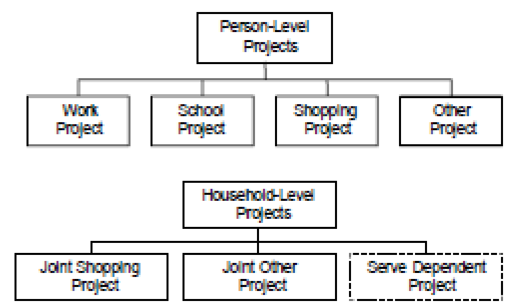
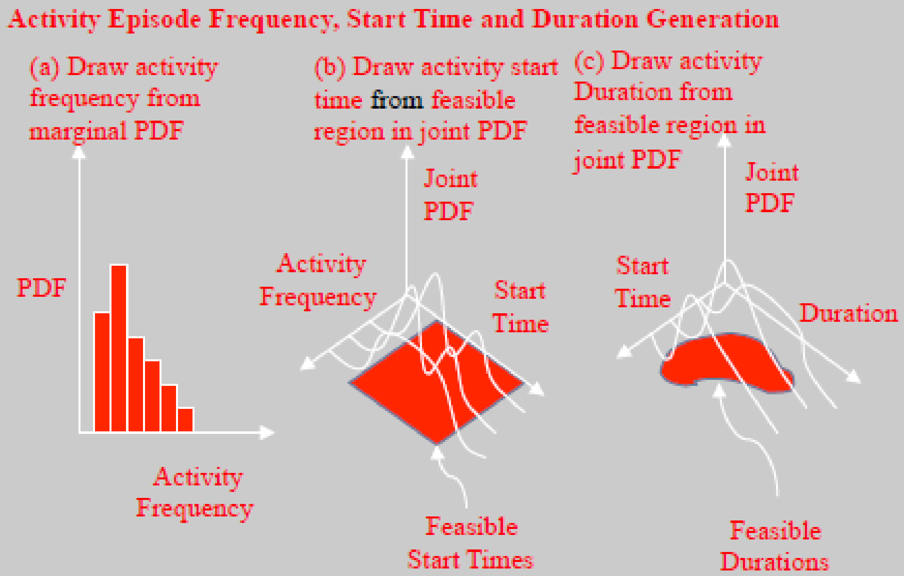


FIGURE 2 Project types.

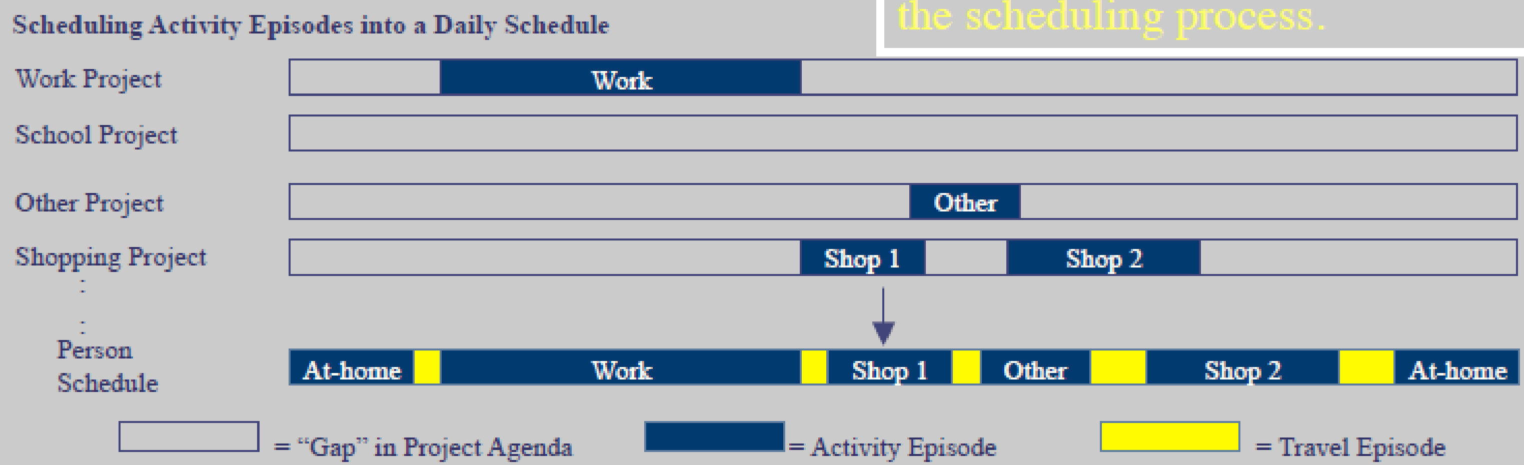
GTA Model with TASHA



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.

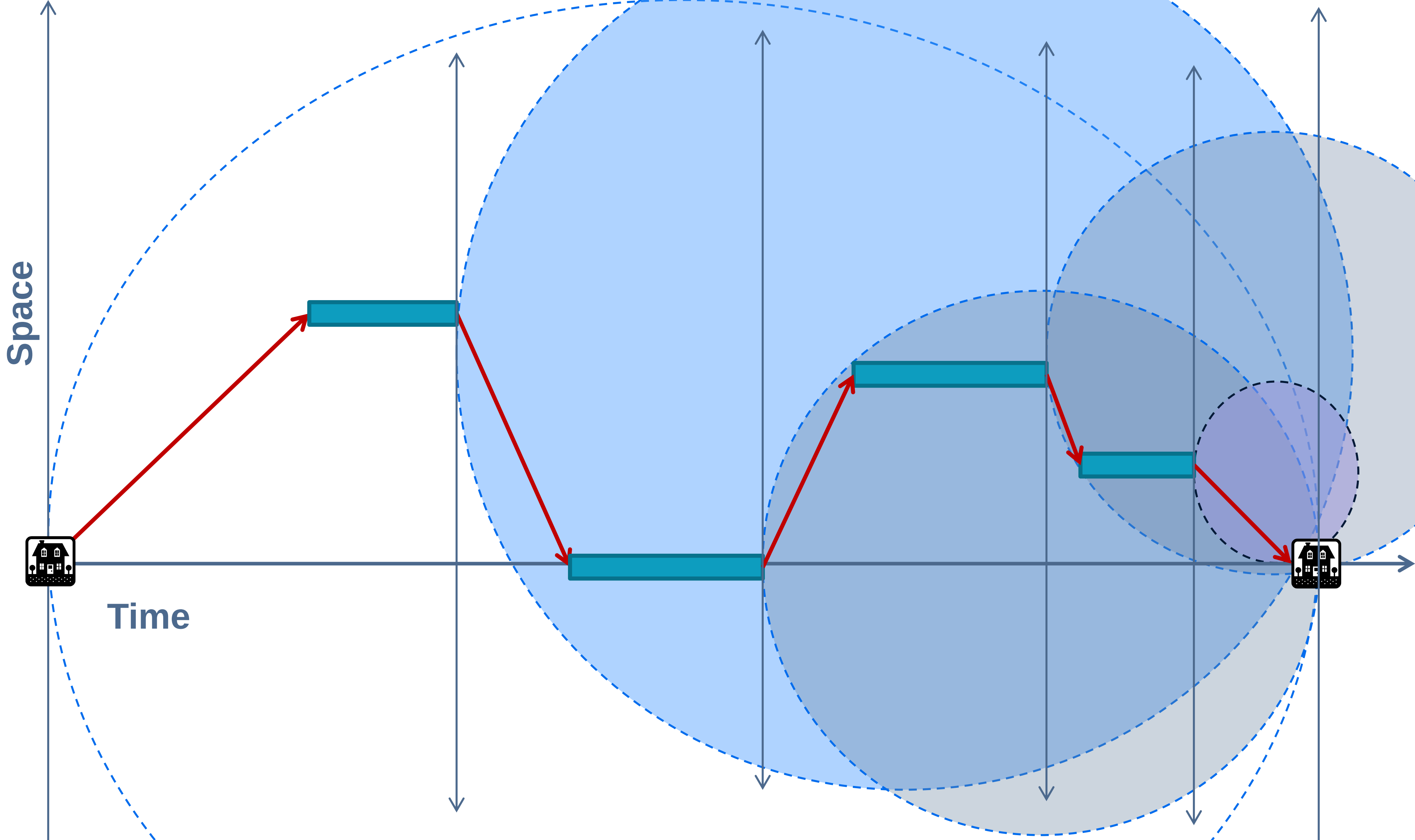


GTA Model

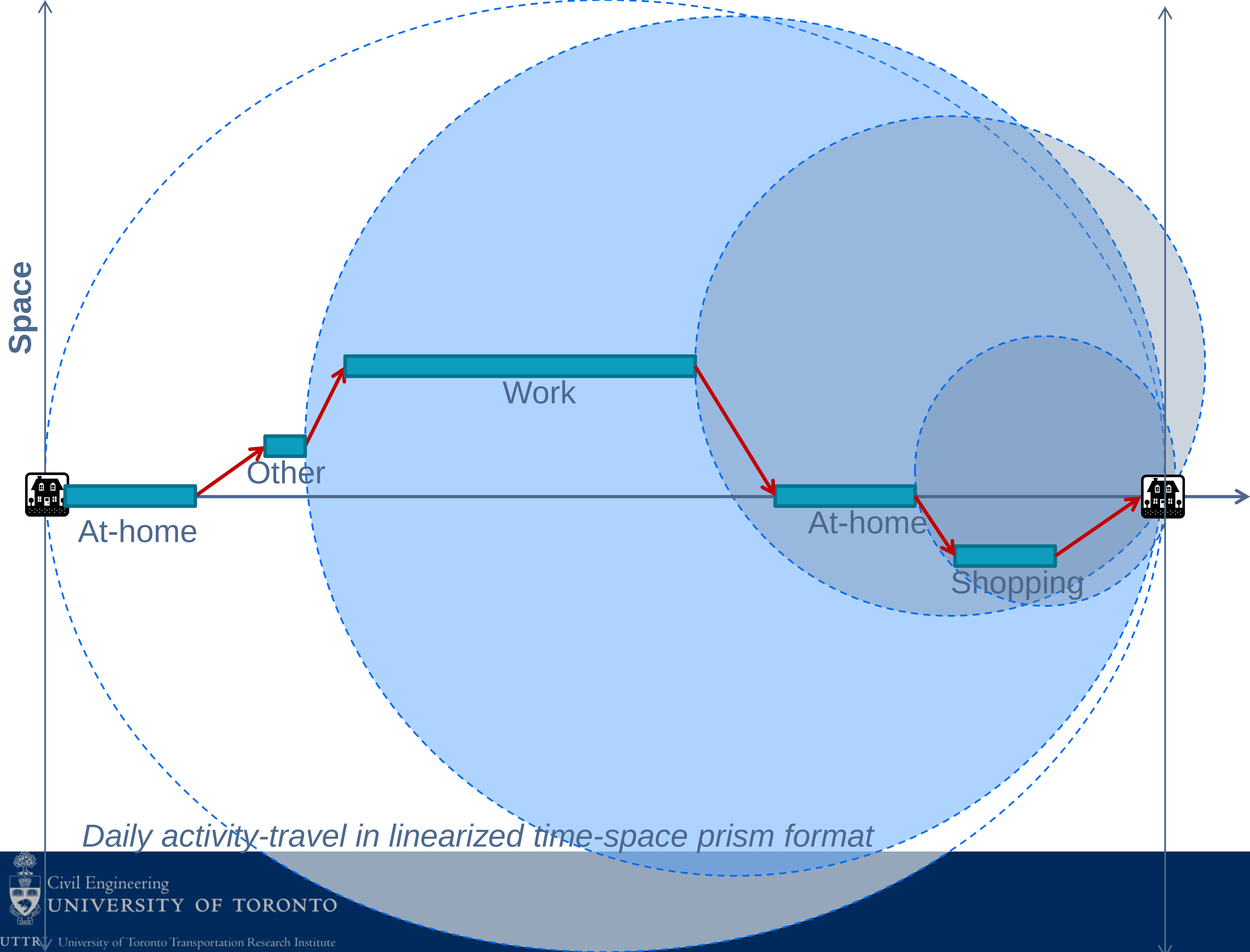
GTA model is called activity-based model even though:

- ✓ Activity/trips are based on non-parametric simulation that lack any policy sensitivity
- ✓ Activity schedules are formed based on deterministic rules
- ✓ Schedule are formed for individual level, but destination choice is not modelled at that level: uses aggregate gravity type model
- ✓ Mode choice is based on a household-based mode/task allocation approach that suffers mathematical identification approach

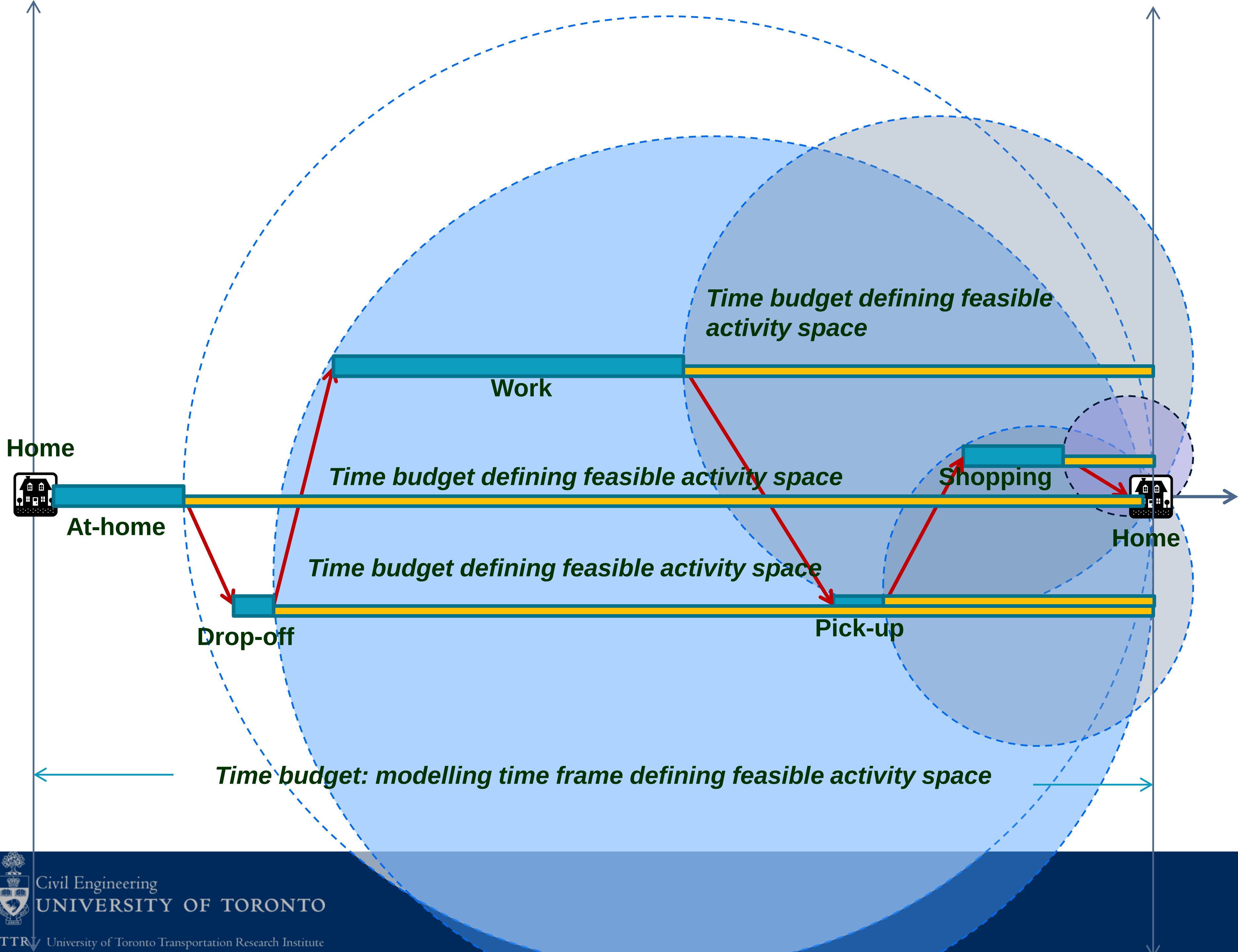
Modelling Travel Demand in the way it should be modelled!



Daily activity-travel in linearized time-space prism format



Daily activity-travel in linearized time-space prism format


Time budget defining feasible activity space
Work
Home
Time budget defining feasible activity space
Shopping
At-home
Home
Time budget defining feasible activity space
Drop-off
Pick-up
Time budget: modelling time frame defining feasible activity space

Comprehensive **U**tility-maximizing **S**ystem of **T**ravel **O**ptions **M**odelling (CUSTOM)

What Do we Observe?

- Observed Daily Activity-Travel Pattern of an Individual

1st Activity type, Location, Duration, Travel Model, etc.
2nd Activity type, Location, Duration, Travel Model, etc.
3rd Activity type, Location, Duration, Travel Model, etc.
4th Activity type, Location, Duration, Travel Model, etc.
……………………………………………
…………………………………………….
Last Activity type, Location, Duration, Travel Model, etc.

↔

A1,L1,D1,M1, etc.
A1,L1,D1,M1, etc.
A1,L1,D1,M1, etc.
A1,L1,D1,M1, etc.
……………….
……………….
Aj,Lj,Dj,Mj, etc.

- A set of **discrete choice bundles** (type, location, mode) under **continuous time frames** (star time and duration)
- A classical example of dynamic programing

What can we Assume?

A1,L1,D1,M1, etc.
A1,L1,D1,M1, etc.
A1,L1,D1,M1, etc.
A1,L1,D1,M1, etc.
………………
………………
Aj,Lj,Dj,Mj, etc.

- An Individual optimizes her/his daily activity travel patterns
  - ✓ An observed pattern are user's optimized pattern
- User optimization is influenced by:
  - ✓ transportation system performance that may have daily variations
  - ✓ Spatial distributions of land uses that do not change on daily basis
- An observed day's patterns is composed of one or multiple scheduling cycles. Each cycle includes:
  - ✓ Discrete choice bundle: activity type, destination location, travel mode and perhaps travel route
  - ✓ In context of shrinking time budgets

Dynamic and Behavioural Approach

- Modelling all such dimensions of activity-travel patters altogether is a mammoth task
  - ✓ Perhaps absolute optimization is absurd
  - ✓ However, dynamic optimization is obvious
  - ✓ Classical Bellman's approach of optimality is useful
- Assume a daily patterns is a panel of one or multiple activity scheduling cycles:
  - ✓ Choice of any cycle is based on maximizing utility of instantaneous choices along with discounted utilities of further expected choices ahead
  - ✓ Each scheduling cycle is constrained by time space prism: Maximum accessible area to road within the available time budgets → The Potential Path Area: PPA

Dynamic Discrete Choice Modelling Approach

Utility of a day's activity travel pattern at any time of day t

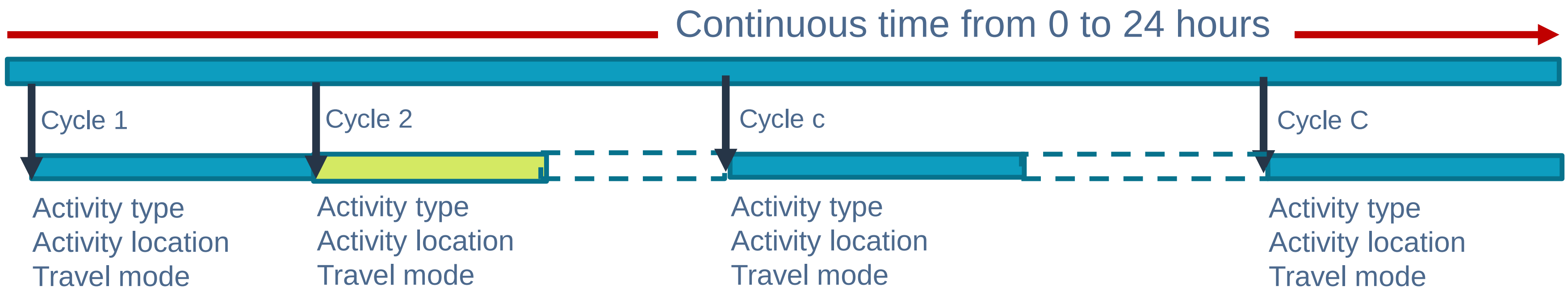
$$U_{pattern} = Maximize \int_{t=1}^{T} \left(\sum_{a=a}^{A} \sum_{l=l}^{L} \sum_{m=m}^{M} V_{alm}(\beta, x, d_t) + \varepsilon_a + \varepsilon_{l|a} + \varepsilon_{m|l} \right)_t f(t) dt$$

Under Bellman's approach of optimality (with finite horizon), scheduling of any activity at a particular time of the day (t) follows a dynamic approach

$$U_t = Maximize \begin{bmatrix} \left(V_{alm} + \varepsilon_a + \varepsilon_{l|a} + \varepsilon_{m|l} \right)_t \\ E\left(\int_{t'=t+1}^{T} \mu^{t'} \left(\sum_{a=a}^{A} \sum_{l=l}^{L} \sum_{m=m}^{M} (V_{alm} + \varepsilon_a + \varepsilon_{l|a} + \varepsilon_{m|l}) \right)_{t'} f(t') dt' \right) \end{bmatrix}$$

Dynamic Discrete Choice Modelling Approach

Considering panels of scheduling cycles within a day by separating embedded temporal function from discrete choices



$$U_{pattern} = Maximize \int_{t=1}^{T} \left(\sum_{a=a}^{A} \sum_{l=l}^{L} \sum_{m=m}^{M} V_{alm}(\beta, x, d_t) + \varepsilon_a + \varepsilon_{l|a} + \varepsilon_{m|l} \right)_t f(t)dt$$

Considering Discrete number of cycles:

$$= Maximize \int_{t=1}^{T} \left(\sum_{c=1}^{C} \left(V_{alm}(\beta, x, d_t) + \varepsilon_a + \varepsilon_{l|a} + \varepsilon_{m|l} \right)_c \right)_t f(t)dt$$

Dynamic Discrete Choice Modelling Approach

Dynamic Utility of Daily Activity Pattern Choices follows maximizing

$$U_{pattern} = Maximize \int_{t=1}^{T} \left(\sum_{c=1}^{C} \left(V_{alm}(\beta, x, d_t) + \varepsilon_a + \varepsilon_{l|a} + \varepsilon_{m|l} \right)_c \right)_t f(t)dt$$

Since Schedules are Formed Sequentially we can assume Bellman's approach of dynamic scheduling choice

For a panel of cycles, utility at any cycle (c):

$$U_c = Maximize \left[\begin{array}{l} \left(V_{alm} + \varepsilon_a + \varepsilon_{l|a} + \varepsilon_{m|l} \right)_c \\ + \mu^{c'} E \left(\sum_{c'=c+1}^{C} \left(V_{alm} + \varepsilon_a + \varepsilon_{l|a} + \varepsilon_{m|l} \right)_{c'} \mid cycle\ choice\ c \right) \end{array} \right]$$

Dynamic Discrete Choice Modelling Approach

Utility of dynamic activity scheduling choices:

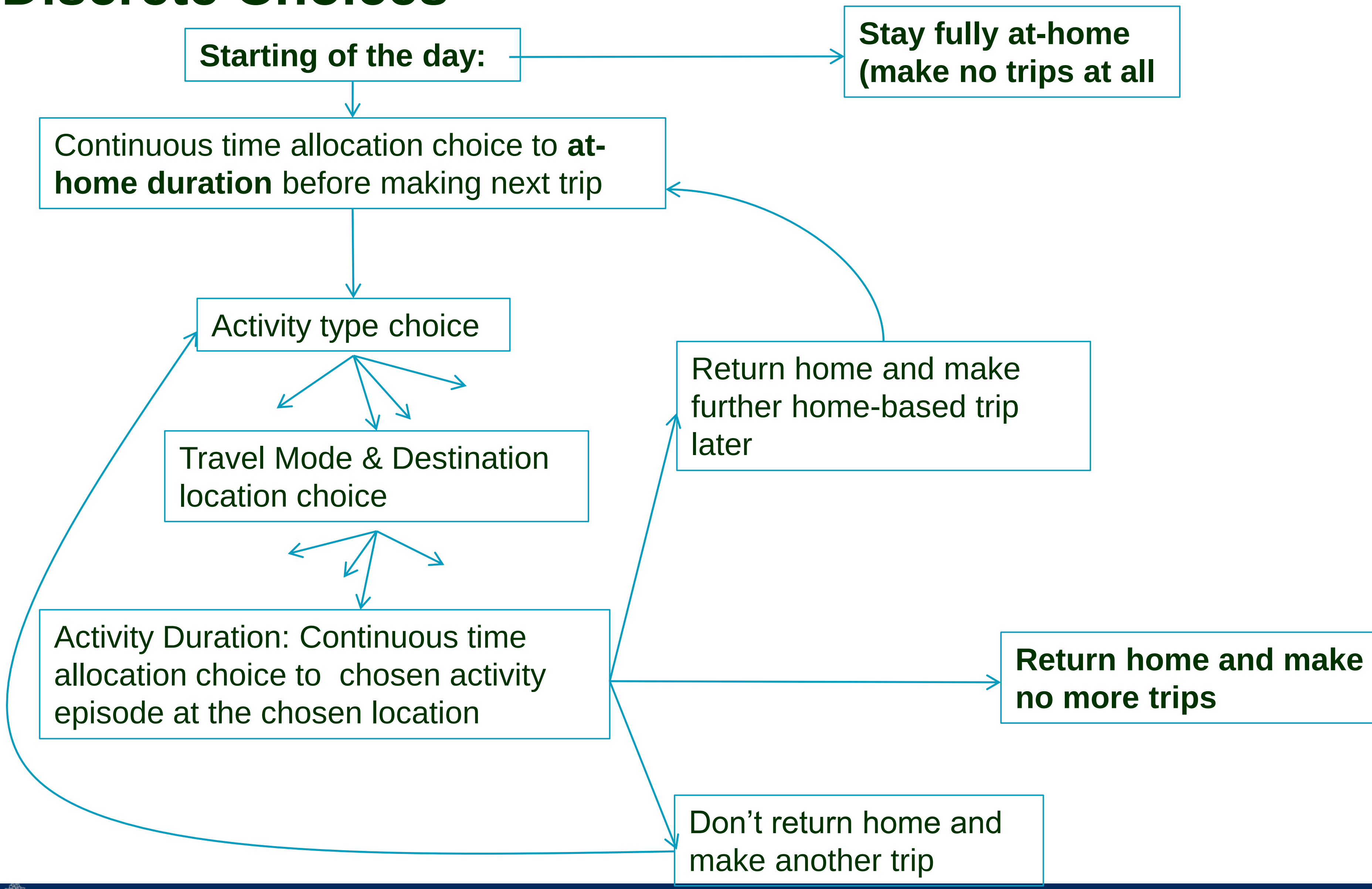
$$U_c = Maximize\begin{bmatrix} \left(V_{alm} + \varepsilon_a + \varepsilon_{l|a} + \varepsilon_{m|l}\right)_c \\ + \mu^{c'} E\left(\sum_{c'=c+1}^{C}\left(V_{alm} + \varepsilon_a + \varepsilon_{l|a} + \varepsilon_{m|l}\right)_{c'} \mid cycle\ choice\ c\right) \end{bmatrix}$$

With IID Type I Extreme Value Assumption of error terms:

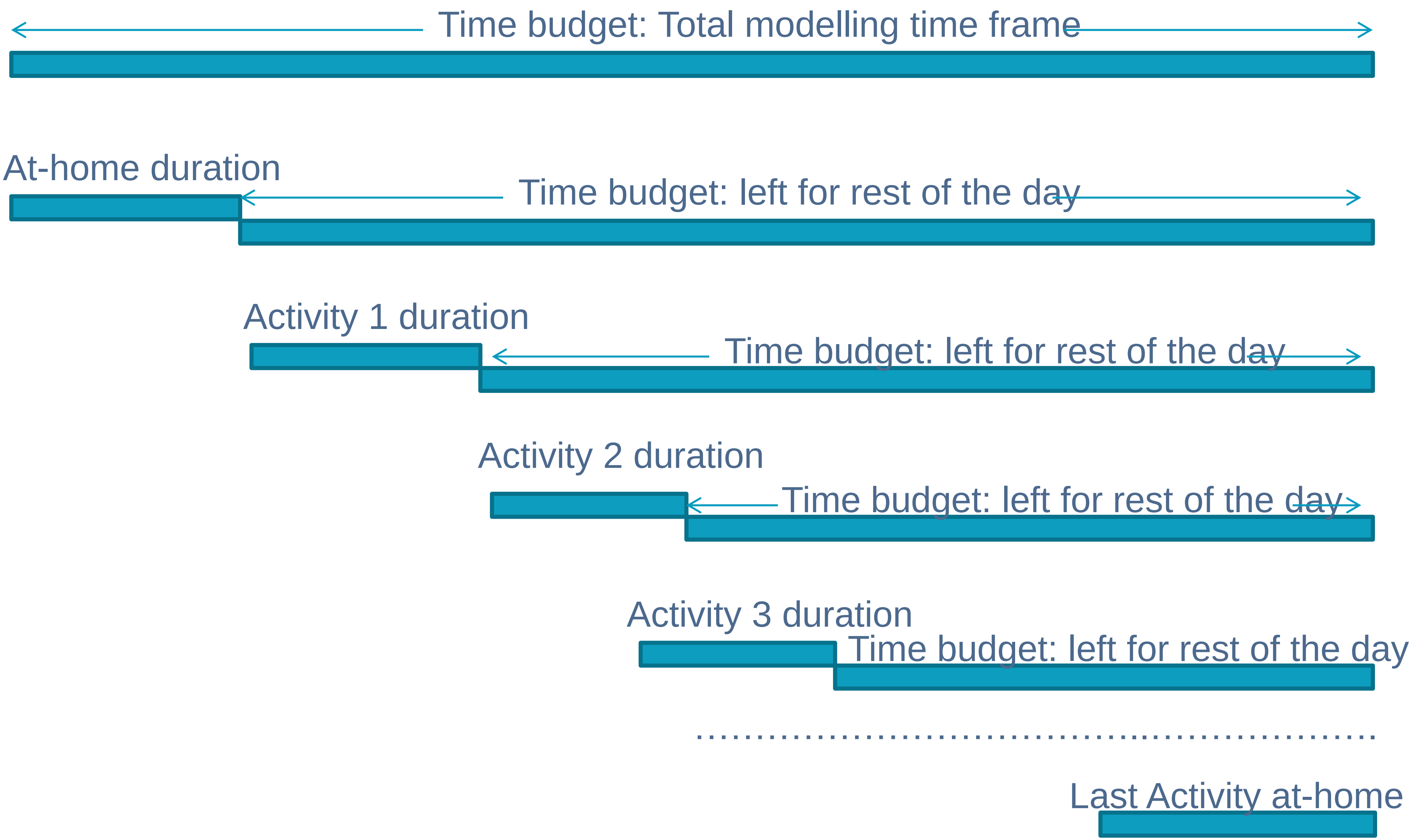
$$= Maximize\begin{bmatrix} \left(V_{alm} + \varepsilon_a + \varepsilon_{l|a} + \varepsilon_{m|l}\right)_c \\ + Summation\ of\ \ LOGSUMs \\ of\ all\ \ future\ cycles\ \ discounted\ by\ \mu^{c'} \mid cycle\ choice\ c \end{bmatrix}$$

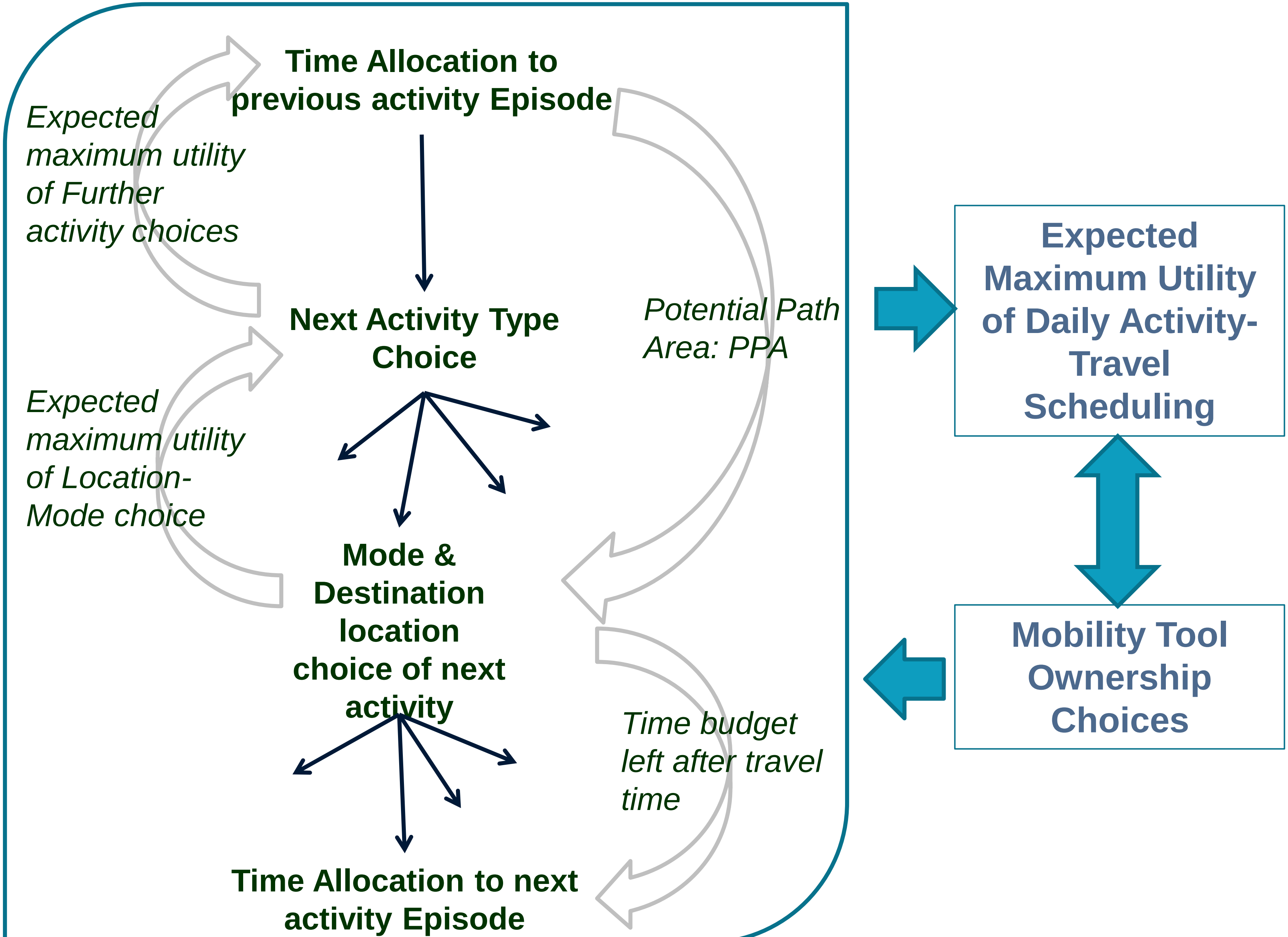
Resulting scheduling choice model can be a Dynamic-GEV model of activity type, location and mode choice

Discrete Choices

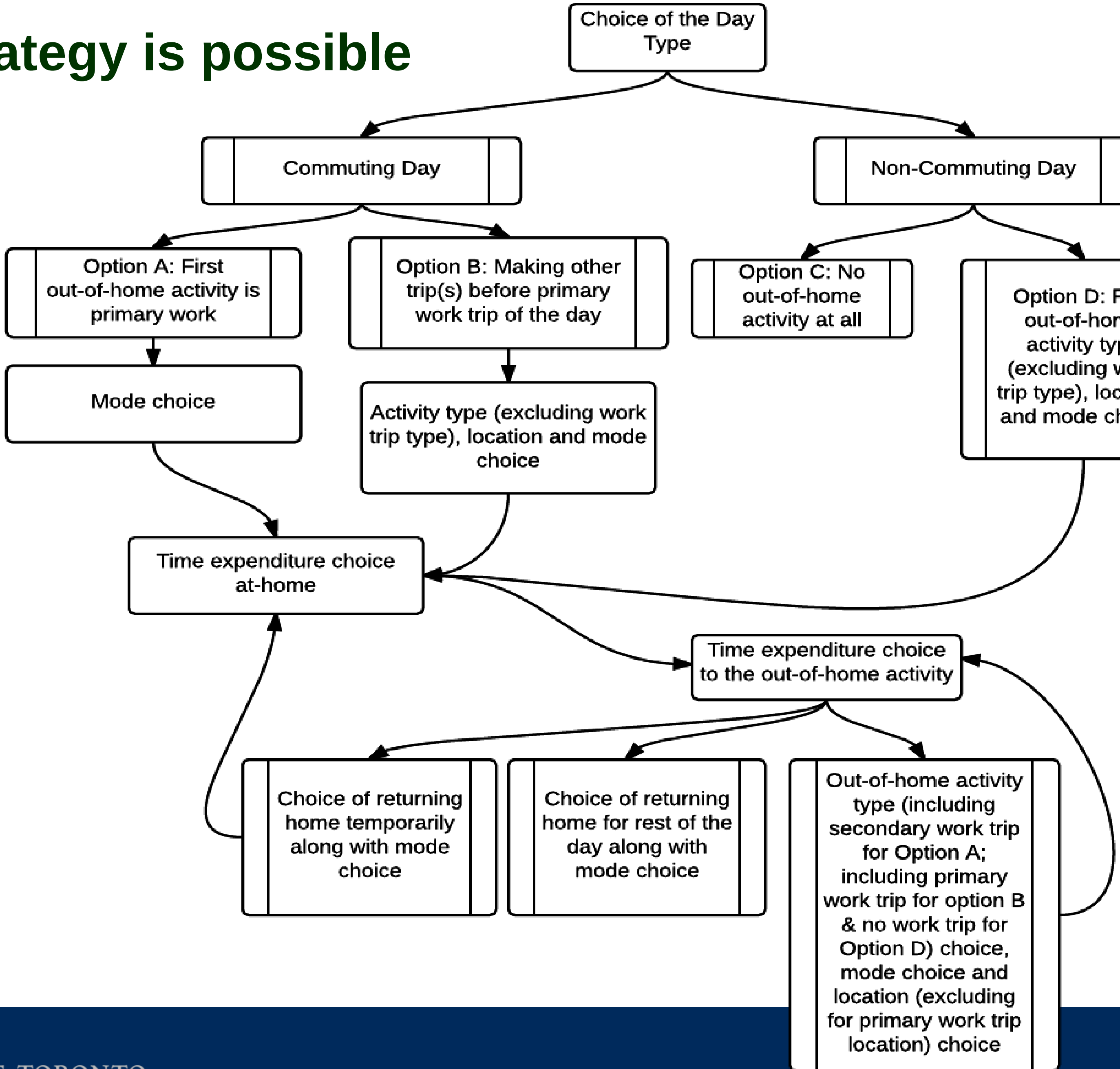


Continuous Time Allocations/Consumptions




Time Allocation to previous activity Episode
Expected maximum utility of Further activity choices
Next Activity Type Choice
Potential Path Area: PPA
Expected maximum utility of Location-Mode choice
Mode & Destination location choice of next activity
Time budget left after travel time
Time Allocation to next activity Episode
Expected Maximum Utility of Daily Activity-Travel Scheduling
Mobility Tool Ownership Choices

Various strategy is possible



At any Cycle, the Duration of Chosen Activity Type (that gives the start time of next cycle)

$$U(t_k) = \frac{1}{\alpha_j}\exp(\psi_j z_j + \varepsilon_j)\ (t_j^{\alpha_j} - 1) + \frac{1}{\alpha_c}\exp(\psi_c z_c + \varepsilon_c)\ (t_c^{\alpha_c} - 1)$$

$$\text{Time budget constraint}: t_j + t_c = T$$

Applying Kuhn-Tucker Optimality conditions and direct utility maximization under GEV random error

$$\Pr(t = t_j) = \left(\frac{1-\alpha}{t} + \frac{1-\alpha_c}{t_c}\right)\mu_{t_j}\ \exp\left(-\mu_{t_j}(V_c - V_j)\right)\left[1 + \exp\left(-\mu_{t_j}(V_c - V_j)\right)\right]^{-2}$$

where,

$$\left(\frac{d\left(V_c - V_j\right)}{dt}\right) = \frac{(1-\alpha_j)}{t_j} + \frac{(1-\alpha_c)}{t_c}$$

$$V_j = (\psi z)_j + (\alpha_j - 1)\ln\left(t_j\right) + I_{Act_j} / \mu_{h_j}$$

Discrete Activity Scheduling Choices

For any cycle (c) starting out-of-home, possible options:

1. Return home temporarily (HT_c)
2. Return home for the day (H_c)
3. Choose any (a_c) of total A_c number of possible non-return home activities

➢ Considering a GEV structure of activity choice:

$$P(HT_c) = \frac{\exp\left(\mu_{h_c} V_{ht_c} + \mu_{h_c} \left(\sum_{c'=c+1}^{C} LogSum_{Cycle'-c'} / \mu_{h_{c'}} \right) \mid HT_c \right)}{\left[\begin{array}{l} \exp\left(\mu_{h_c} V_{ht_c} + \mu_{h_c} \left(\sum_{c'=c+1}^{C} LogSum_{Cycle'-c'} / \mu_{h_{c'}} \right) \mid HT_c \right) \\ + \exp\left(\mu_{h_c} V_{h_c}\right) \\ + \exp\left(\mu_{h_c} I_{A_c} / \mu_{a_c} + \mu_{h_c} \left(\sum_{c'=c+1}^{C} LogSum_{Cycle'-c'} / \mu_{h_{c'}} \right) \mid a_c \right) \end{array} \right]}$$

Discrete Activity Scheduling Choices

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Discrete Activity Scheduling Choices

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Discrete Activity Scheduling Choices

The expected maximum utility of non-return home activity type choice

$$I_{A_c} = \ln\left(\sum_{A_c} \exp(\mu_{a_c} V_{a_c})\right)$$

The expected maximum utility of activity type choice at the end of j[th] scheduling cycle

$$I_{Act_c} = \ln\left(\exp(\mu_{h_c} V_{ht_c}) + \exp(\mu_{h_c} V_{h_c}) + \exp(\mu_{h_c} I_{A_c} / \mu_{a_c})\right)$$

The systematic utility of non-return home activity type choice:

$$V_{a_c} = (\beta x)_{a_c} + I_{l_c} / \mu_{l_c}$$

I_{lj} is the expected maximum utility of location choice, where location choice utility $U_{l_c} = V_{l_c} + I_m / \mu_m + \varepsilon_{l_c}$

Discrete Activity Scheduling Choices

Location choice probability & expected maximum utility of location choice considering a total L_j location at cycle j randomly selected from potential path area (PPA) defined by time budget of at the end of j^{th} cycle

$$P(l_j) = \frac{\exp(\mu_{l_j} V_{l_j} + I_m \mu_{l_j} / \mu_m)}{\sum_{L_j} \exp(\mu_{l_j} V_{l_j} + I_m \mu_{l_j} / \mu_m)} \qquad I_{l_j} = \ln\left(\sum_{L_j} \exp(\mu_{l_j} V_{l_j} + I_m \mu_{l_j} / \mu_m) \right)$$

The mode choice for a particular destination choice:

$$U_m = V_m + \varepsilon_m$$

The mode choice probability:

$$P(m) = \frac{\exp(\mu_m V_m)}{\sum_m \exp(\mu_m V_m)}$$

Dynamic Random Utility Maximization

Within a specific cycle c

$$\mu_{t_c} < \mu_{h_c} < \mu_{l_c} < \mu_{m_c}$$

Between 2 consecutive cycles (c-1) and c

$$\mu_{l_{c-1}} < \mu_{t_c}$$

$$\mu_{t_c} = \mu_{l_{c-1}} + \exp((\gamma z)_{t_c})$$

$$\mu_{h_c} = \mu_{t_c} + \exp((\gamma z)_{h_c})$$

$$\mu_{l_m} = \mu_{h_c} + \exp((\gamma z)_{l_c})$$

$$\mu_{m_c} = \mu_{l_c} + \exp((\gamma z)_{m_c})$$

- Estimation would require recursion: Backward recursion techniques works well in this case

Identification-Estimation

- Model identification requires fixing all scale parameters of first cycle that starts at home to be unity.

- Scale parameters captures the conceptual linkages among time allocation choice to an activity episode, end activity type choice, destination location choice and between the scheduling cycles

- Potential Path Area (PPA) at any scheduling cycle for destination location choice is defined by composite activity duration

Components of CUSTOM

1. Scale parameter functions:
   a. Scale parameter of time allocation choice
   b. Scale parameter of return home activity choice
      I. Scale parameter of out-of-home activity type choice
         i. Scale parameter of destination location choice
2. Base line direct utility function for activity duration choice:
   a. Baseline utility of at-home activity duration choice at the beginning of the day
   b. Baseline utility of subsequent activity duration choice if out-of-home trips are made

Components of CUSTOM

1. …
2. …

3. Satiation parameter function of activity duration choice:
    a. Satiation parameter of at-home duration at the beginning of the day
    b. Satiation parameter of subsequent activity durations
4. Activity type choice systematic indirect utility function:
    a. Out-of-home activity type choice utility
    b. Stay home choice utility
5. Destination location choice systematic indirect utility
6. Mode choice systematic indirect utility

Behavioural Ingredients of CUSTOM

1. Scale parameter functions:
   - Defines choice scale, the implicit correlations among choice alternatives under the specific scale
   - Increasing scale refers to increasing correlations among the alternatives (making them more comparable) and subsequently increases choice predictability
2. Systematic baseline marginal utility of time allocation choice:
   - Systematic baseline preference of time allocation against composite activity (which is references as exp(0)=1)
   - Increasing baseline utility refers to increasing minimum activity duration

Behavioural Ingredients of CUSTOM

1. …
2. …
3. Satiation parameter function of activity duration choice:
   - Explains the rate at which the marginal utility of time allocation choice decreases with time
   - $\alpha = 1$ refers to constant marginal utility
   - $1 > \alpha > 0$ refers to decreasing rate of marginal utility
   - $\alpha \rightarrow$ negative infinity refer to immediate satiation and time allocation is based on baseline utility mostly
4. Utility of choosing an activity type
   - Higher utility refers to higher probability of scheduling the activity
5. Destination location choice systematic indirect utility:
   - Utility of an alternative location
   - Higher utility of a location refers to higher attraction to that destination location

Behavioural Ingredients of CUSTOM

1. …
2. …
3. …
4. …
5. …
6. Mode choice systematic indirect utility:
   - Modal captivity
   - elasticities

Distinction of CUSTOM from Other Activity-Based Models

- Unlike fully discrete-choice based modelling framework Bowman and Ben-Akiva model, CT-RAMP model) CUSTOM uses choice model to model the 'processes' of activity-travel schedule than considering the end product of the 'processes' as choice units:
  - ✓ Activity-travel patterns are outcome of scheduling process
  - ✓ Trip chains are modelled naturally without any pre-specified chaining style/pattern

Distinction of CUSTOM from Other Activity-Based Models

- Unlike hybrid models (e.g. ADAPTS, TASHA, FAMOS etc.), CUSTOM has no hard-wired deterministic rules in the scheduling model
  - ✓ Use potential path area (PPA) to define constrained destination choice set
  - ✓ Use the assumption of Random Utility Maximization in choice behaviour
  - ✓ Capturing behavioural trade-offs in time-space-activity type choices
  - ✓ Capture conditionality and endogeneity.

Distinction of CUSTOM from Other Activity-Based Models

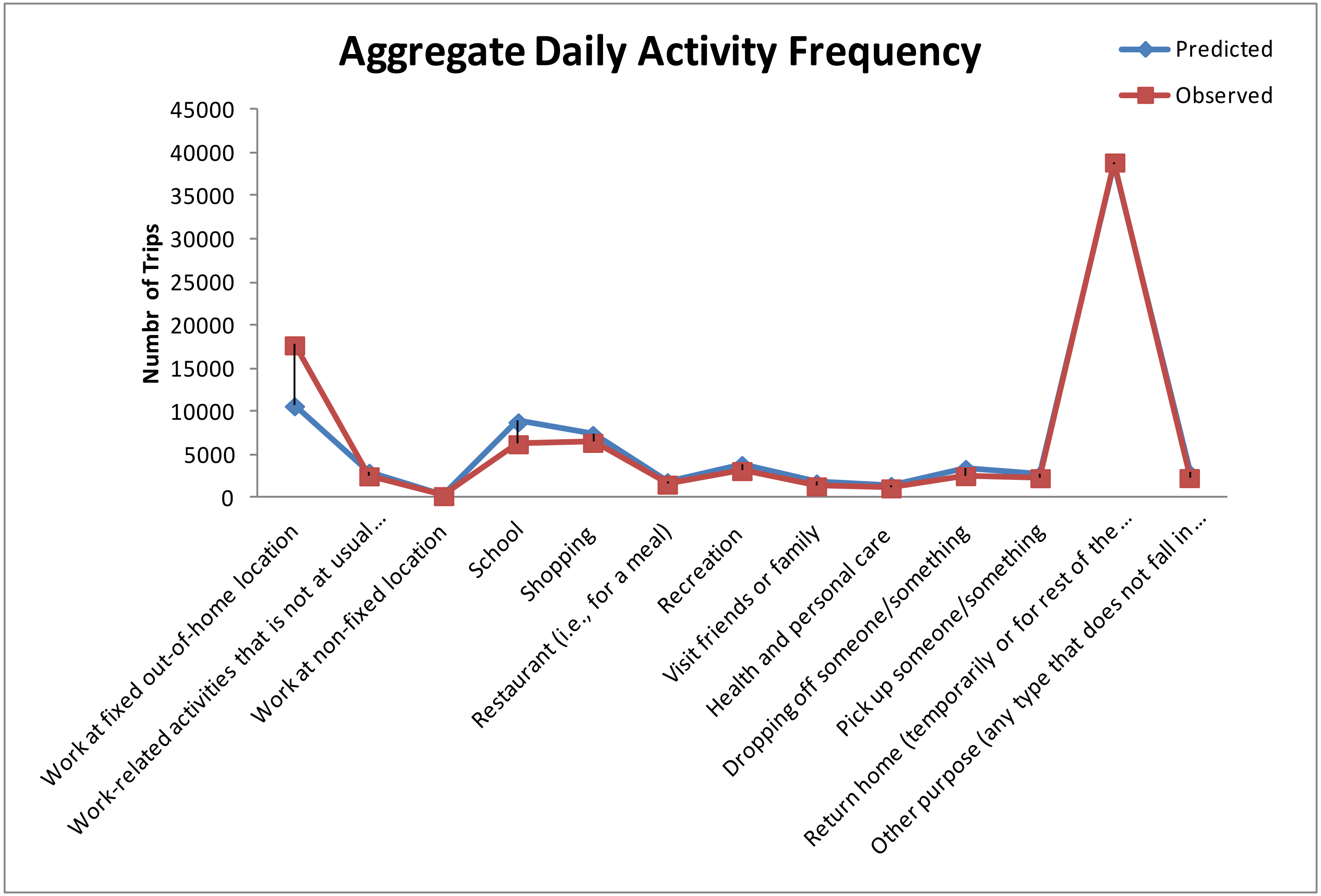
- Like simulation models, e.g. PCAT, CUSTOM considered time-space prism to define activity-travel constraints:
  - ✓ In addition to defining the PPA, the consideration of composite activity concept allows capturing time constrains in duration choice.

- Unlike conglomerate econometric models (e.g. CEMDEP), CUSTOM models all elements of activity-travel demand (trip generation, destination location choice and activity episode duration and start time) jointly
  - ✓ Capturing behavioural trade-offs in time-space-activity type choices
  - ✓ Capture conditionality and endogeneity.

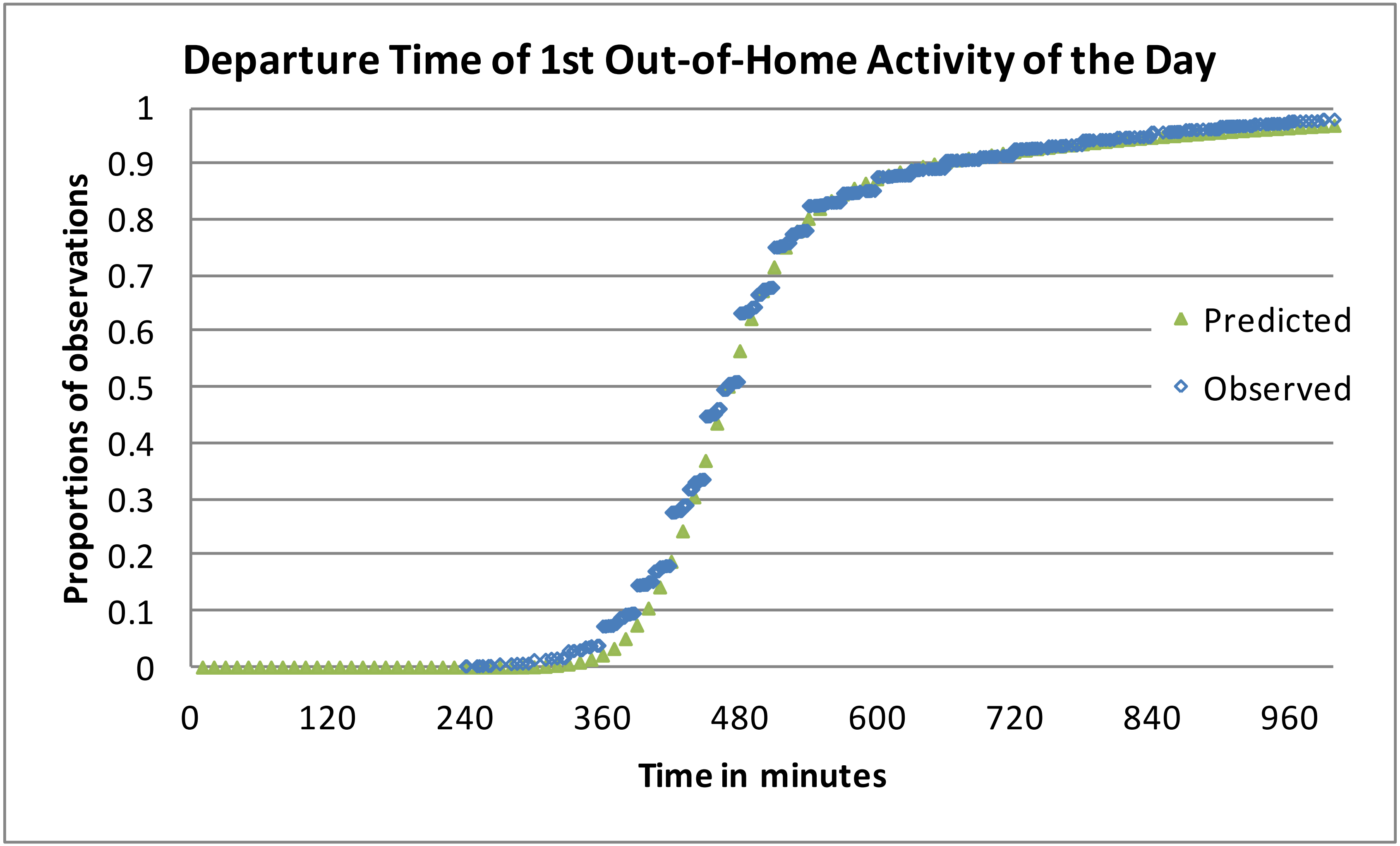
A Prototype Application: Modelling Daily Scheduling of Workers in the National Capital Region (NCR)

- 2011 NCR Household Travel Survey Data
- 24-hour schedules of 30,000 workers are selected: 15000 records are used to estimate the model and 15000 records are used for validation

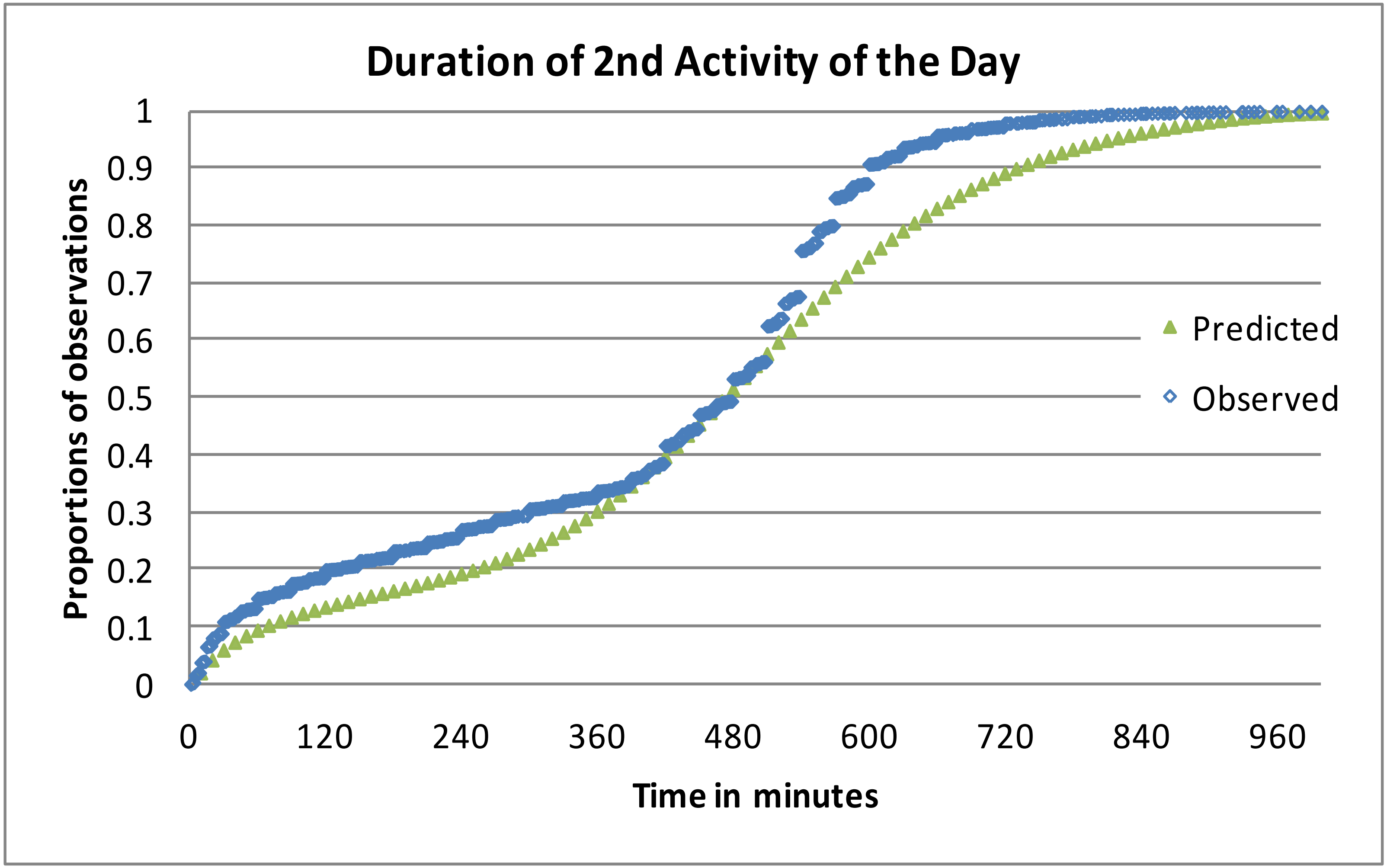
Results: Aggregate Trips



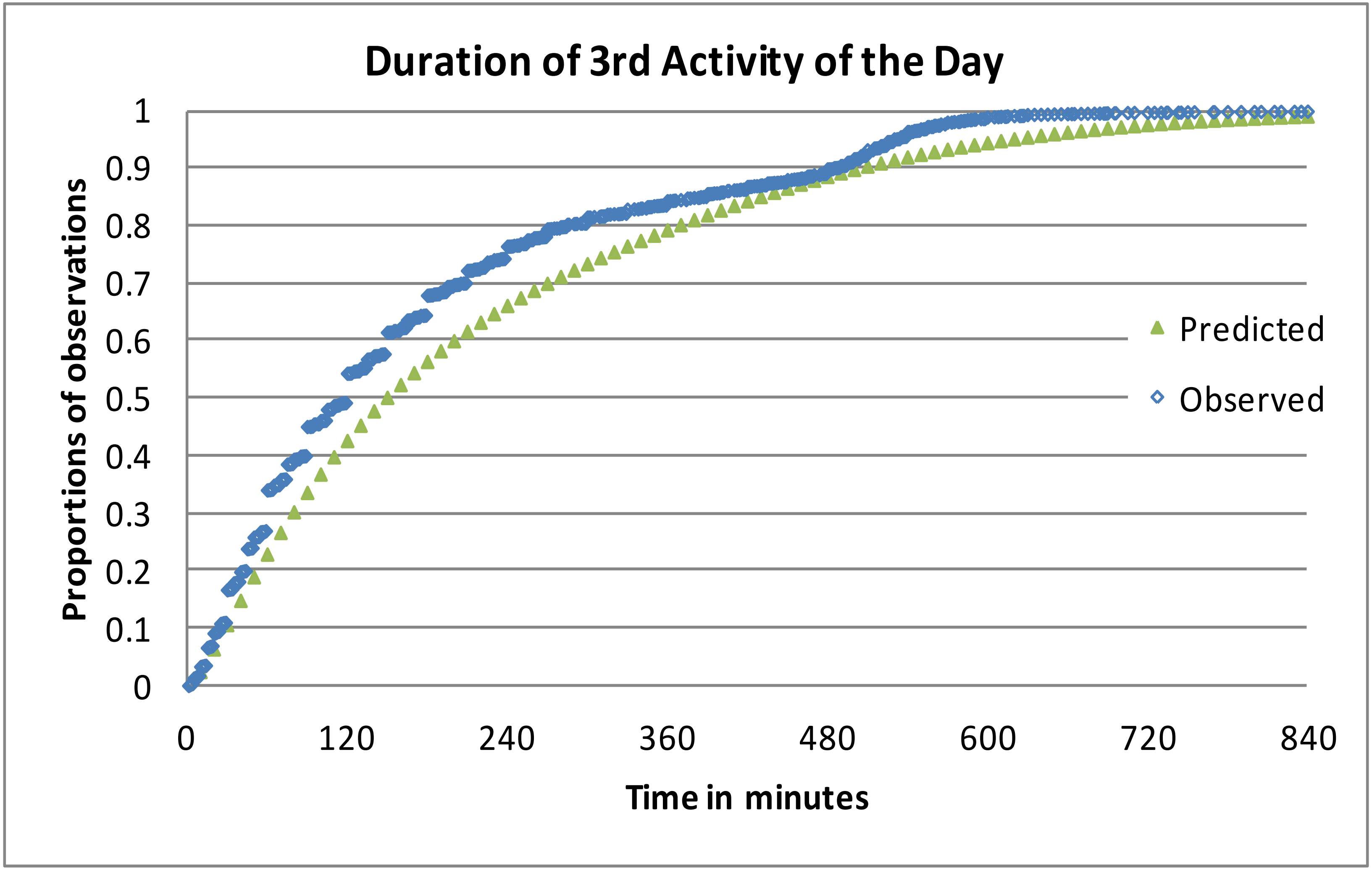
Results: Departure Time



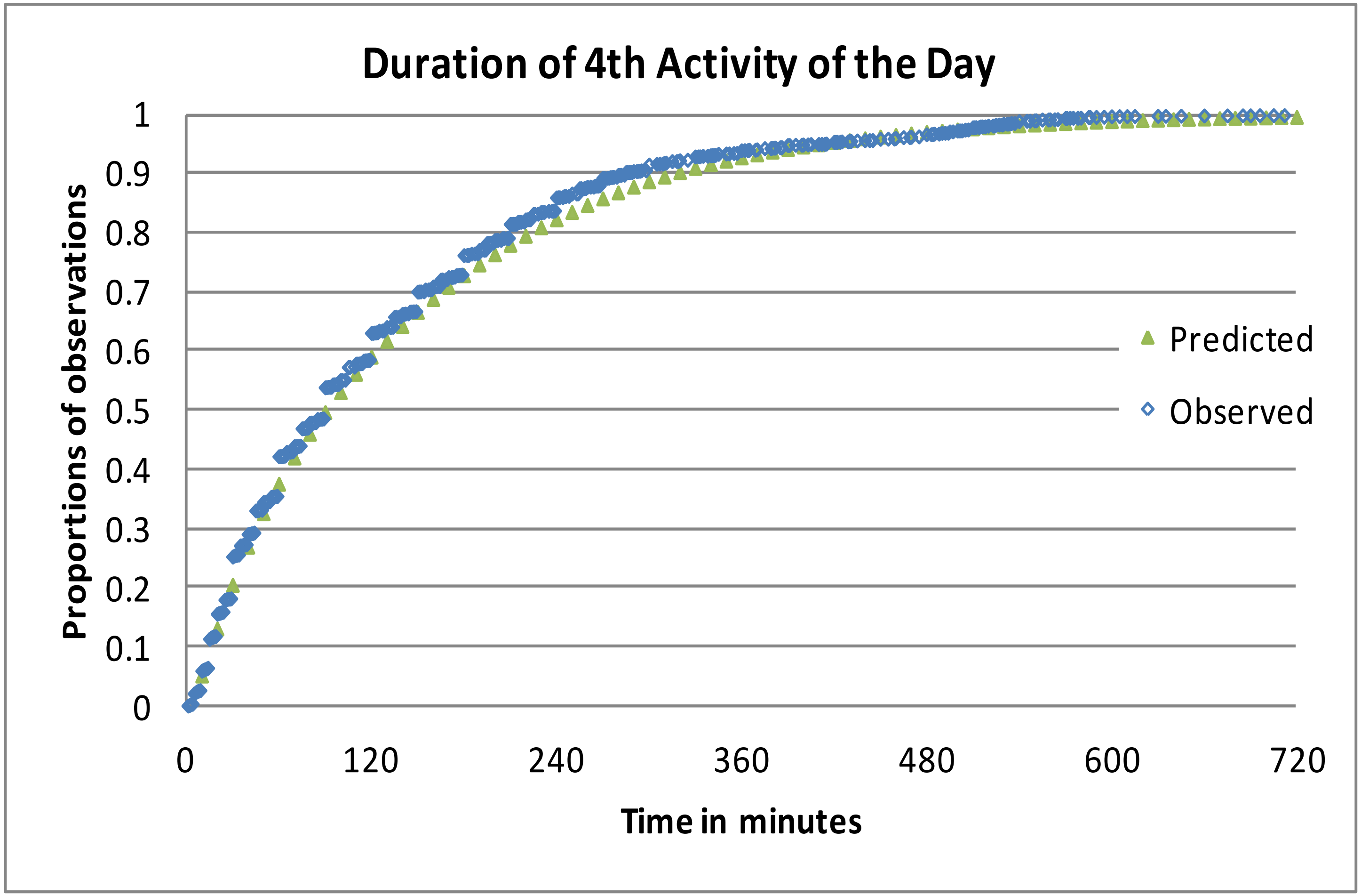
Results: Activity Durations



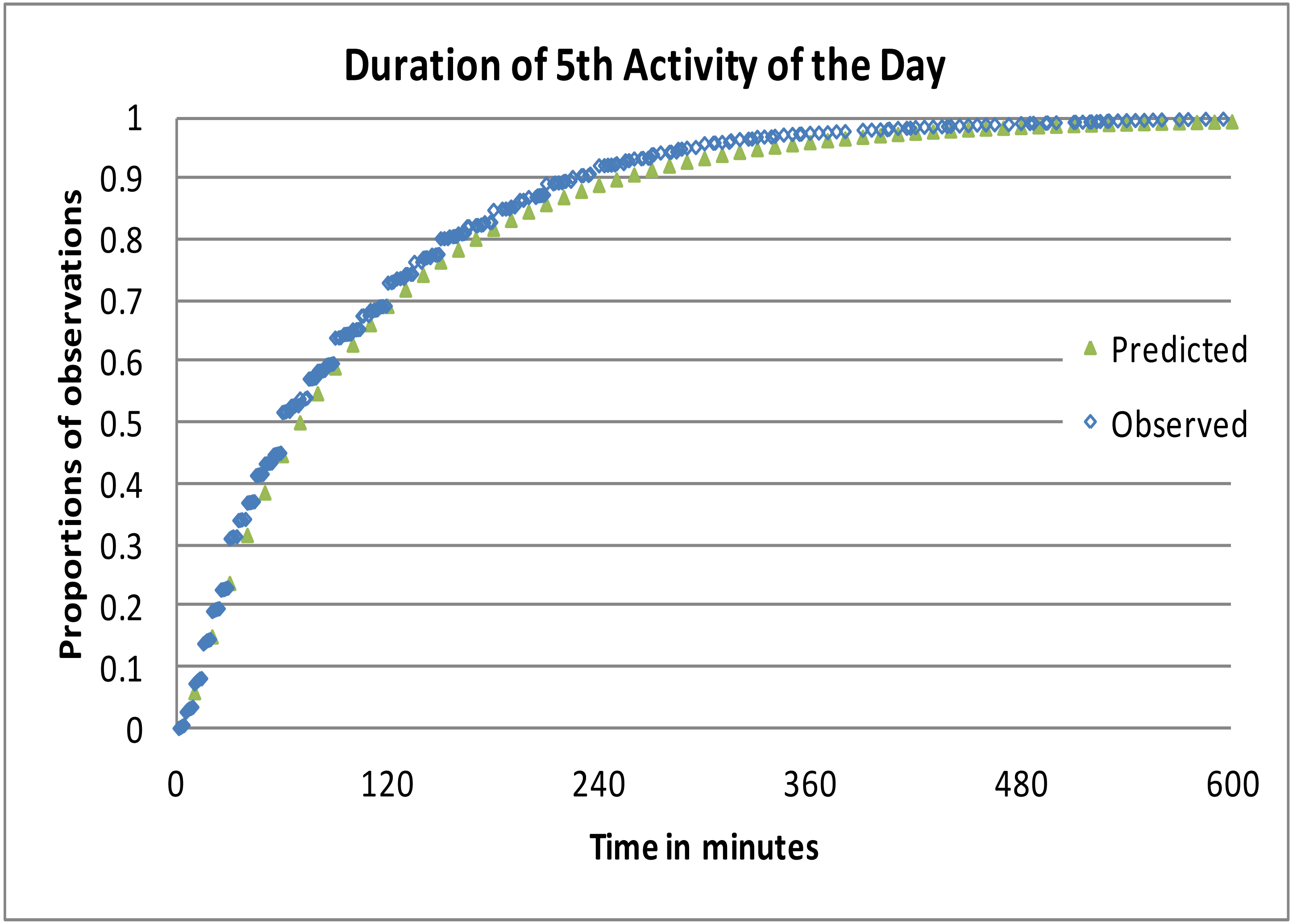
Results: Activity Durations



Results: Activity Durations



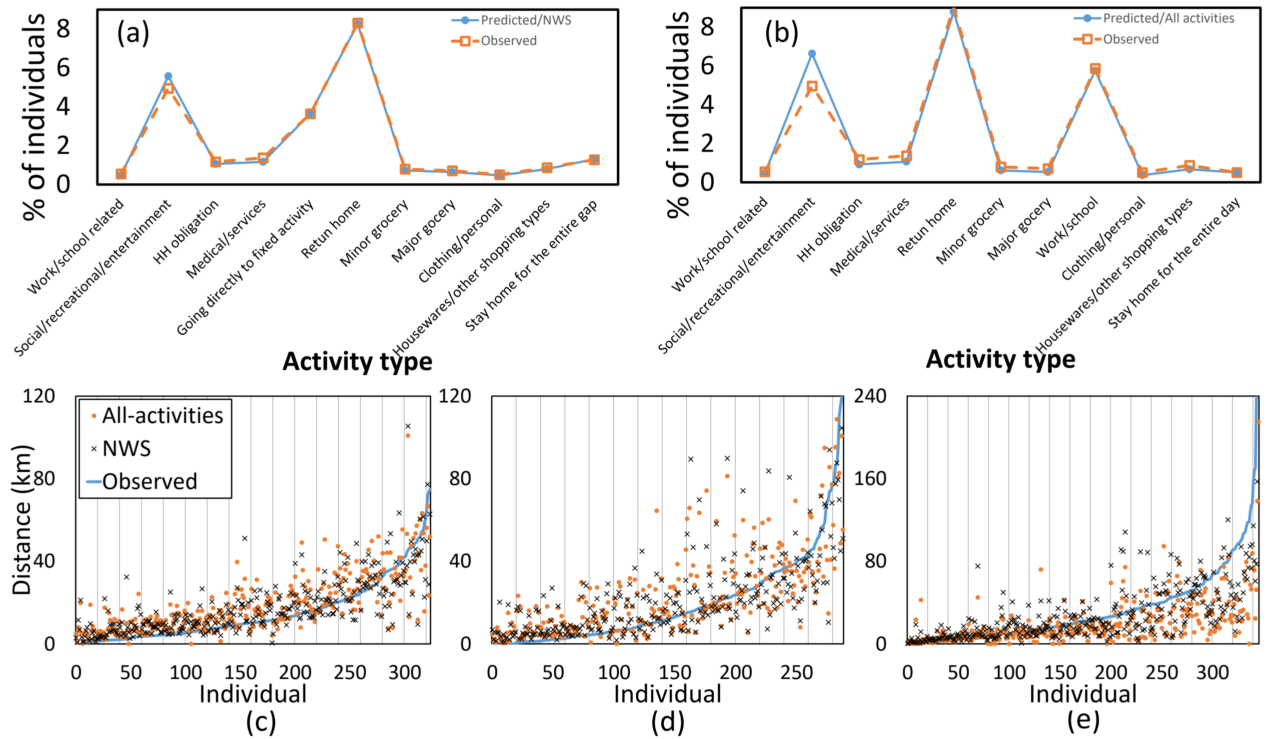
Results: Activity Durations



A Prototype Application: Modelling Daily Activity Schedules of Workers in the GTHA

- 2003 CHASE Data collected in the GTHA
- A relatively small, but 7-day activity diary data
- A total of 416 individuals
- Applied to model daily activity schedules of workers only

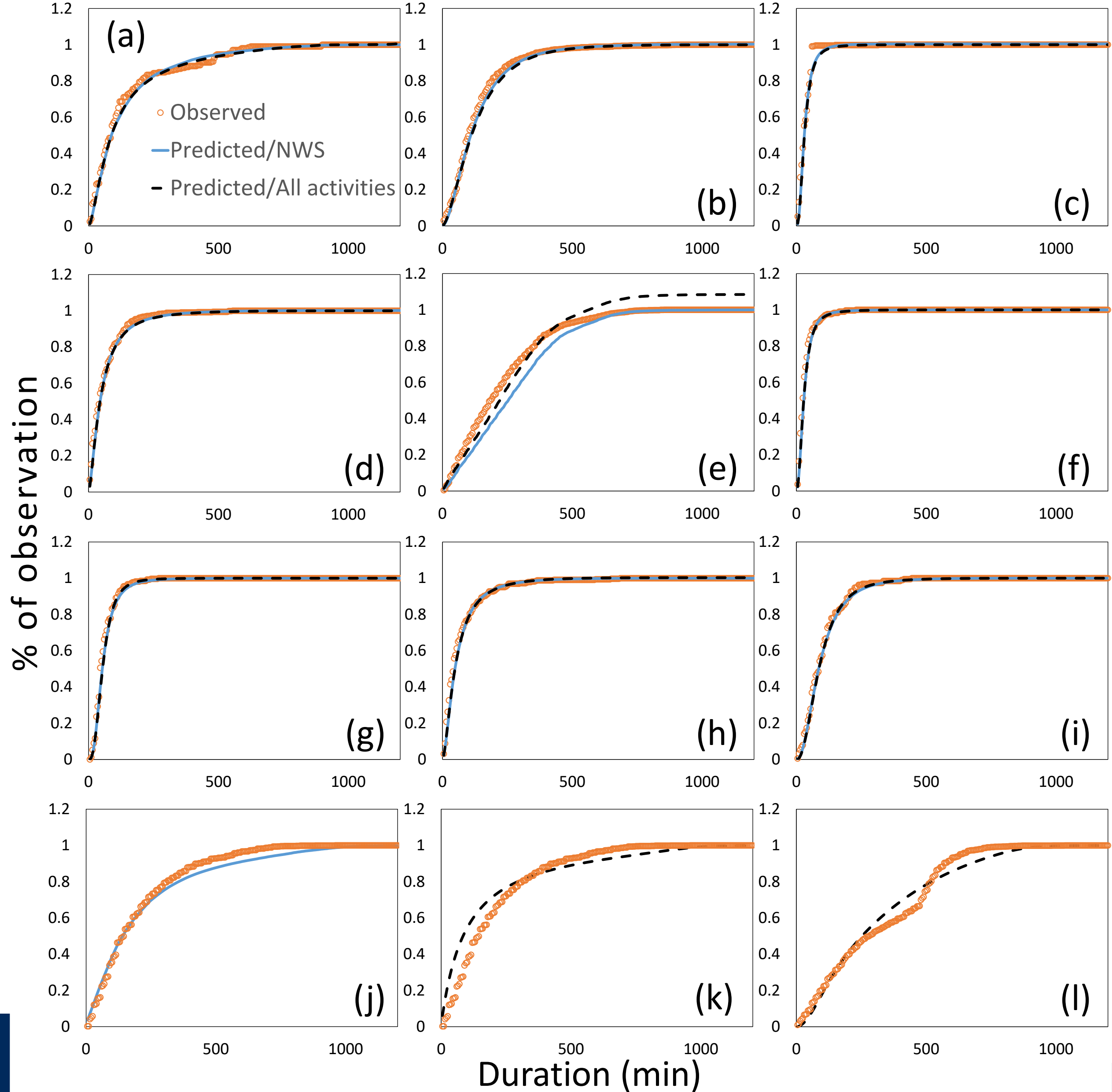
Activity and Destination Choices Validation Results



(a) Activity type validation of the NWS scheduling model, (b) Activity type validation of the all-activities scheduling model, (c) destination choice validation of shopping episodes, (d) destination choice validation of household obligation, medical/services and work/school related episodes, (e) destination choice validation of social/recreational/entertainment.

Activity Duration/Start time validation

(a) work/school related episodes, (b) social/recreational/entertainment, (c) household obligation, (d) medical/services, (e) return home, (f) minor grocery shopping, (g) major grocery shopping, (h) housewares/other shopping episodes, (i) clothing/personal shopping episodes, (j) at-home time expenditure in the first sequence of NWS model, (k) at-home time expenditure in the first sequence of all-activities model, (l) work/school episodes.

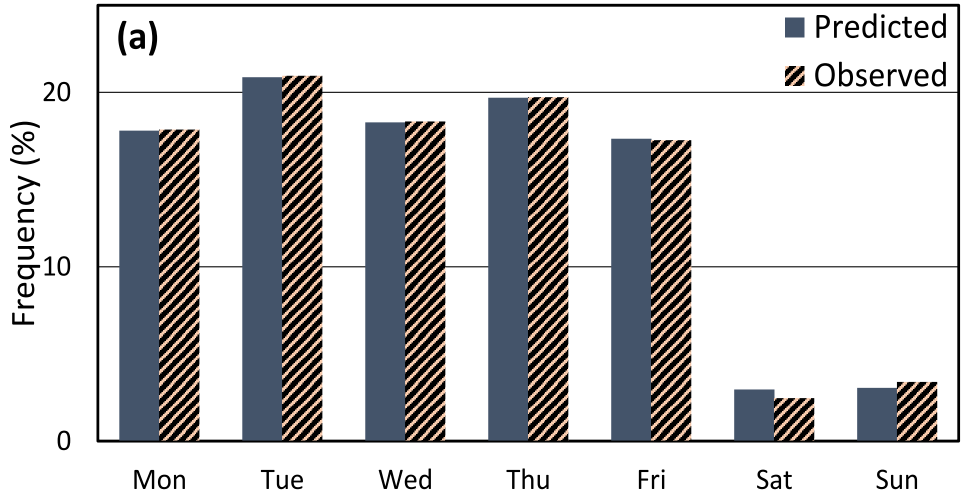


A Prototype Application: Modelling Week-long Work Schedules of Workers in the GTHA

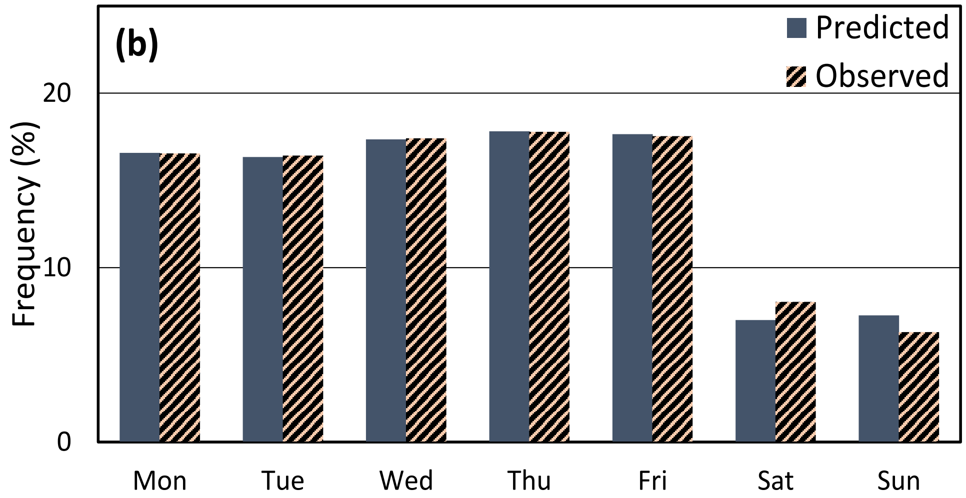
- 2003 CHASE Data collected in the GTHA
- A relatively small, but 7-day activity diary data
- A total of 416 individuals
- Applied to model only work schedules: pre-planned and un-planned work activities

Work trip Frequencies:

Pre-planned



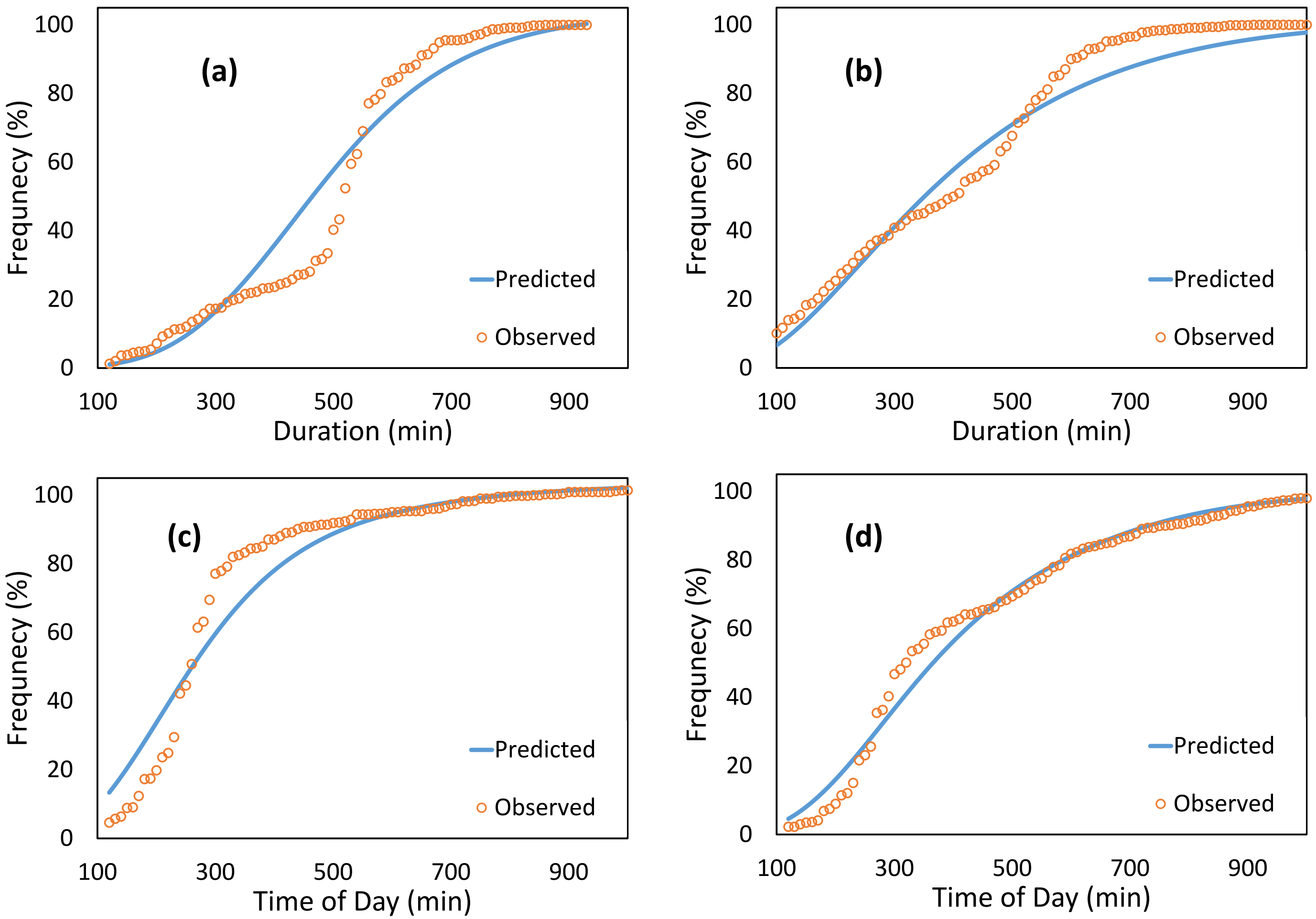
Un-planned



Results: Work Activity Start time and Durations

Pre-planned

Un-planned



Peer Reviewed Publications on CUSTOM Formulations

- Habib, K.M.N. 2011. “A RUM based dynamic activity scheduling model: Application in weekend activity scheduling”. Presented at the 90th Annual Meeting of Trans. Res. Board, January 22–27, 2011.
- Habib, K.M.N. 2015 “Comprehensive Utility based System of Travel Options Modelling (CUSTOM) considering dynamic time-budget constrained potential path areas in activity scheduling process: Application in modelling workers’ daily activity-travel scheduling”. Presented at the 94th Annual Meeting of Trans. Res. Board, January 13–17, 2015.
- Habib, K.M.N., Hui, V. 2015. “An activity-based approach of investigating travel demand of older people: Application of a time-space constrained scheduling model for older people in the National Capital Region (NCR) of Canada”. Transportation (Forthcoming)
- Habib, K.M.N., El-Assi, W., Hasnine, S., Lamers, J.. 2016. “Activity-travel behaviour of non-workers in the National Capital Region of Canada: Application of CUSTOM”. Presented at the 95th Annual Meeting of Trans. Res. Board, January 10–14, 2016.

On-Going Works

- Full specification of household-based travel demand by CUSTOM: Currently on-going for the GTHA using TTS

- Development of Simulation framework and integration with traffic assignment model

Questions ?