Modelling Demands for Transportation Energy: Applications and Scope in Transportation Planning

Professor Khandker Nurul Habib

INSTITUT DE L'ÉNERGIE TROTTIER

Civil Engineering
UNIVERSITY OF TORONTO

UTTRI University of Toronto Transportation Research Institute

Location: Groupe Deschênes
HEC Montréal

Date/Time: 4:00 pm, Jan 31st 2017

Symposium annuel Trottier sur l'ingénierie, l'énergie et la conception durables

Annual Trottier Symposium on Sustainable Engineering, Energy and Design

Transport : à quoi carbure la transition ?

Transportation : What's Fuelling the Transition ?

11 – 12 avril 2017
Polytechnique Montréal

April 11 – 12, 2017
Polytechnique Montréal

McGill | Faculty of Engineering

TISED
Trottier Institute for Sustainability in Engineering and Design

IET INSTITUT DE L'ÉNERGIE TROTTIER

POLYTECHNIQUE MONTRÉAL

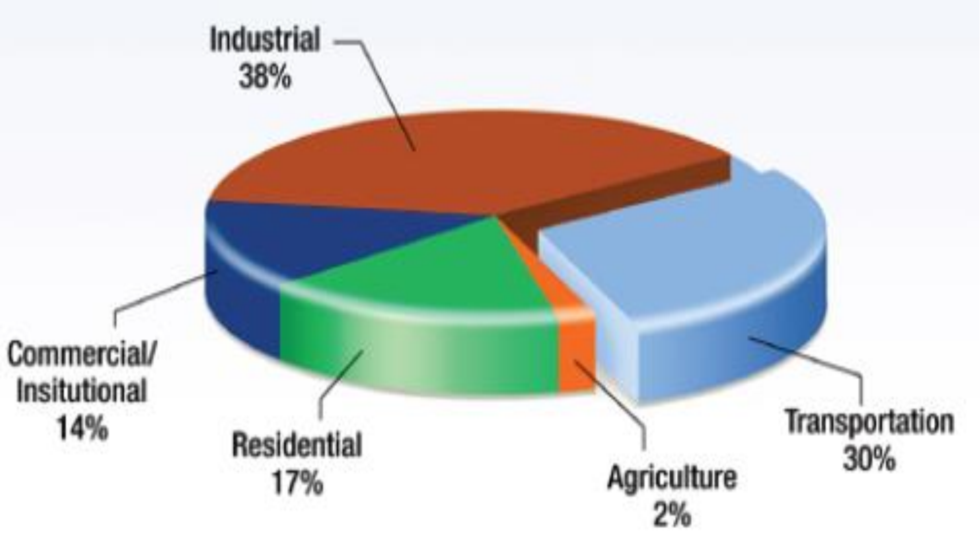
Outline

- Transportation Energy Demands and Influential Factors
- Practices of Energy System Modelling for Energy Policies
- Practices of Transport Energy Demand Modelling Frameworks
- Combining Energy System Model to Enhance Transportation Demand/Behaviour Representations

Introduction

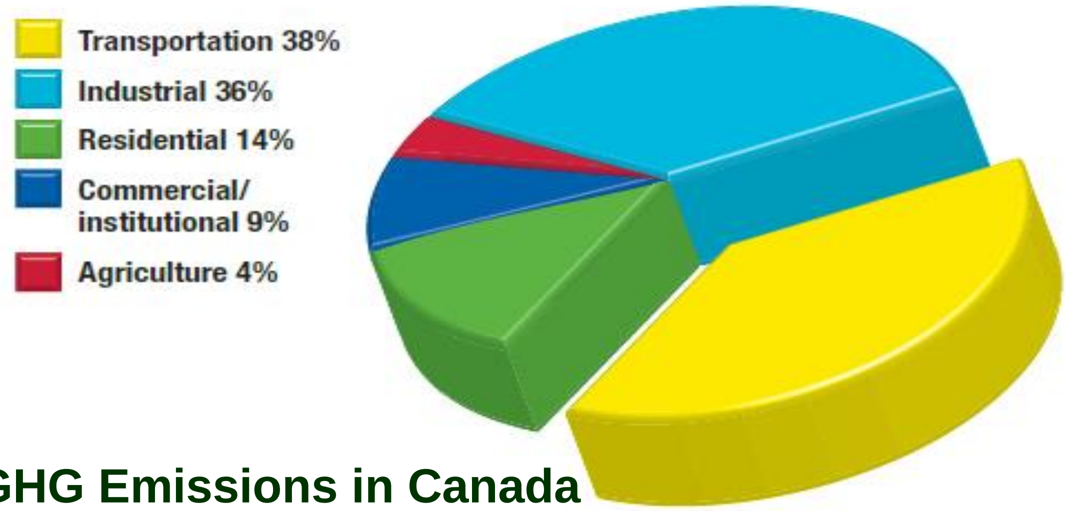
- Energy is the fundamental enabler of transportation system:
  - ✓ Emission is a major externality of transportation.
- Obviously, transportation planning exercise target more of urban transportation issues (congestion, emissions, fatalities, etc.) than energy policy
  - ✓ Energy policy effects are considered external factors, e.g. fuel price, availability of mode technologies, fuel efficiency.
- Combining behavioural elements of travel demand into energy system modelling is a research challenge

Transportation Energy and Emissions



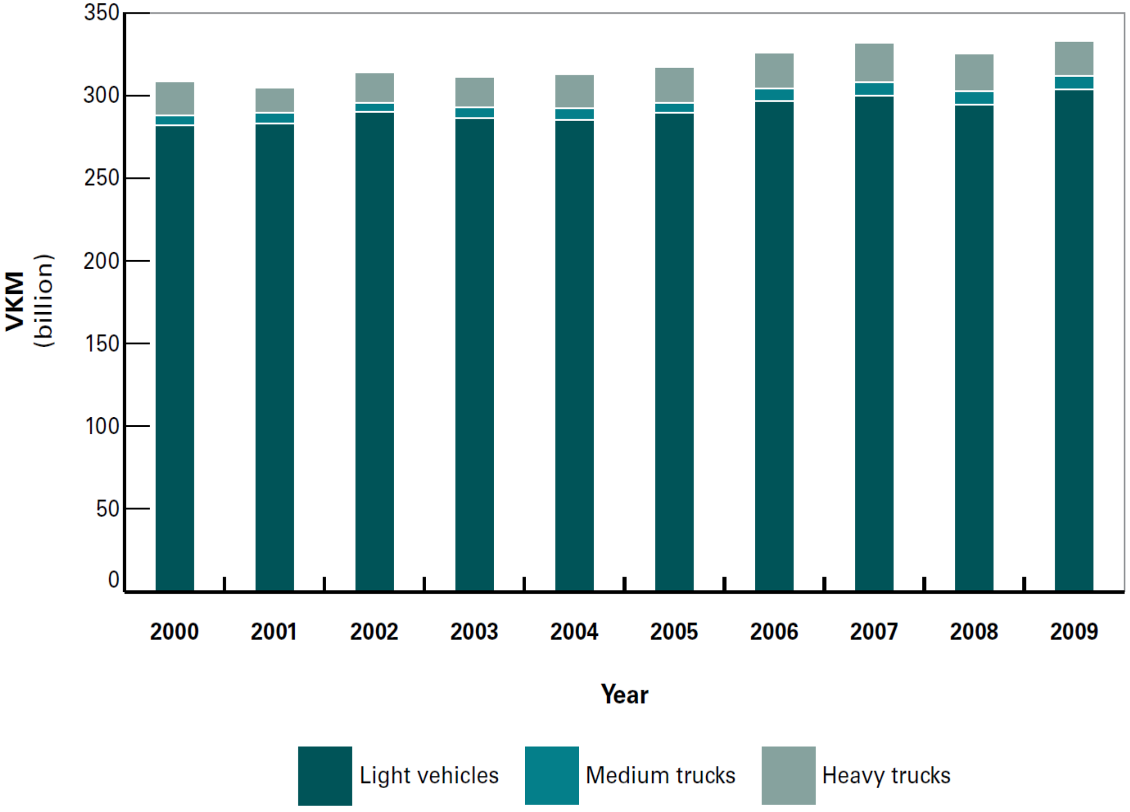
Energy Consumptions in Canada

- 30% energy share, but 38% GHG contribution



GHG Emissions in Canada

Transportation Demand: Travel Modes



- **Energy is a derivative of demand for transportation**
- **Demand for transportation is a derivative of travel modes**

Canadian Vehicle Use Survey Report 2009

Growth in Passenger Transport

1990

- 14.2 million vehicles
- 19.4 percent are light trucks
- 17,246 km/year on average per vehicle
- 378.3 billion Pkm covered
- 0.68 vehicles per person aged 18 years and over

2013

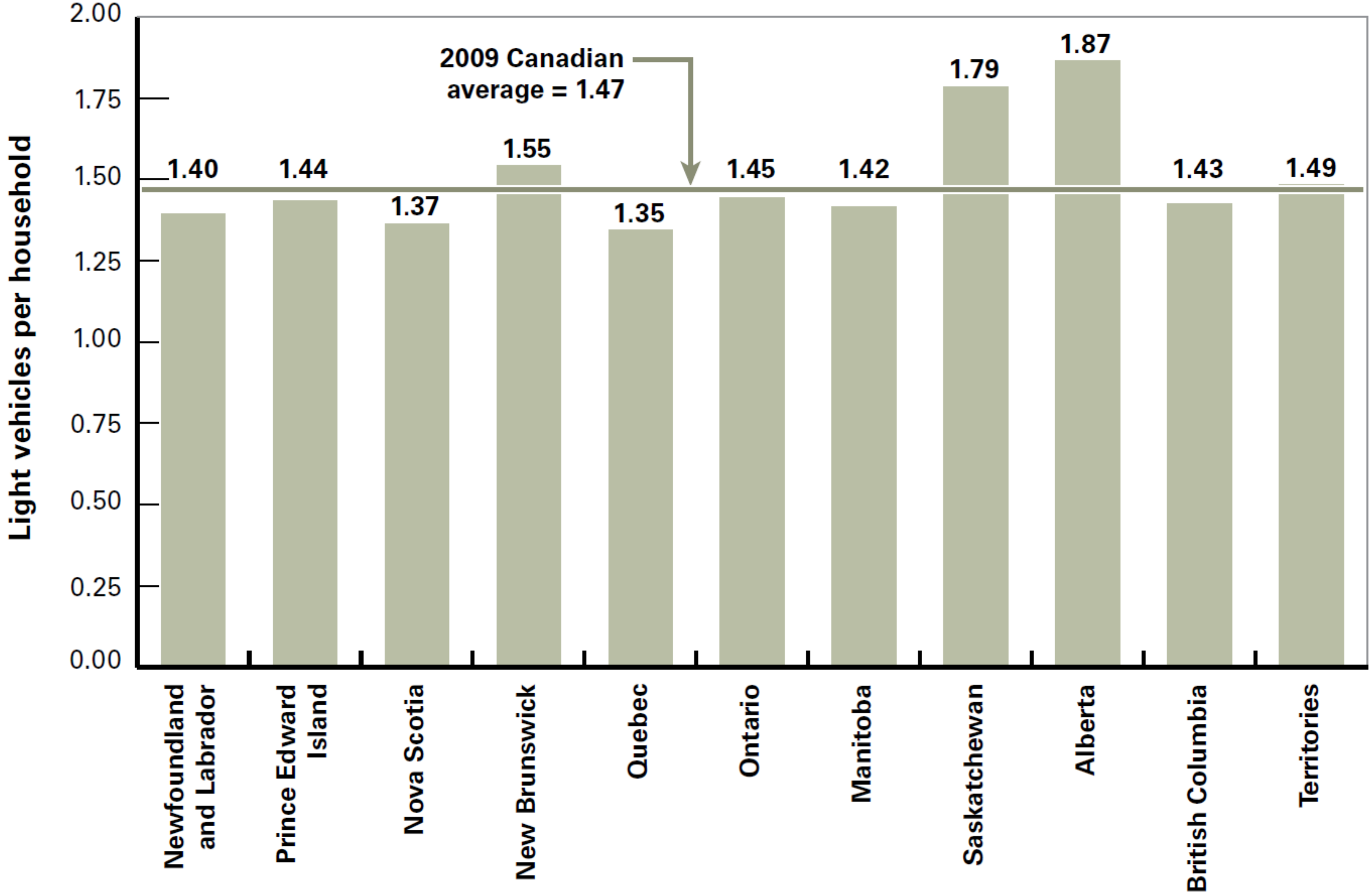
- 20.5 million vehicles
- 37.2 percent are light trucks
- 15,552 km/year on average per vehicle
- 519.7 billion Pkm covered
- 0.73 vehicles per person aged 18 years and over

Increasing private car ownership

&

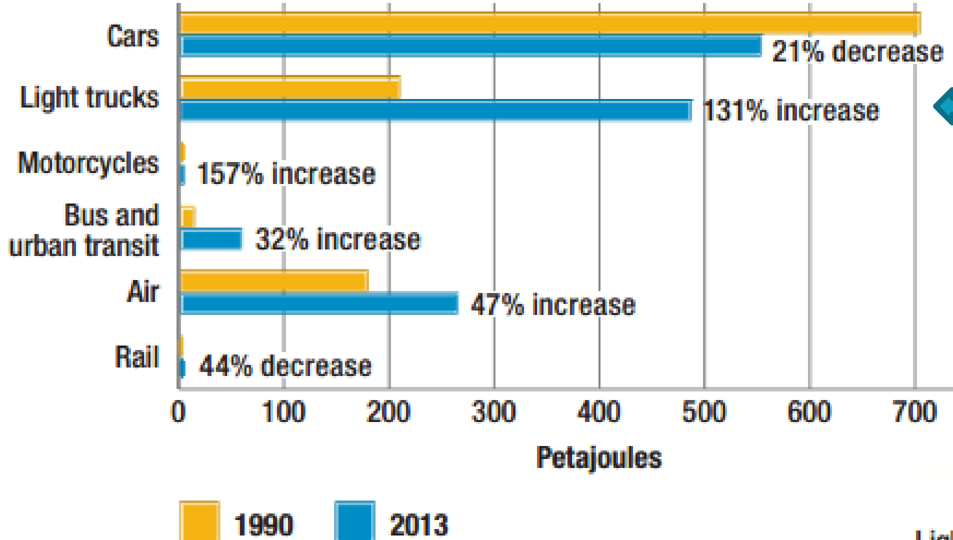
Increasing SUV ownership

Passenger Car Ownership



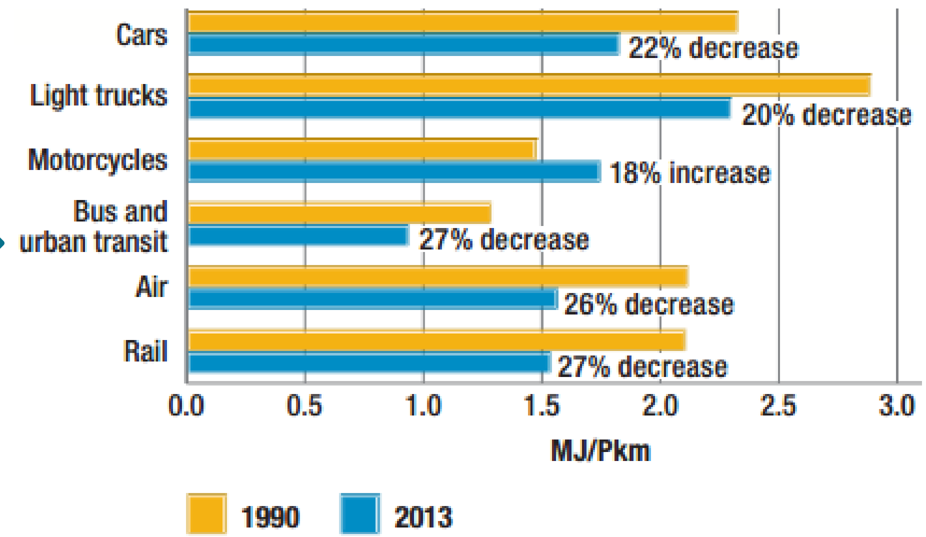
Canadian Vehicle Use Survey Report 2009

What Drives the Growths?



Higher rate of increasing light truck (SUV)

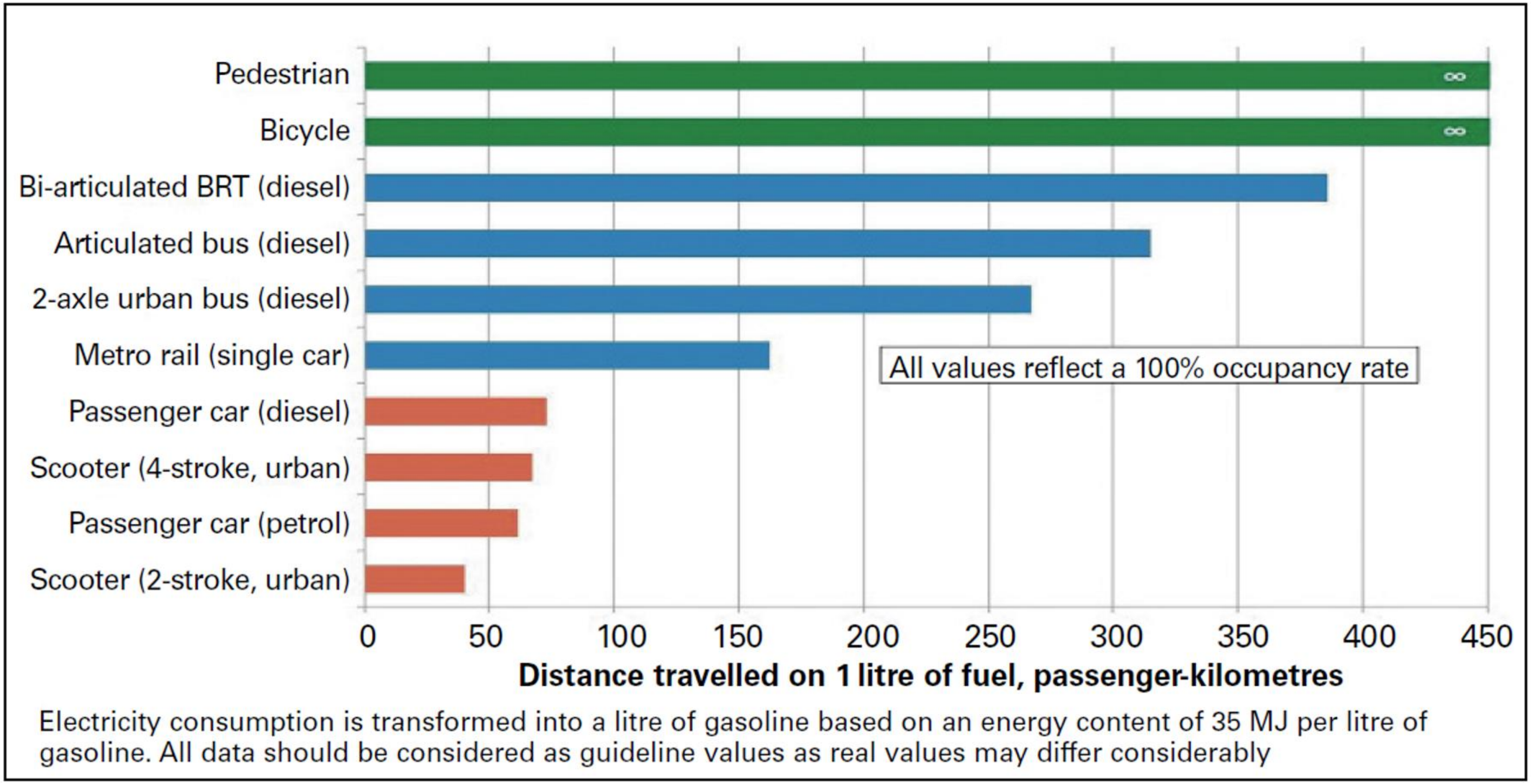
With lower rate of energy intensity gain for light trucks (SUV)



With increasing constraints in energy availability/source, increasing only fuel efficiency of motorized vehicles may not be enough

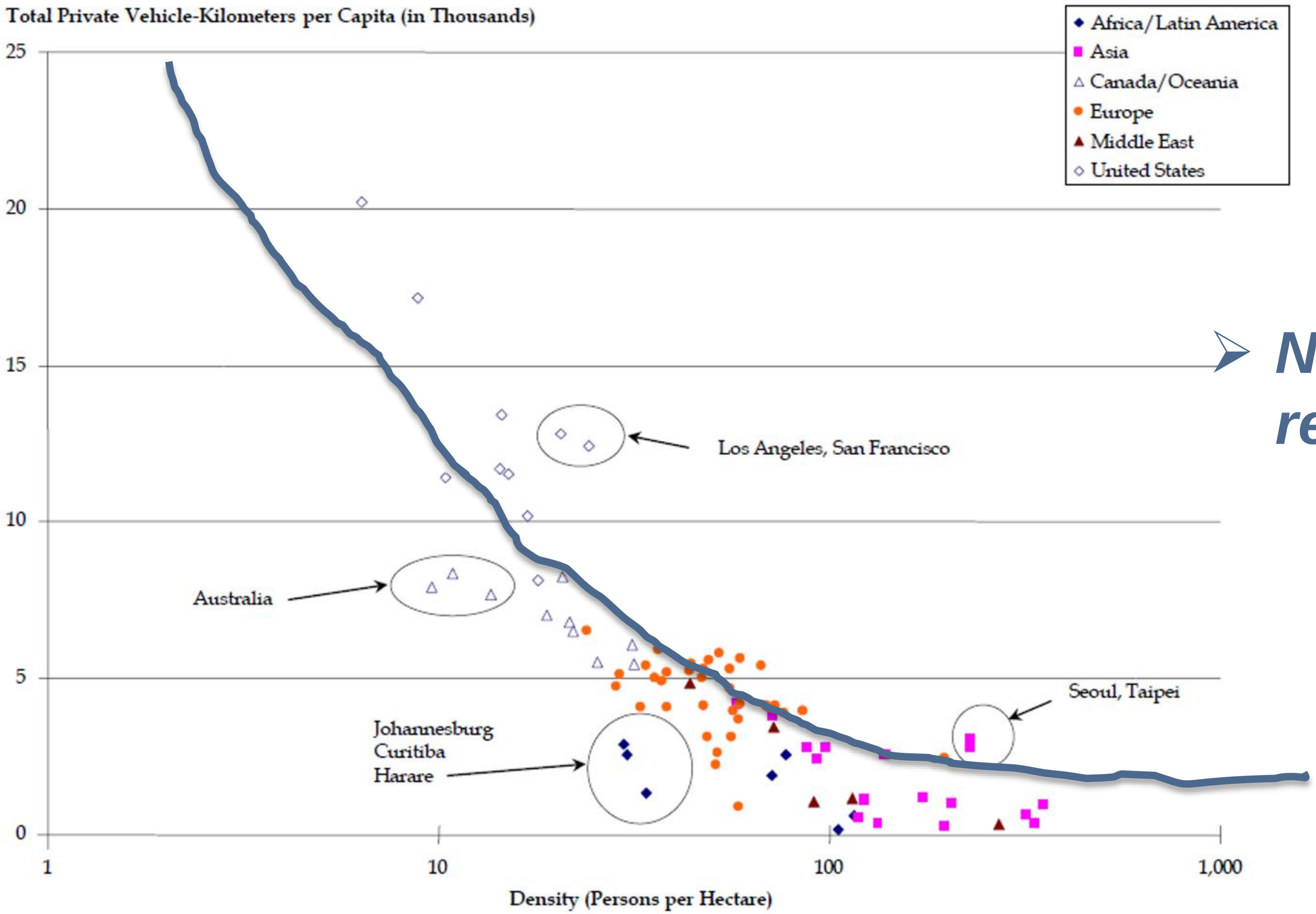
-Need to promote non-motorized modes and supporting land use

Travel Mode & Transport Energy Demands



Bohler-Baedeker and Huging 2012

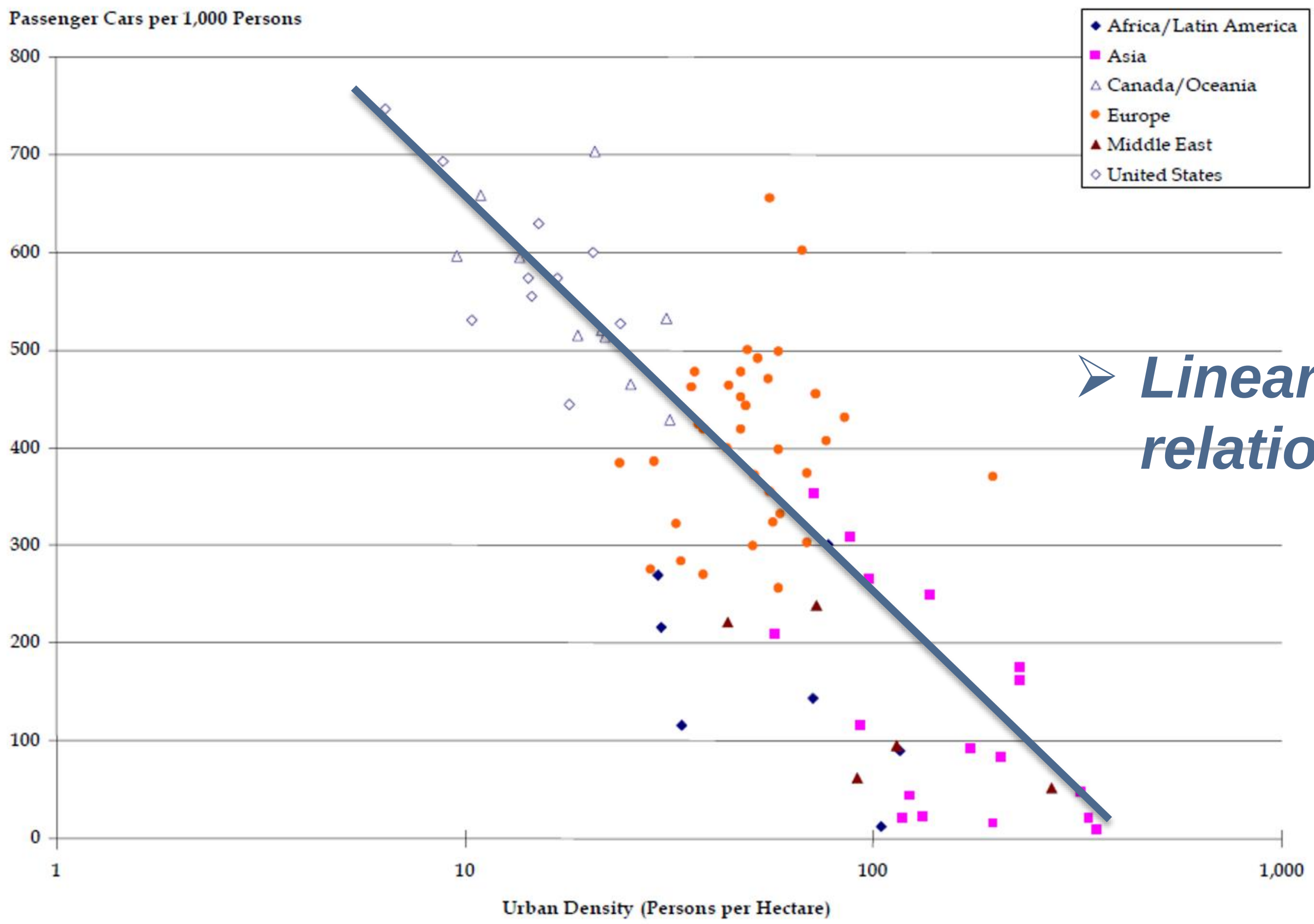
Transportation Demand – Urban Density



- ***Non-linear relationship***

Porter et al 2013

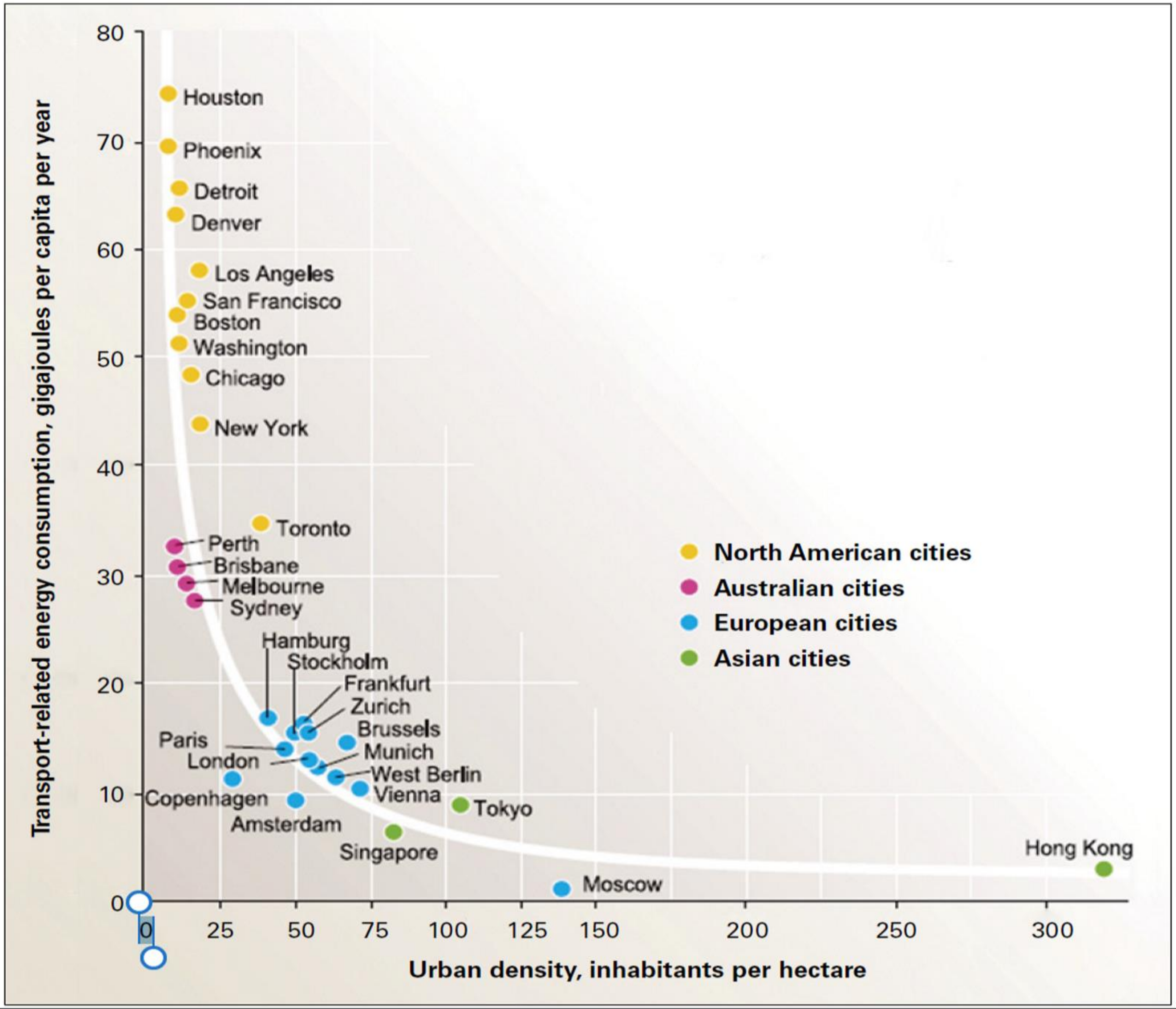
Passenger Car Ownership – Urban Density



➢ ***Linear relationship***

Porter et al 2013

Urban Density – Energy Consumption



- *Non-linear relationship*
- *Urban density influences car ownership and thereby transport energy demands*

Kenworthy and Laube 1999

How to Manage Energy Demands?

- Managing demand for transportation (TDM: Travel Demand Management)
  - ✓ Pricing: fuel cost, road pricing, tolls, etc.
  - ✓ Land use and smart growth
  - ✓ Encourage active modes (walk, bike, etc.)
  - ✓ Promote public transport
  - ✓ Sharing modes: ride sharing, car sharing, etc.
  - ✓ Regulatory strategies

- Transportation System Management (TSM):
  - ✓ Increase system efficiency: Intelligent Transport System
  - ✓ Bottleneck relief, capacity expansion
  - ✓ Multimodal freight transport

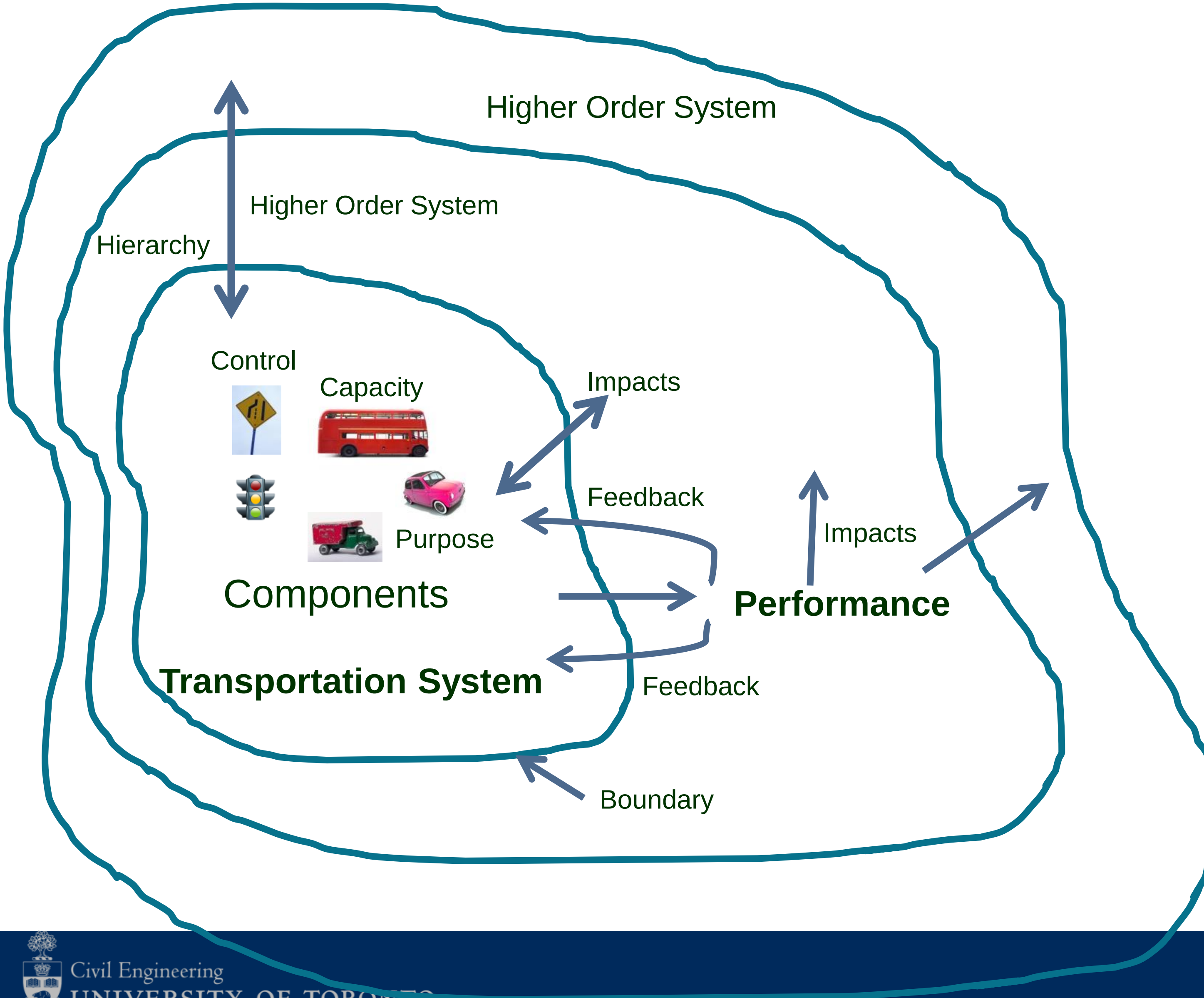
Example Estimates

Strategy	Percentage of On-Road Energy/GHG Reduction
Pricing	
PAYD Insurance (Mandatory)	2.5%
VMT Fee – $0.02-$0.05/Mile	1.0%-2.5%
Congestion Pricing	0.5%-1.1%
Transit Improvements	0.4%-1.1% (2030); 0.6%-2.0% (2050)
Nonmotorized Improvements	0.3%-0.8%
Parking Management	0.3%
Work Site Trip Reduction/Employee Commute Options	0.2%-1.1%
Telework and Alternative Work Schedules	0.9%-1.1%
Ridesharing and Vanpooling	0.1%-2.0%
Carsharing	0.1%-0.2%
Educational and Marketing Campaigns	0.3%-0.5%+
Eco-Driving and Maintenance	1.1%-5.0%
Idle Reduction	0.1%-0.4%
Speed Limit Reduction/Enforcement	1.7%-2.7%
Combined Effects	**7.0%-15.3%**

Source: Effects of Travel Reduction and Efficient Driving on Transportation Energy Use and Greenhouse Gas Emissions, prepared by Cambridge Systematics for National Renewable Energy Laboratory, 2012

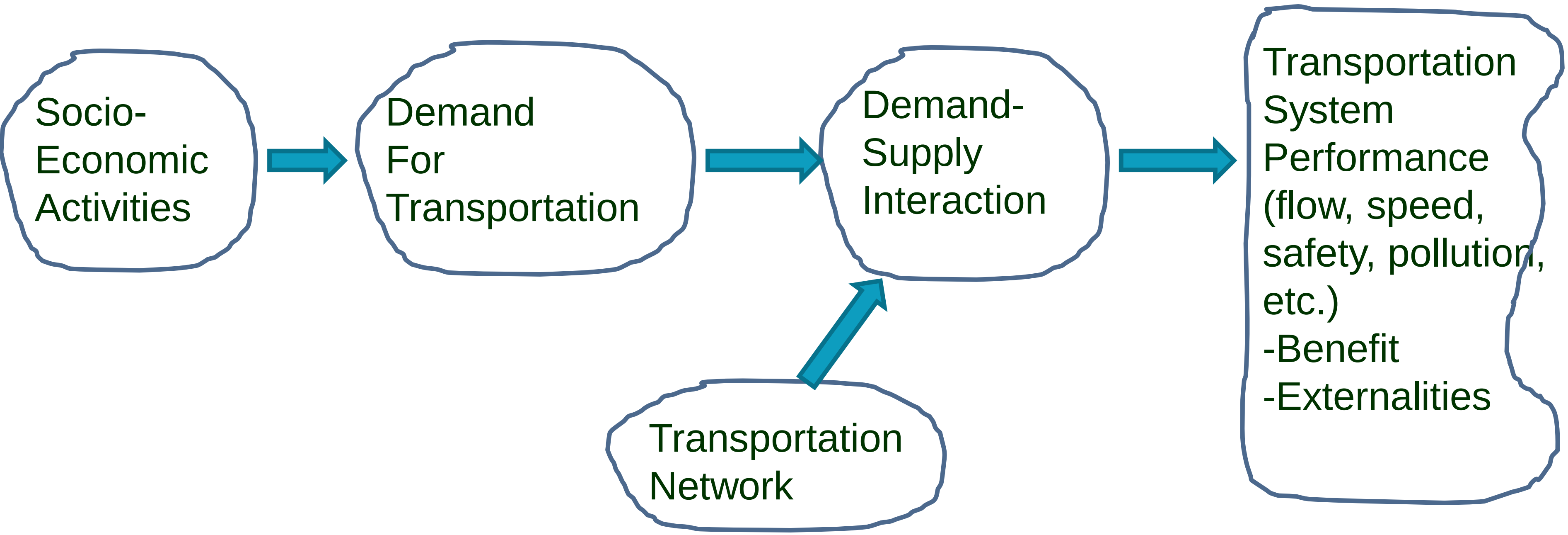
Understanding Transportation Energy Demands requires complete understanding of transportation system

System Perspective of Transportation



- a group of interrelated components.
- form a complicated and unified whole.
- intended to serve some purposes.
- through the performance of its interactive parts.

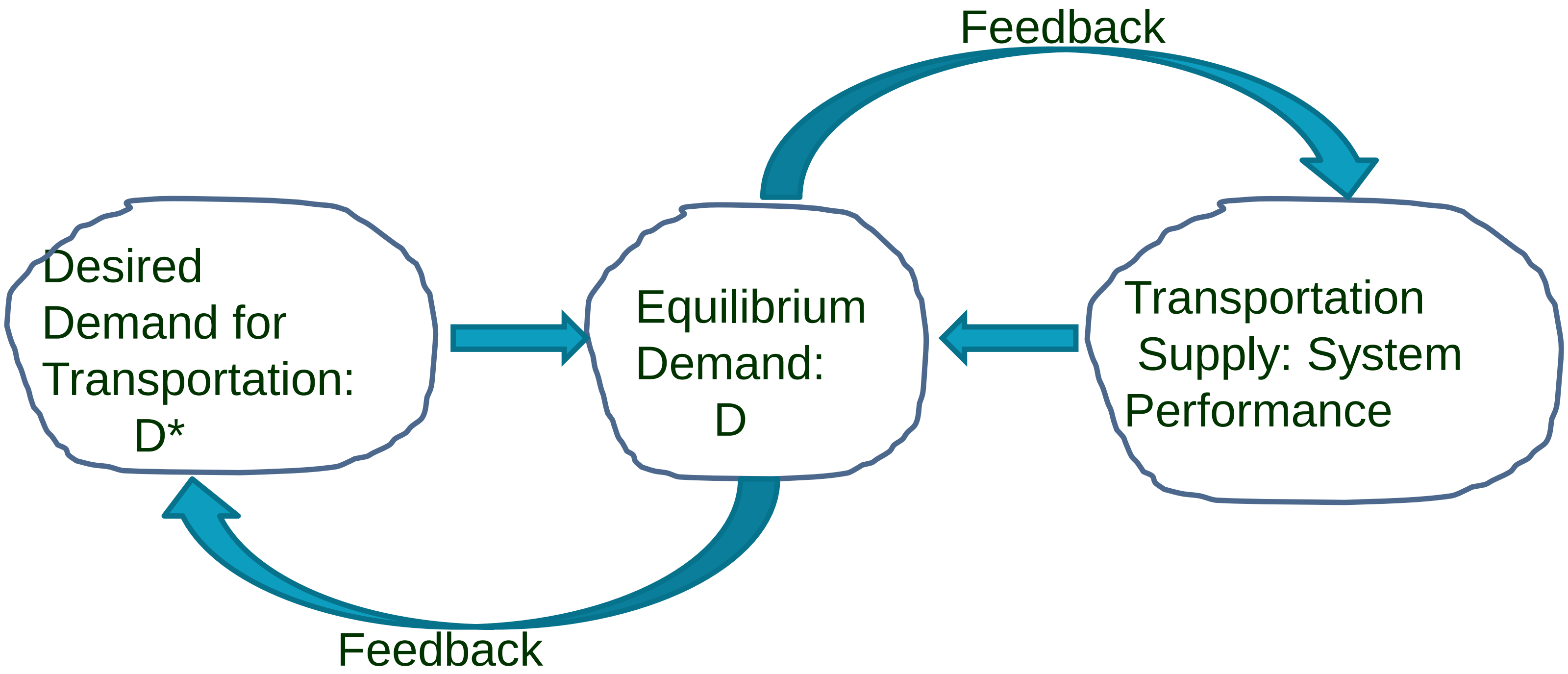
Transportation: Demand-Supply Perspective



System Performance:

- An important consideration guiding the definition of problems and opportunities that become focus of planning efforts.
- System performance measures are necessary for the decision-making process in transportation planning.
- System performance measures should be defined not only as outputs, but also as the outcomes on society.

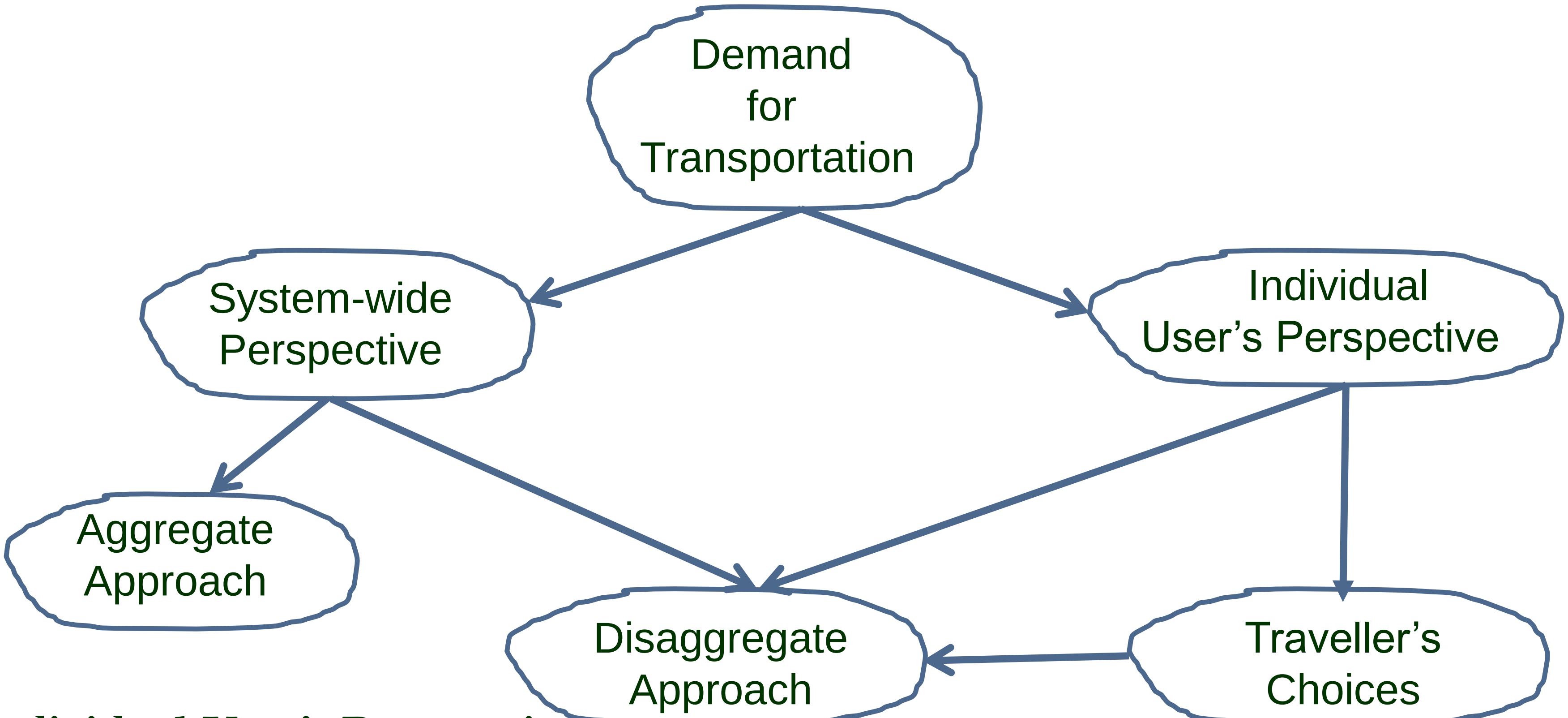
System Performance <> Feedback



Dynamics of Demand-Supply Interaction:

- Observed demand is equilibrium demand.
- Desired demand is always higher than the equilibrium demand.
- Changes in system performance affects demand as well as system performance.
- Truly dynamic and two-way interaction and feedback.

Measuring Demand: Users' Perspective



Individual User's Perspective:

- Understanding urban spatial and socio-economic context.
- Understanding preferences or options.
- Understanding choice making behaviour.
- Evaluating elasticity of demands.

“Demand” *vs* “Behavior”

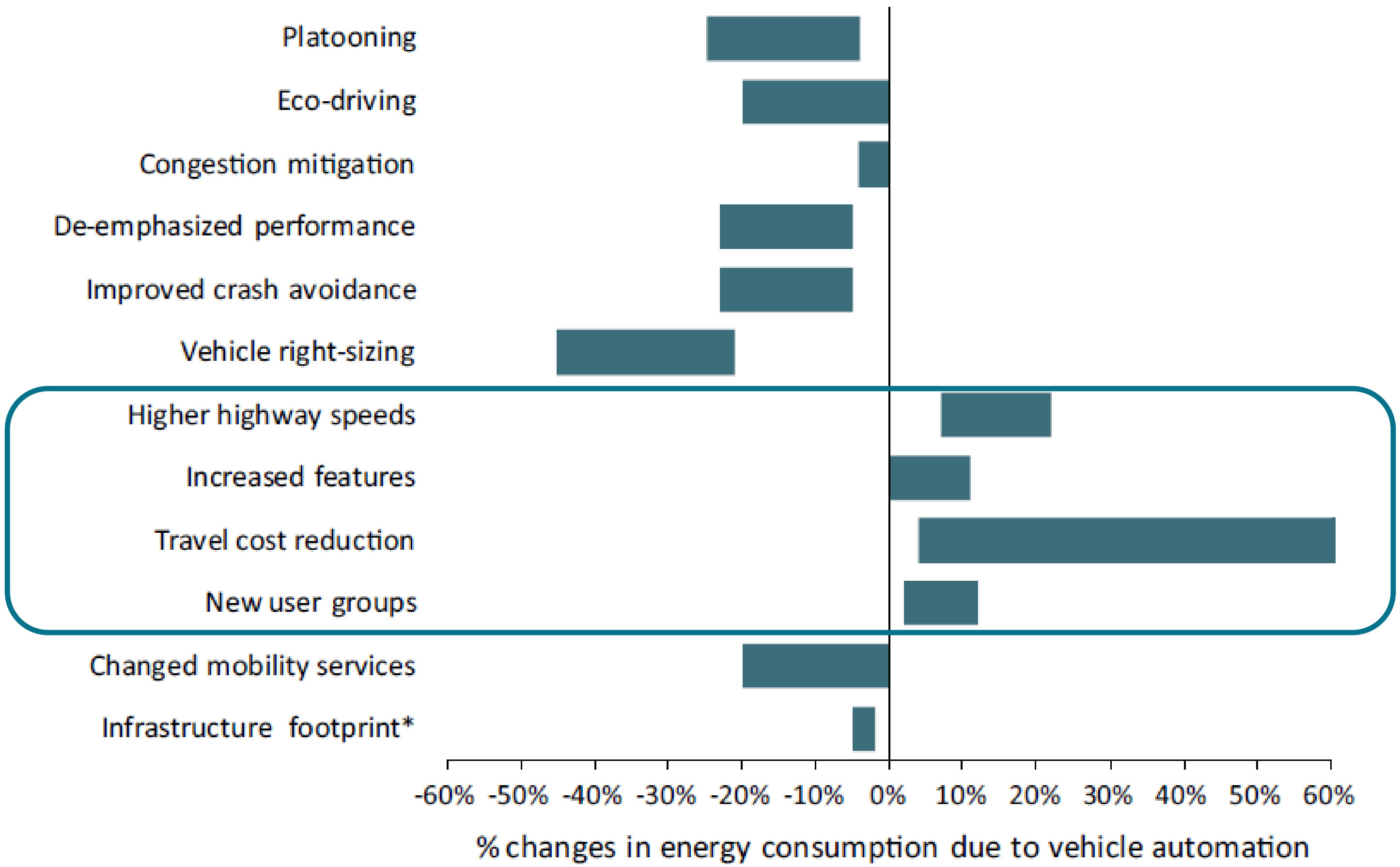
Demand

- Aggregate
- Easy to measure
- Realizations of probable outcomes

Behavior/Choice

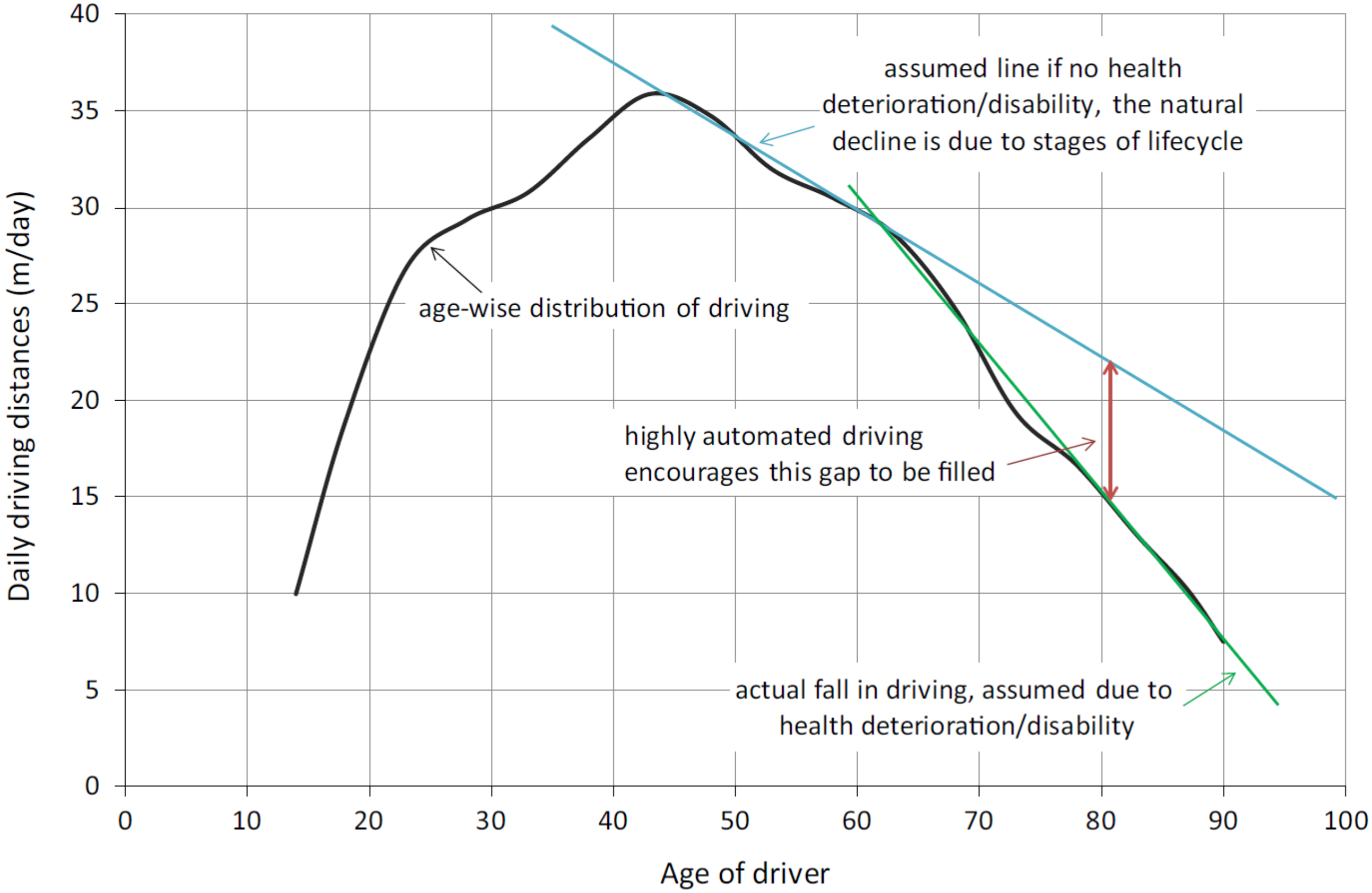
- Disaggregate
- Often abstract and difficult to measure
- Shaped by contexts

Necessity of Behavioral Models



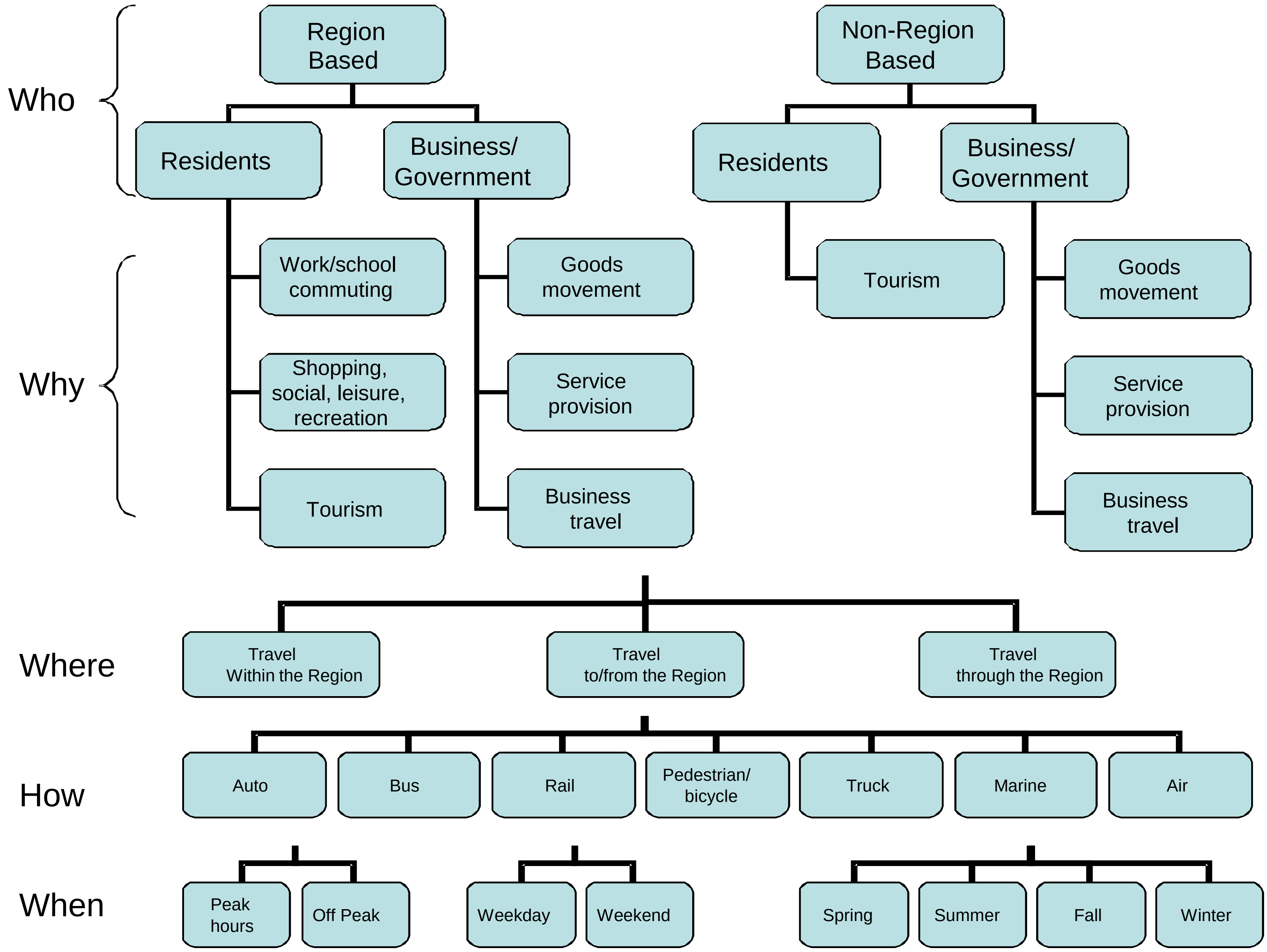
Wadud et al, 2016

Necessity of Capturing Heterogeneity



Wadud et al, 2016

Measuring Transportation Behaviour requires Complete Specification of Transportation Choices/Decision


Who
Why
Where
How
When
Region Based
Non-Region Based
Residents
Business/ Government
Residents
Business/ Government
Work/school commuting
Shopping, social, leisure, recreation
Tourism
Goods movement
Service provision
Business travel
Tourism
Goods movement
Service provision
Business travel
Travel Within the Region
Travel to/from the Region
Travel through the Region
Auto
Bus
Rail
Pedestrian/ bicycle
Truck
Marine
Air
Peak hours
Off Peak
Weekday
Weekend
Spring
Summer
Fall
Winter

Trip-based Aggregate Model

Avg. number of trips

Avg. trip Distance

↓

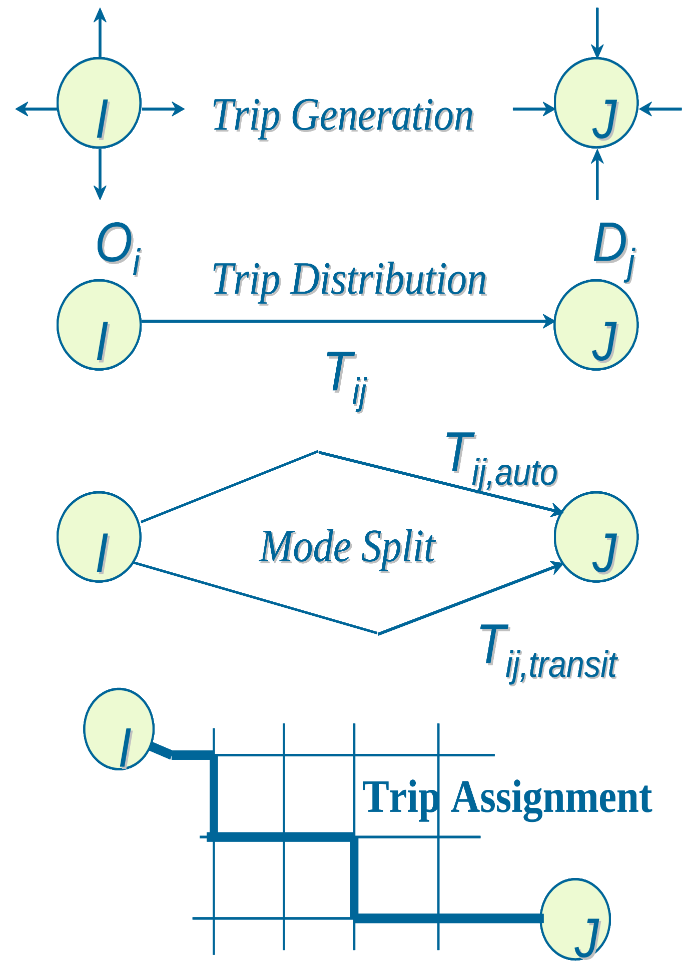
Proportion of trips by different Modes

↓

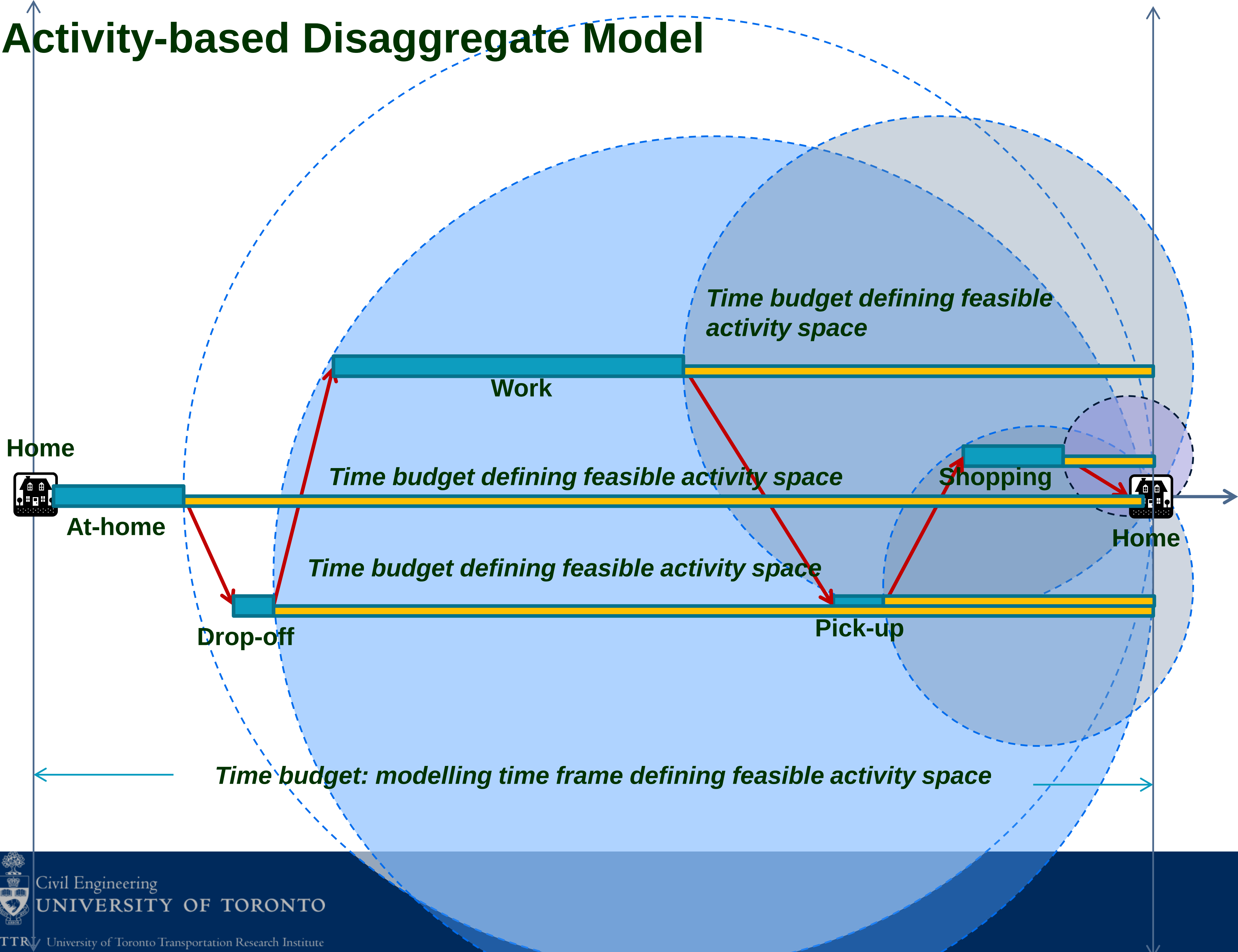
Energy Intensity of each mode

↓

Total energy demand



Activity-based Disaggregate Model



Transportation Energy Demand: Key Determinants

Avg. number of trips

Avg. trip Distance

↓

Proportion of trips by different Modes

Energy Intensity of each mode

↓

Total energy demand

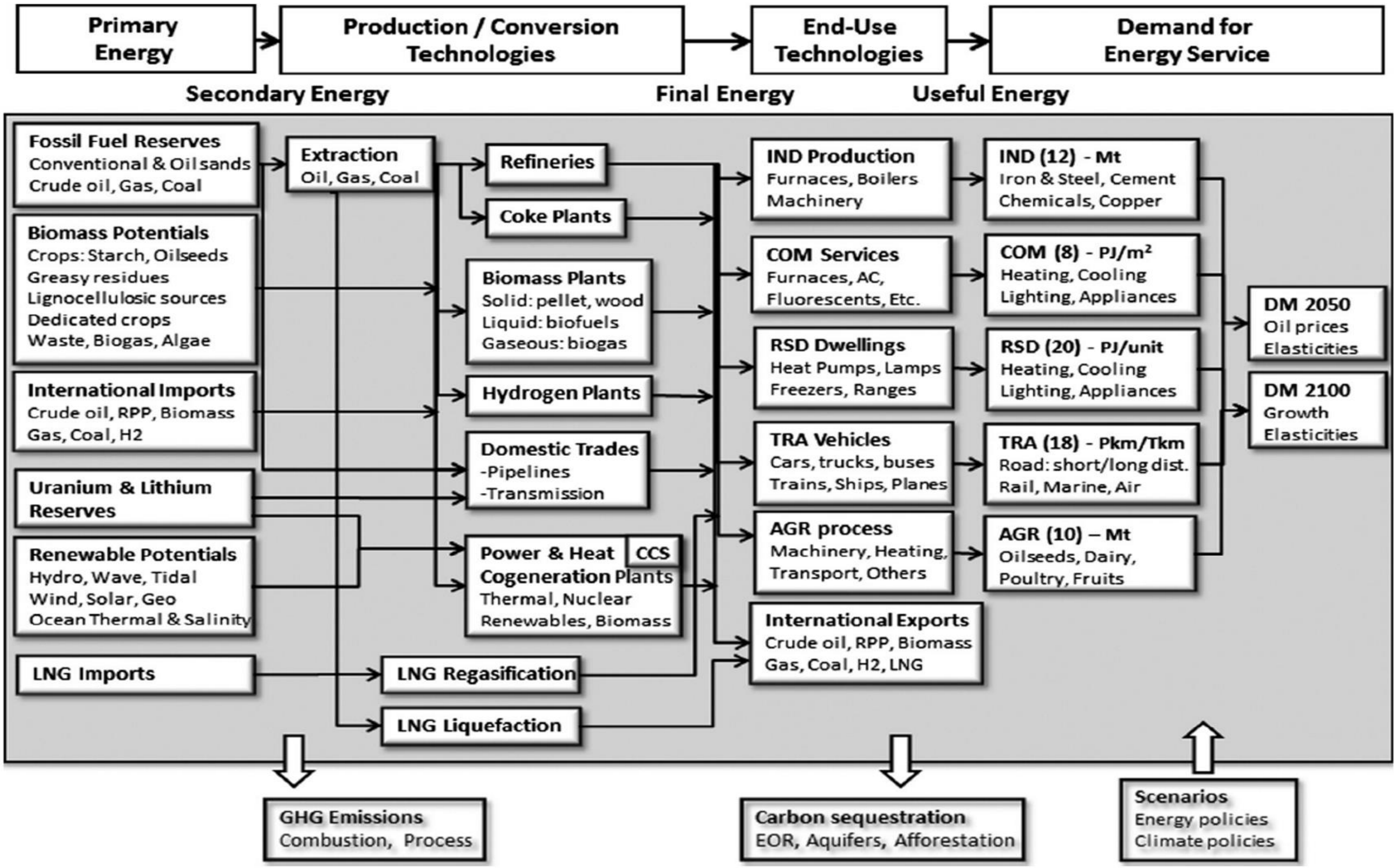
- ✓ Home location
- ✓ Work location
- ✓ Activity locations
- ✓ Social network

- ✓ Car ownership
- ✓ Car type choices
- ✓ Choice of mode for different trips

Energy System Modelling for Energy Policy Analysis

- **Optimization Models**
  - Use linear programming (under constraints) to identify energy systems that provide the least cost means of providing an exogenously specified demand for energy services.
  - Examples: MARKAL (TIMES), EFOM, etc.
- **Simulation Models**
  - Simulate behavior of energy consumers and producers under various exogenous signals (e.g. price, income levels, limits on rate of stock turnover).
  - Examples: ENPEP/BALANCE, Energy 20/20
- **Accounting Frameworks**
  - Rather than simulating decisions of energy consumers and producers, modeler explicitly accounts for outcomes of decisions *So instead of calculating market share based on prices and other variables, Accounting Frameworks simply examine the implications of a scenario that achieves a certain market share.*
  - Examples: LEAP, MEDEE, MESAP
- **Hybrids Models combining elements of each approach**
  - combine elements of optimization, simulation and accounting
  - LEAP operates at two levels: basic accounting relationships are built-in and users can add their own simulation models on top

TIMES-Canada Model



Vaillancourt et al. 2014

TIMES-Canada Model

End-use demand segments within five consumption sectors.

Sectors	Number of segments	Units	End-use demand segments
AGR	9	Million tons	Grains and Oilseeds, Dairy, Beef, Hog, Poultry, Eggs, Fruit, Vegetables, Others
COM	8	PJ	Space heating; Water heating; Space cooling; Lighting; Street lighting; Auxiliary equipments; Auxiliary motors; Others
IND	12	Millions tons	Iron and steel; Pulp and paper (Low quality, High quality); Cement; Non-ferrous metals (Aluminum, Copper, Others); Chemicals (Ammonia, Chlorine, Others); Other manufacturing industries; Other industries
RSD	20	PJ	Space heating (Detached houses; Attached houses; Apartments; Mobile homes); Space cooling (Detached houses; Attached houses; Apartments; Mobile homes); Water heating (Detached houses; Attached houses; Apartments; Mobile homes); Lighting; Refrigeration; Freezing; Dish washing; Cloth washing; Cloth drying; Cooking; Others
TRA	18	Millions passenger-km	- Road/Passenger: Small cars (Short distance, Long distance); Large cars (Short distance, Long distance); Light trucks; Urban buses; Intercity buses; School buses; Motorcycles; Off road
		Millions ton-km	- Road/Freight: Light trucks; Medium trucks; Heavy trucks - Rail: Freight; Passenger - Air: Freight; Passenger - Marine

Vaillancourt et al. 2014

Energy Demand Modelling for Transportation Planning

Modelling Transportation Energy Demands
=
Modelling Transportation Demands

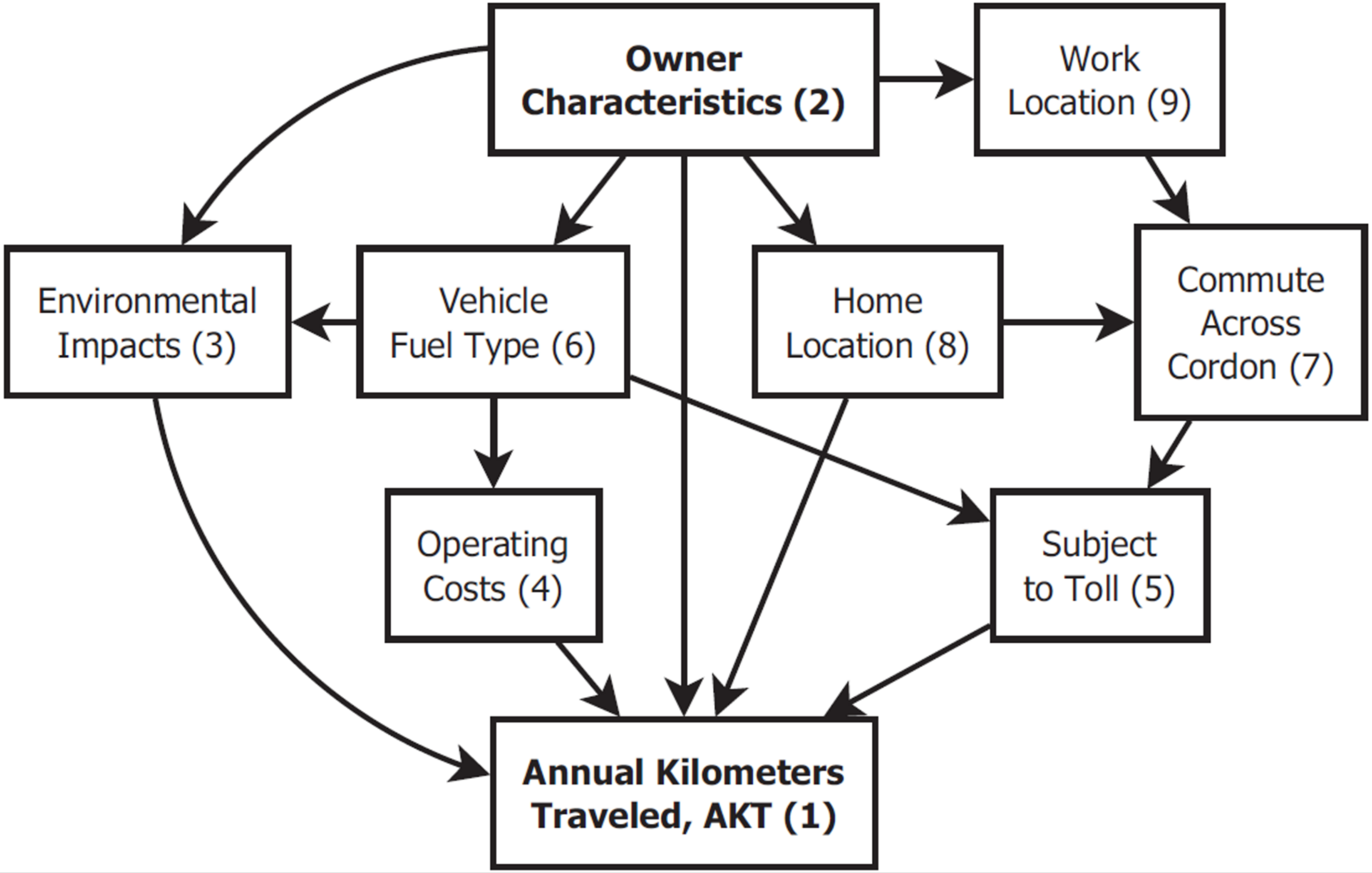
Aggregate Modelling Approach: Top-down approach

Disaggregate Modelling Approach: Bottom-up approach

Historical aggregate data

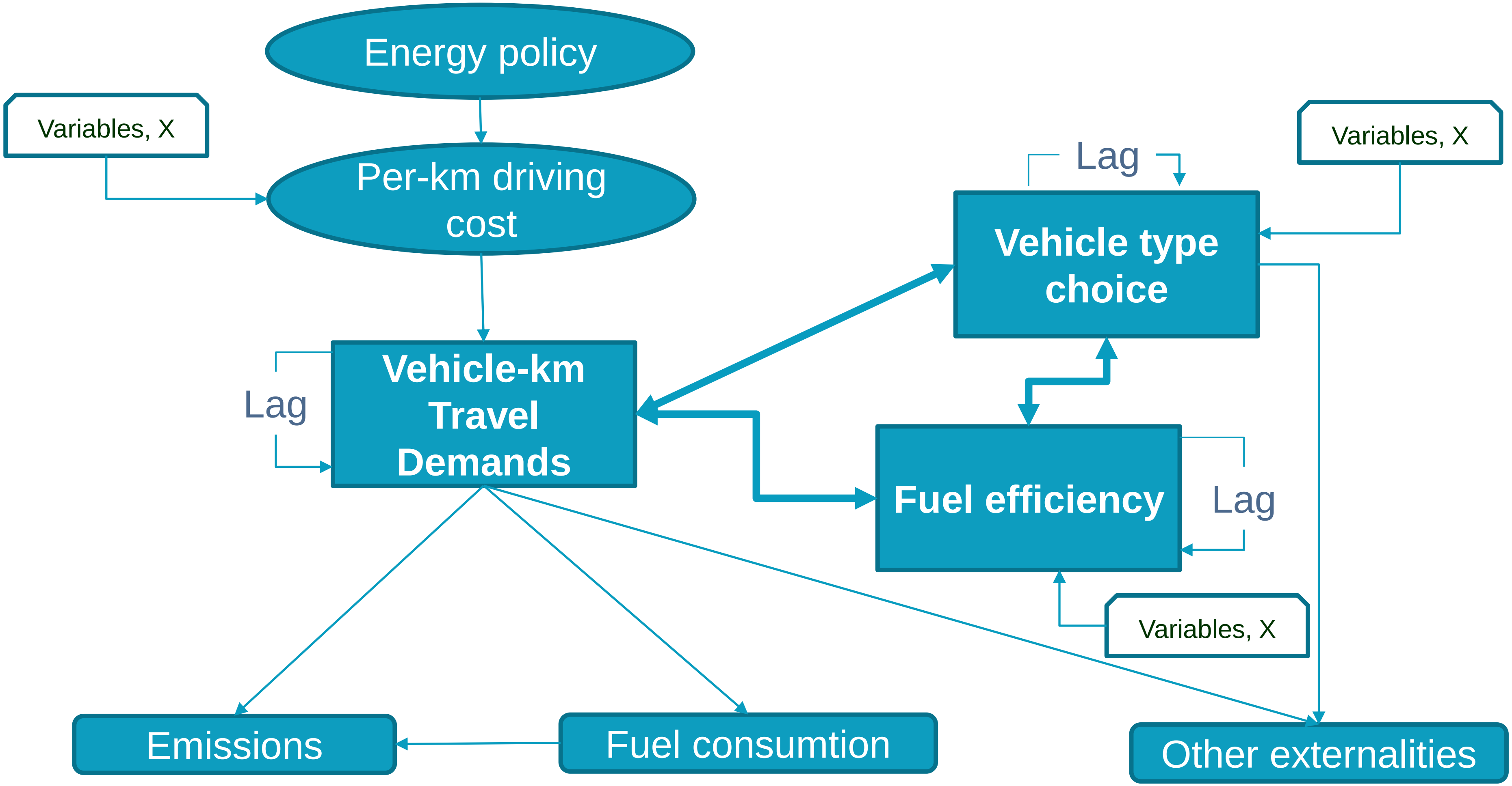
Detailed sample data

Aggregate Model of Transportation Demands



Adapted from Whitehead et al 2015

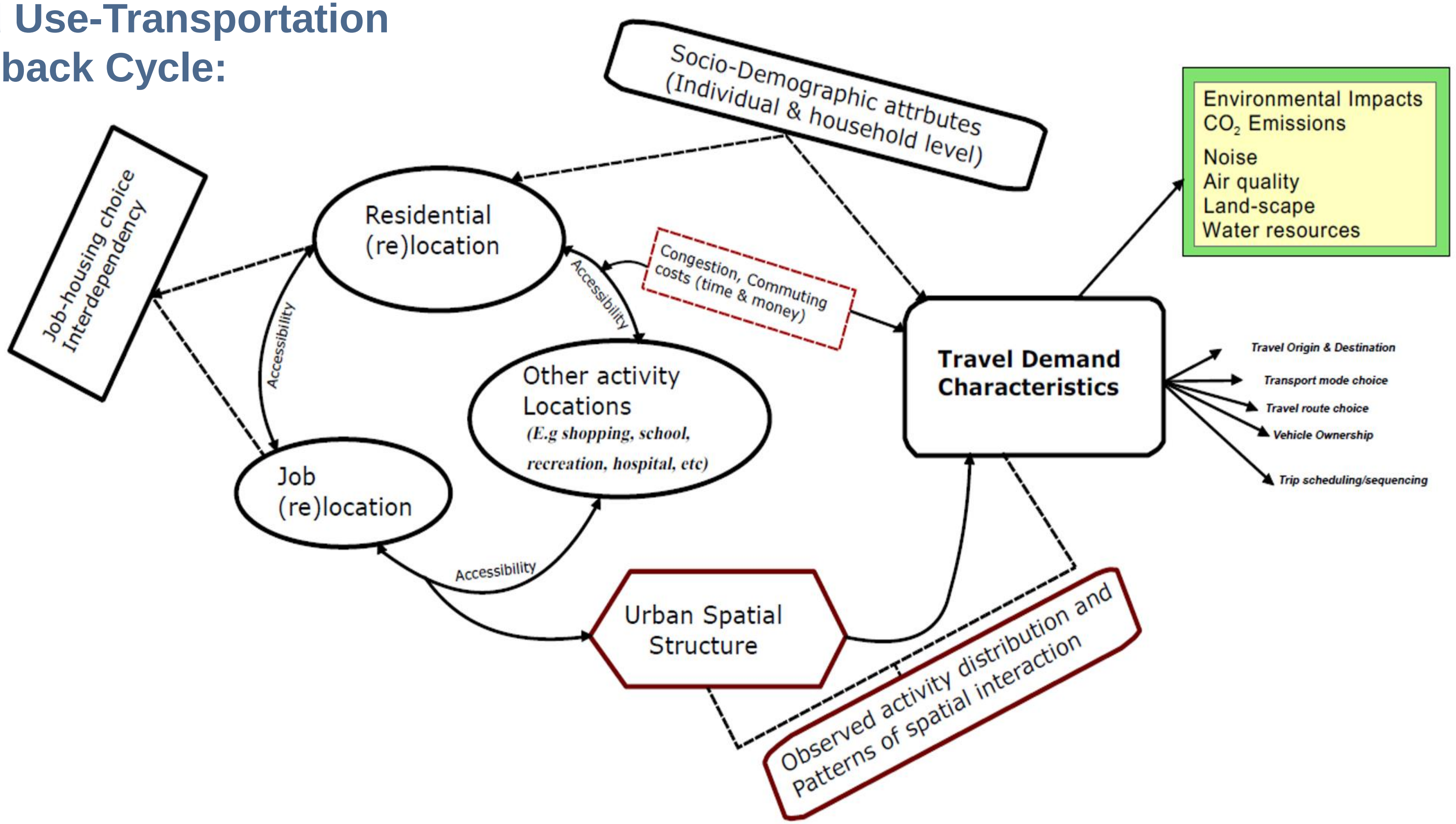
Energy Policy & Transportation Demands: Aggregate Demand Modeling



Adapted from Kim et al 2015

Integrated Transportation Demands: Bottom-Up Approaches

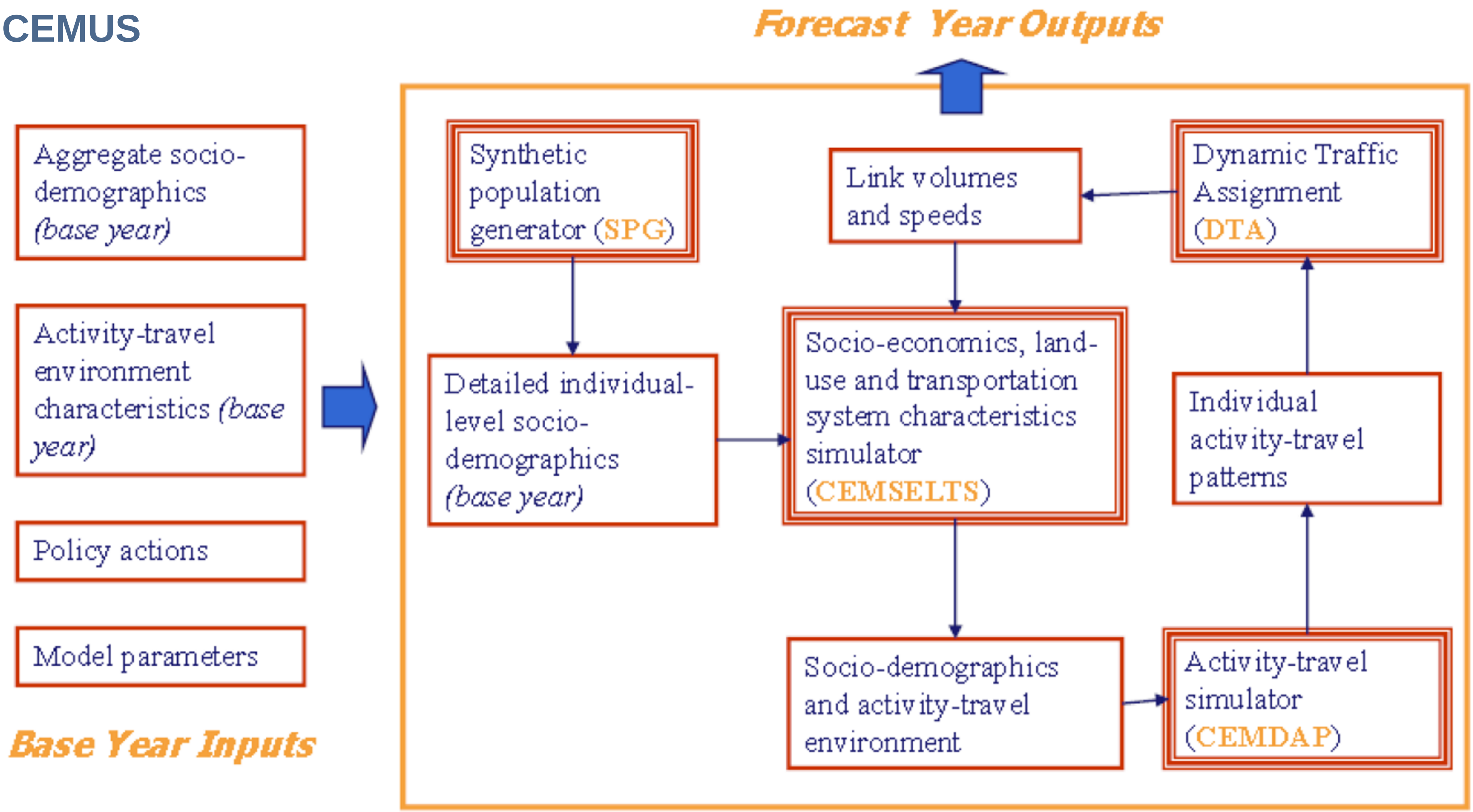
Land Use-Transportation Feedback Cycle:



Acheampong and Silva, 2015

Integrated Transportation Demands: Bottom-Up Approaches

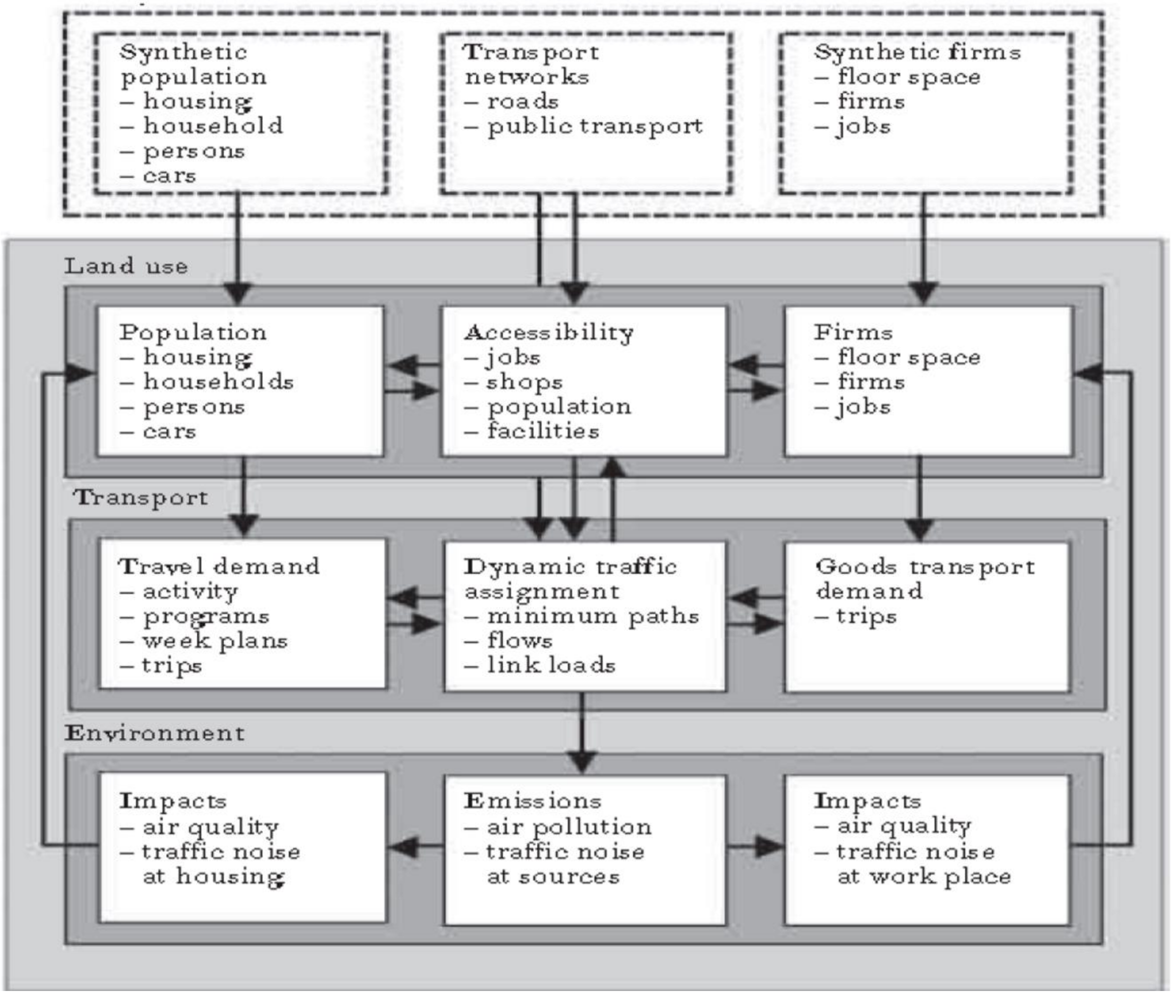
CEMUS



Bhat and Waller 2008

Integrated Transportation Demands: Bottom-Up Approaches

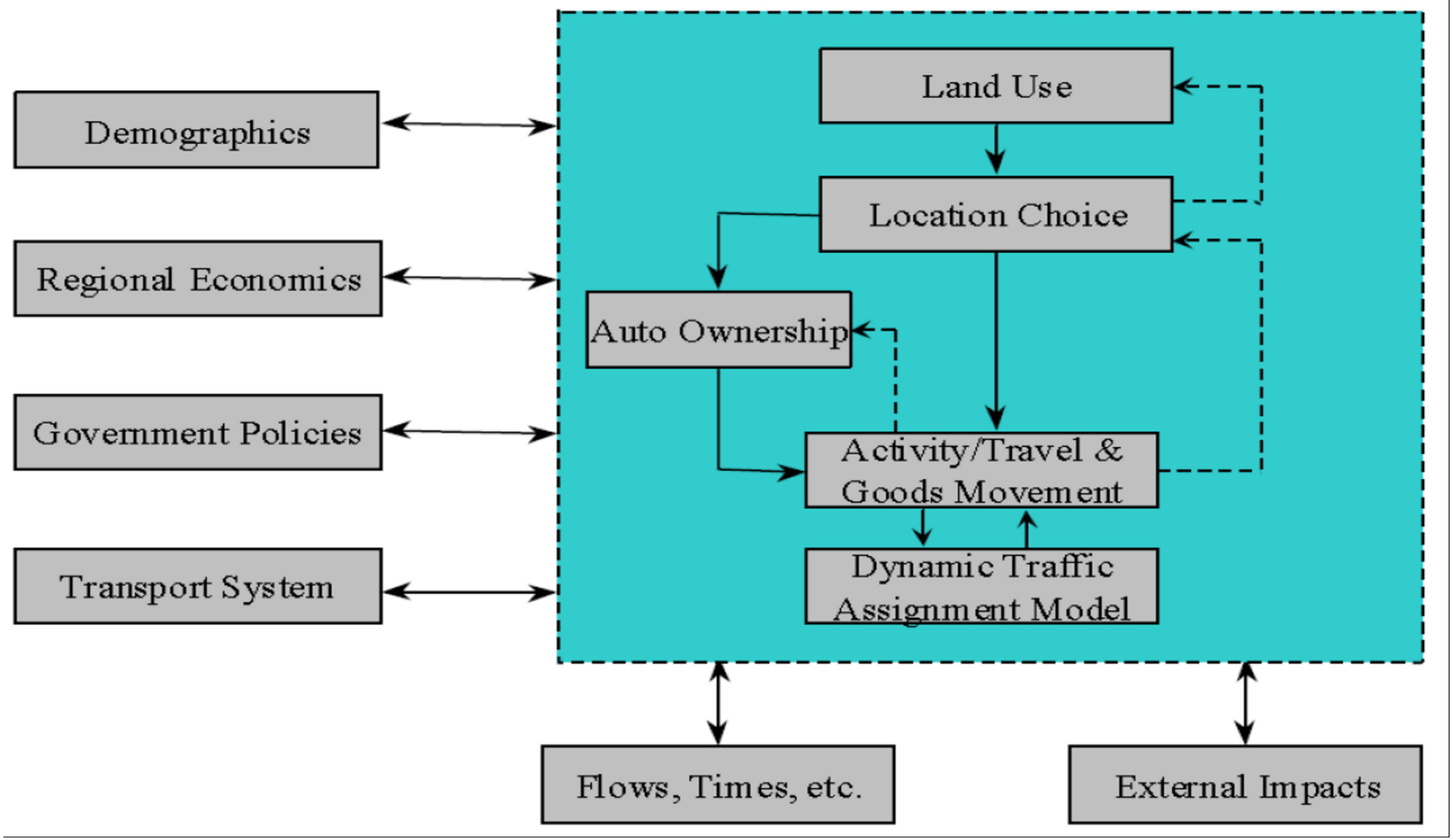
ILUMASS



Wagner and Wagner 2007

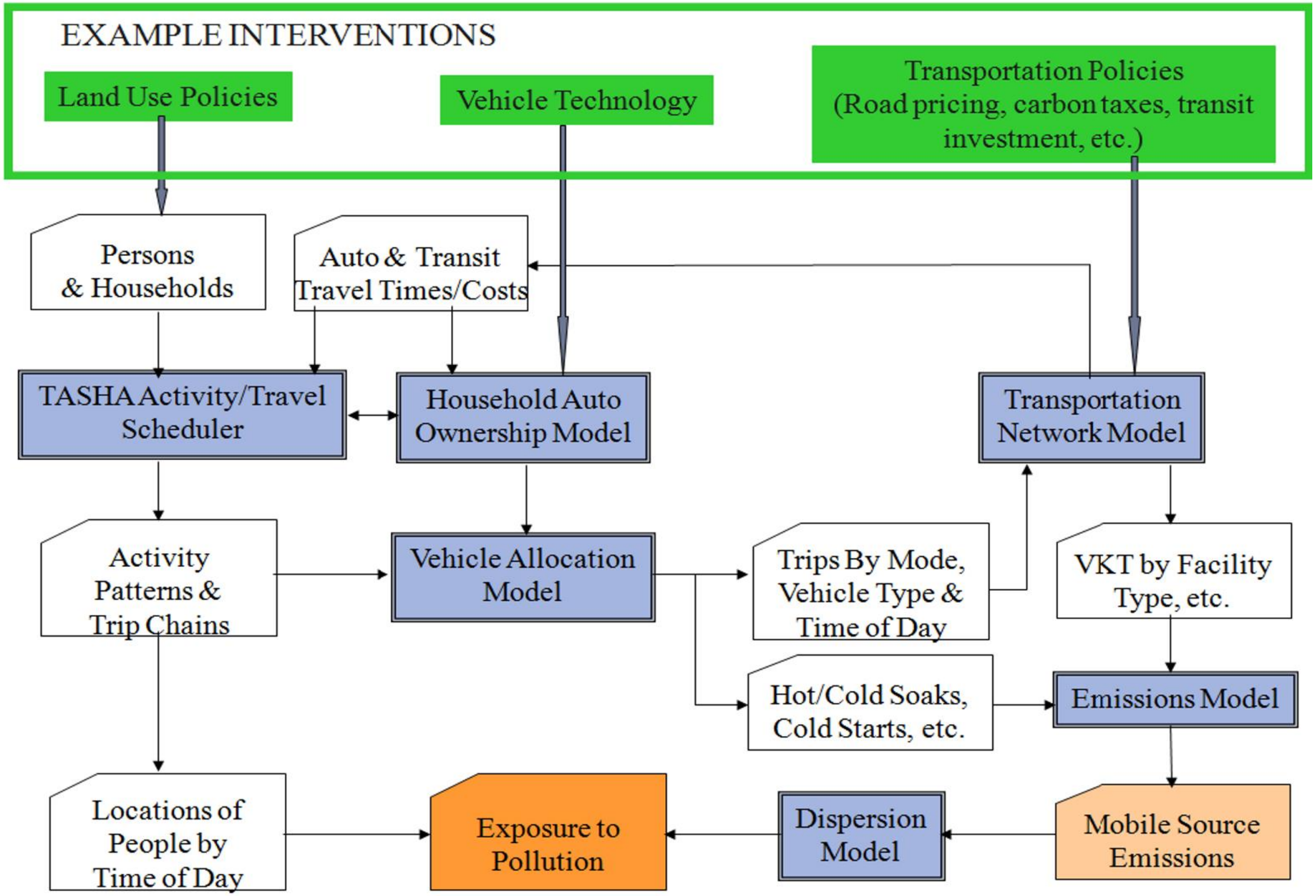
Integrated Transportation Demands: Bottom-Up Approaches

ILUTE



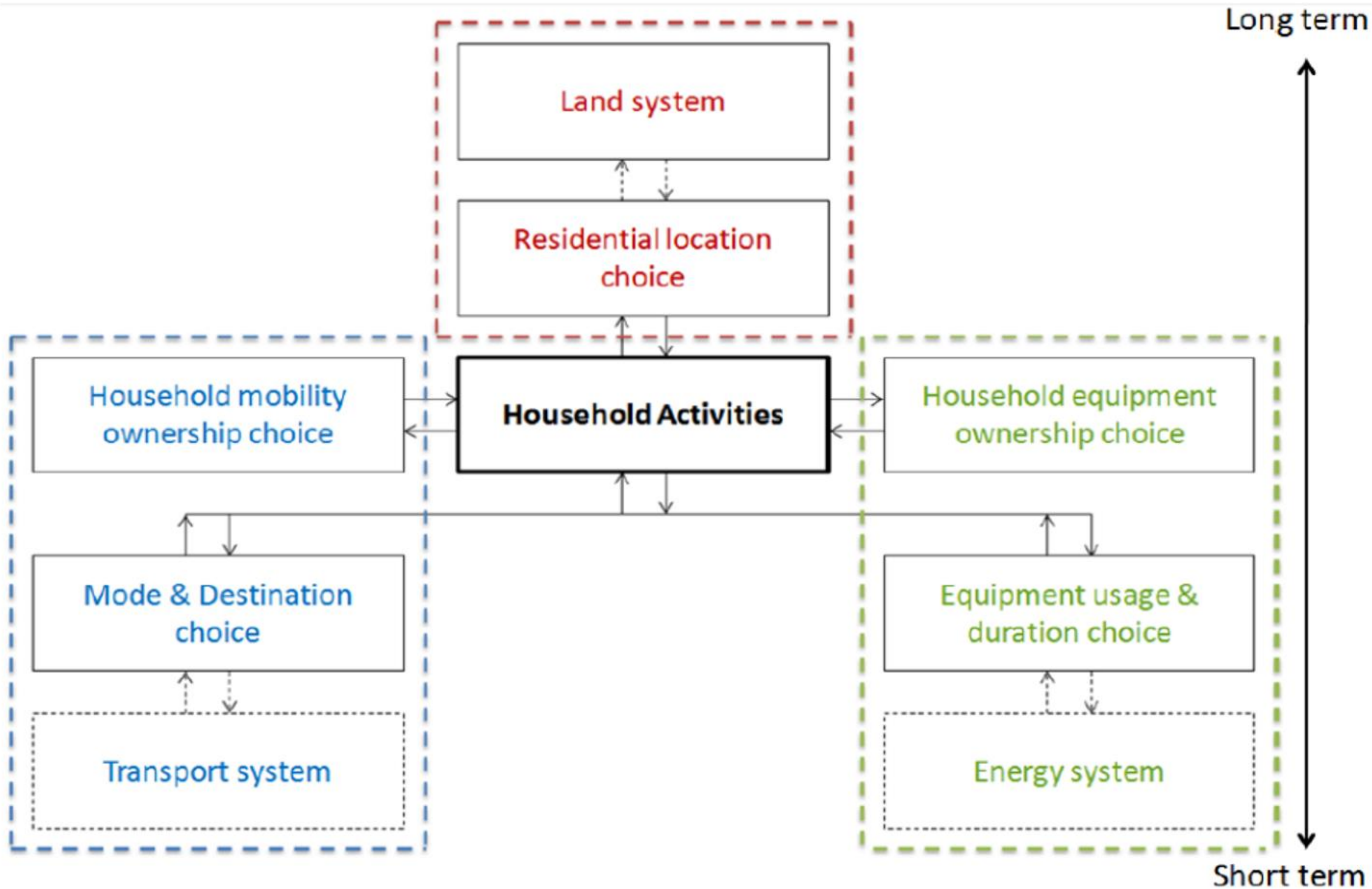
Integrated Transportation Demands: Bottom-Up Approaches

ILUTE Application



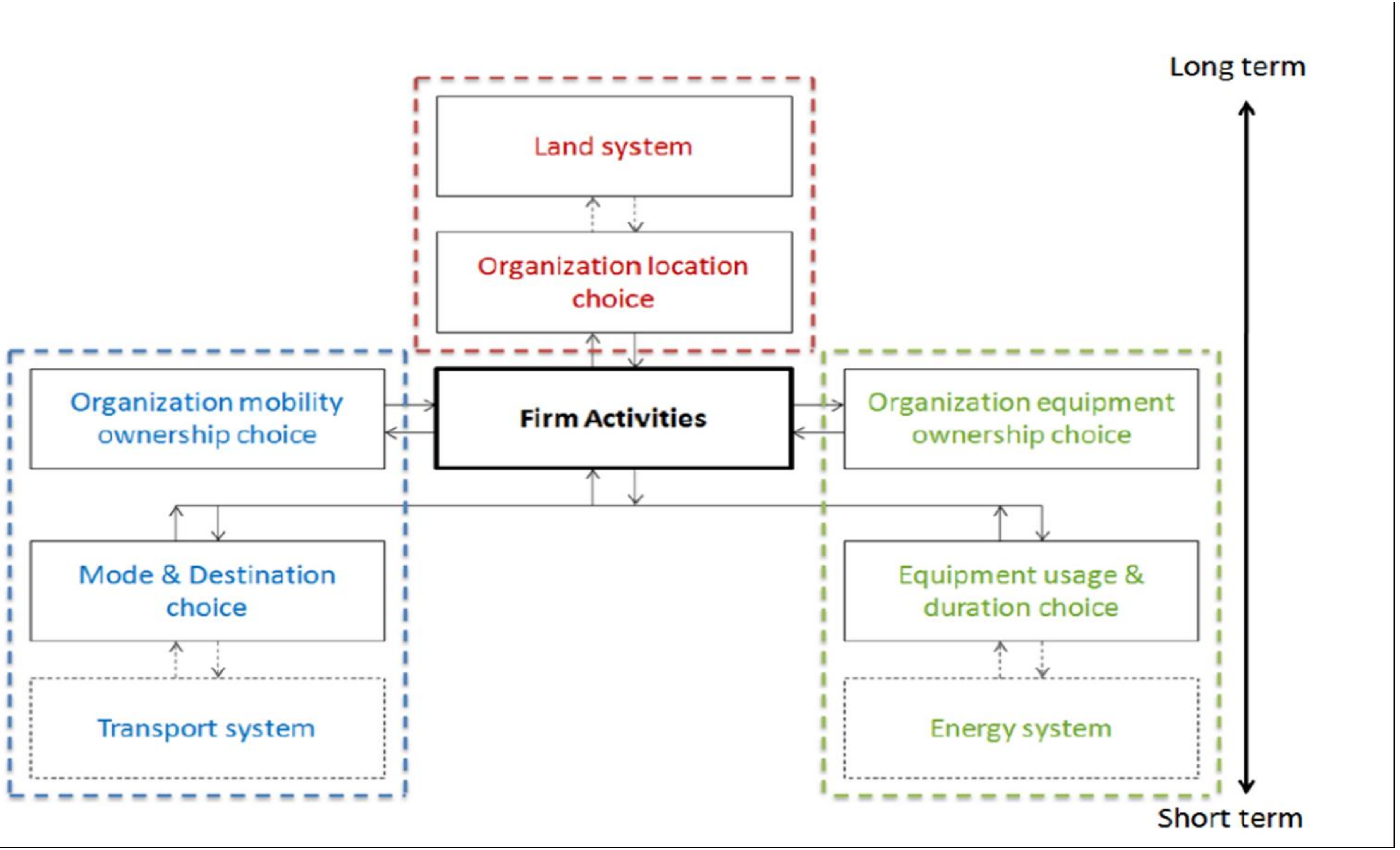
Miller 2009

Key Modelling Modules: Households



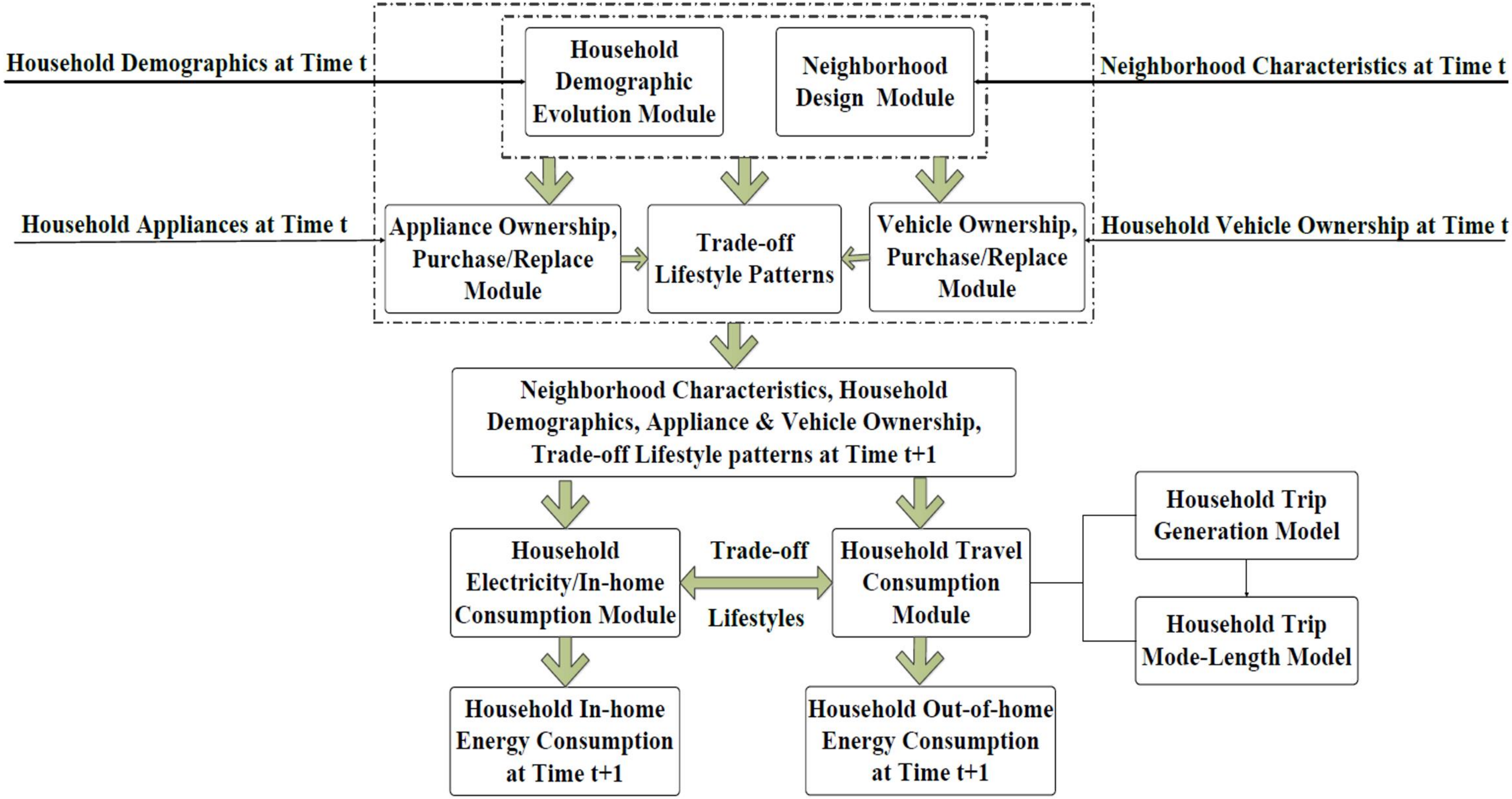
Ghauche 2010

Key Modelling Modules: Firm/Industry

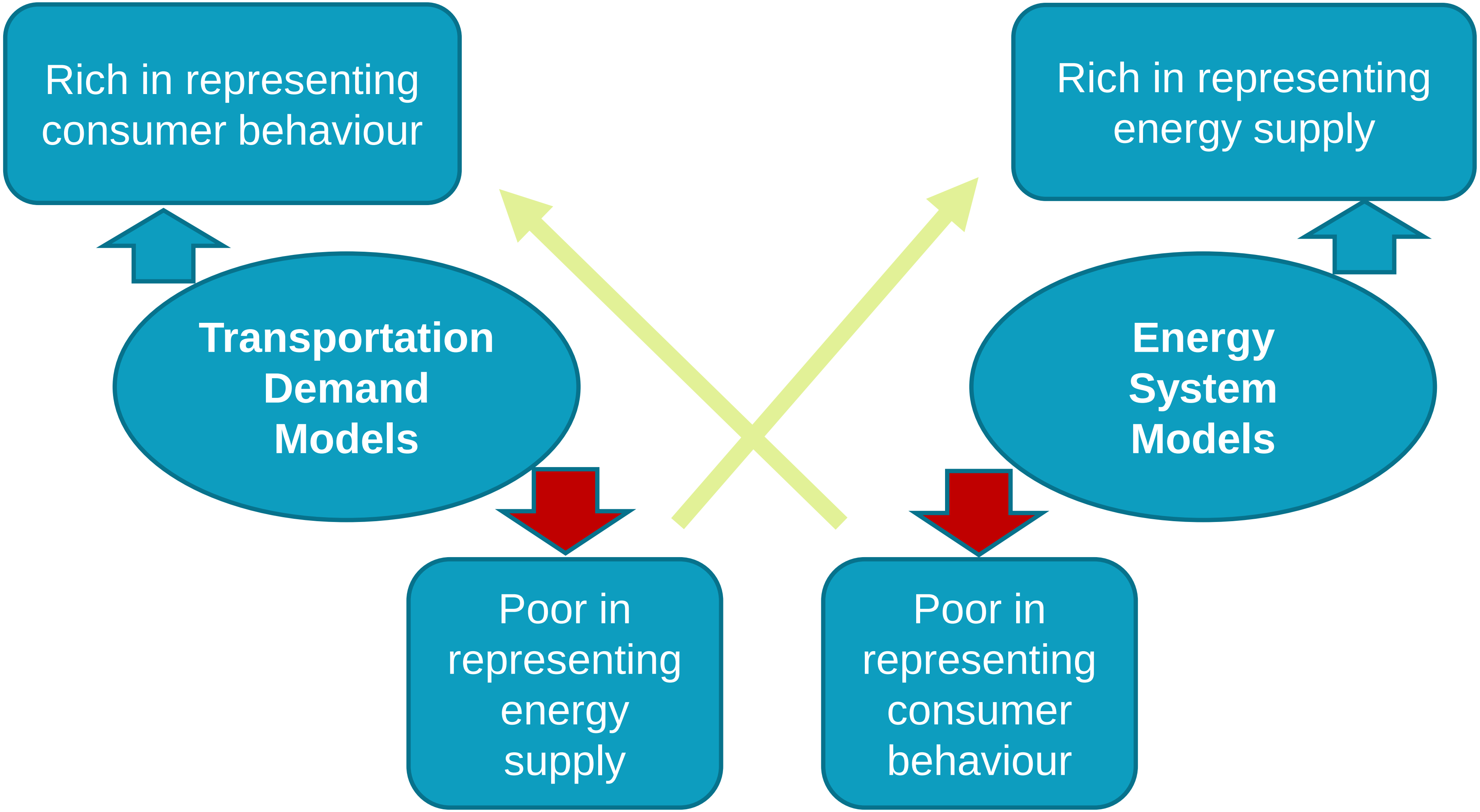


Ghauche 2010

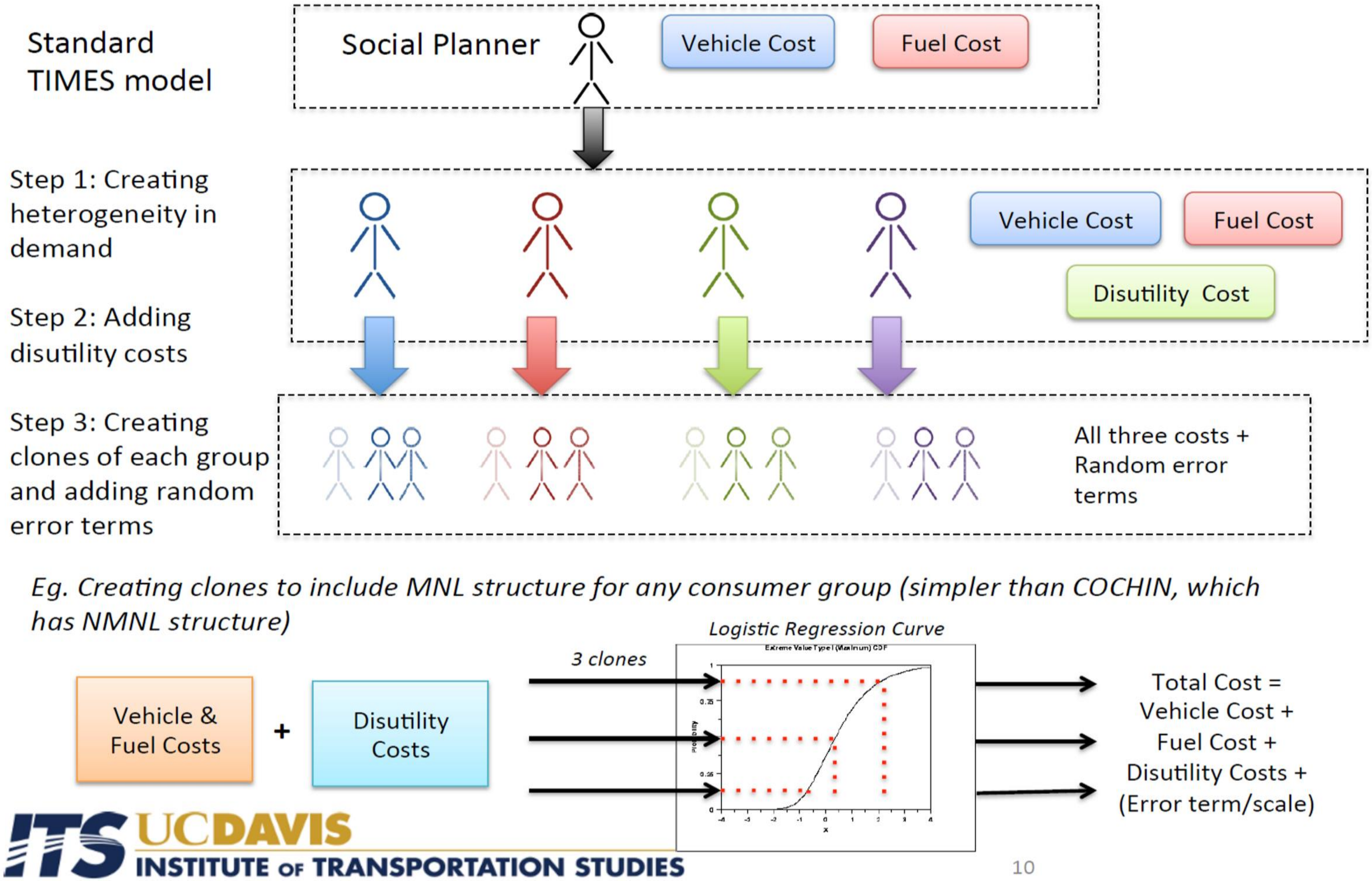
Household Energy Demand: Integrated Model for In-home and Transportation



Energy System Model -vs-Transport Energy Demand Model

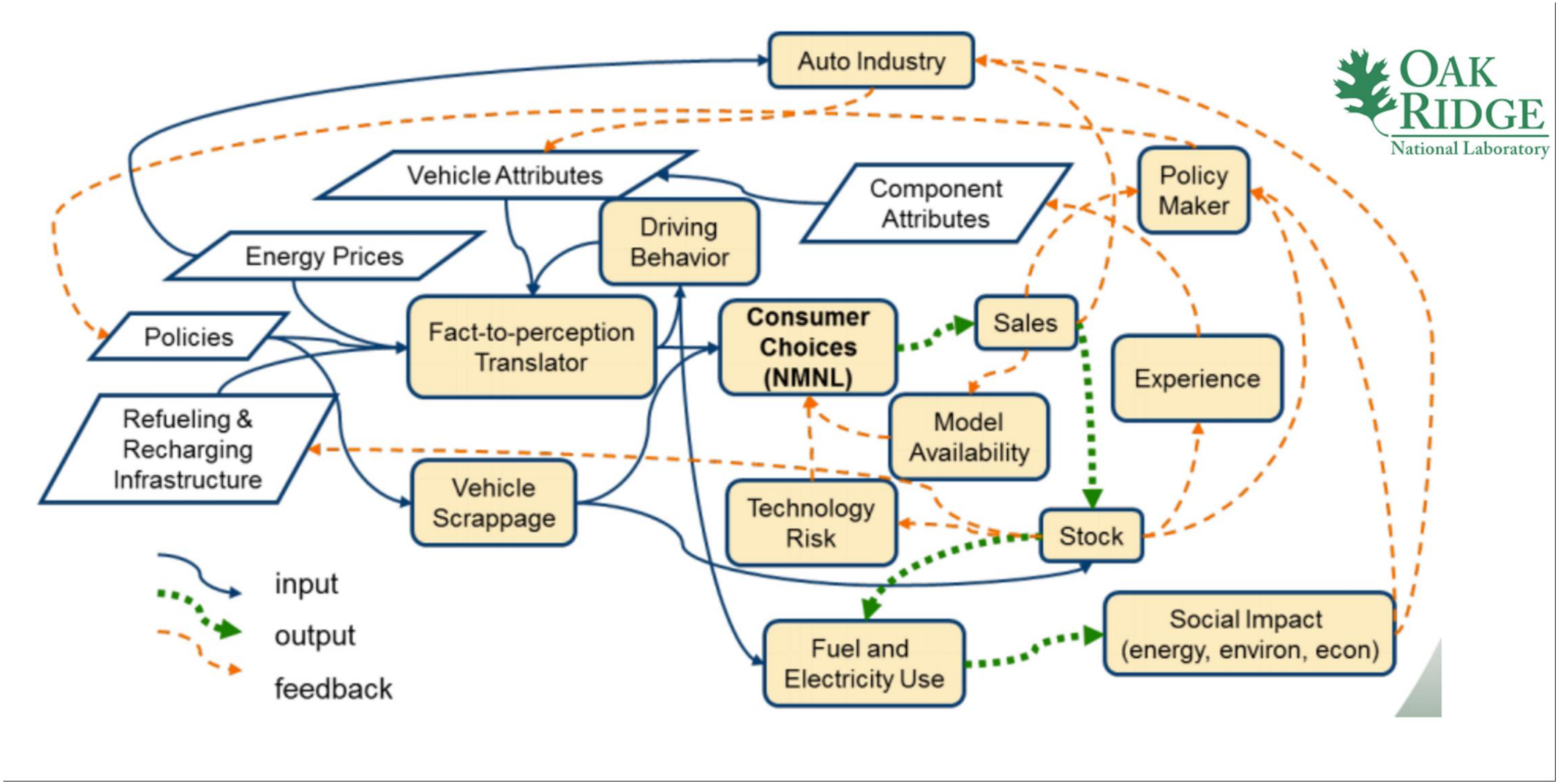


<u>Notable Effort</u>: Consumer Choice IN TIMES (COCHIN-TIMES) at UC Davis



Ramea et al 2015

MA^{3}T (Market Allocation of Advanced Automotive Tech) Consumer Choice Model in COCHIN-TIMES



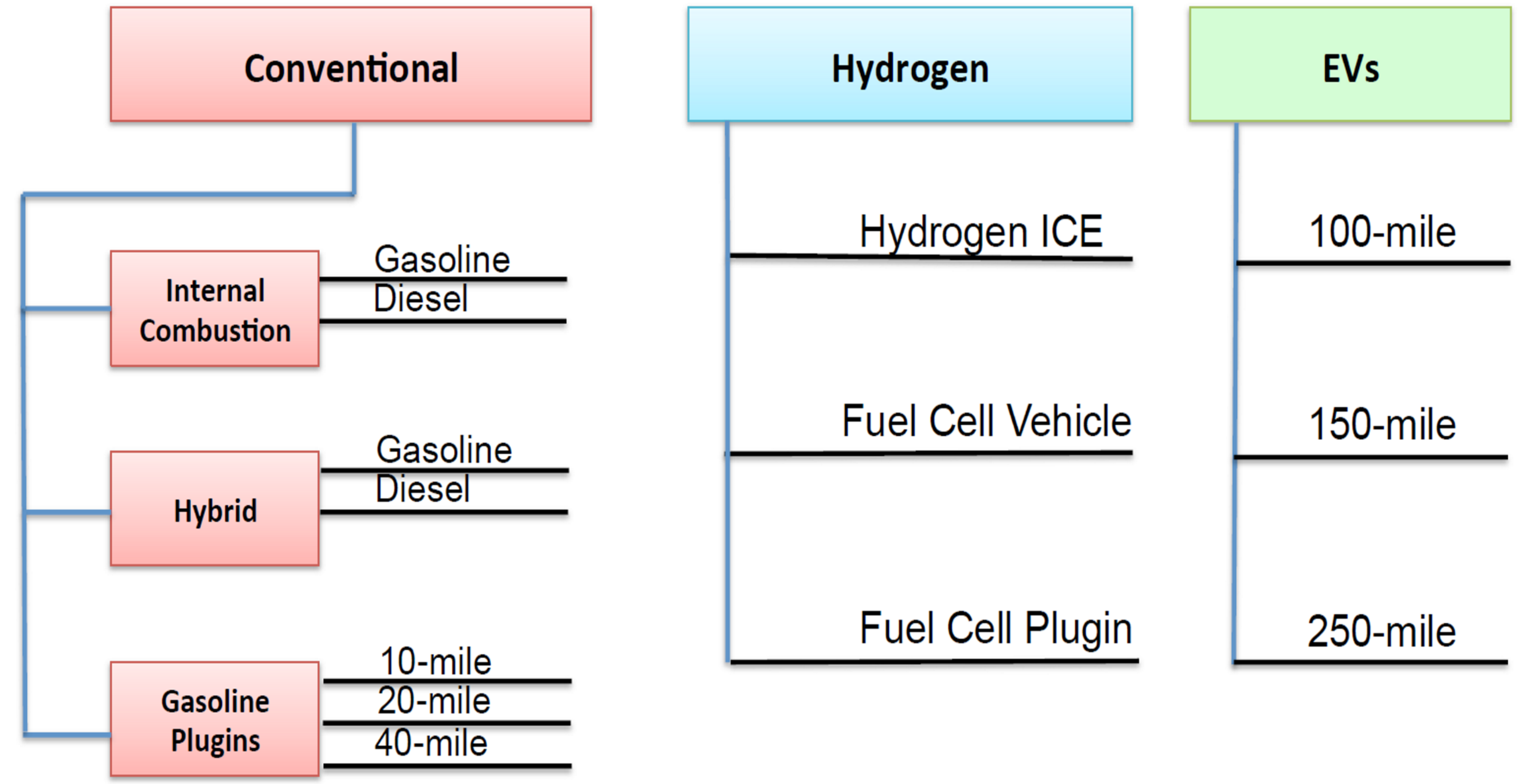
Consumer Classifications in the MA^{3}T (Market Allocation of Advanced Automotive Tech) Model

Settlement Type	Urban
	Suburban
	Rural
Risk Attitude	Early Adopter (8%)
	Early Majority (38%)
	Late Majority (54%)
Driving Behavior	Low Annual VMT (8656 miles)
	Medium Annual VMT (16068 miles)
	High Annual VMT (28288 miles)
Recharging Infrastructure	Home + Work
	Home + No Work
	No Home + Work
	No Home + No Work

(+ public recharging infrastructure common to all)

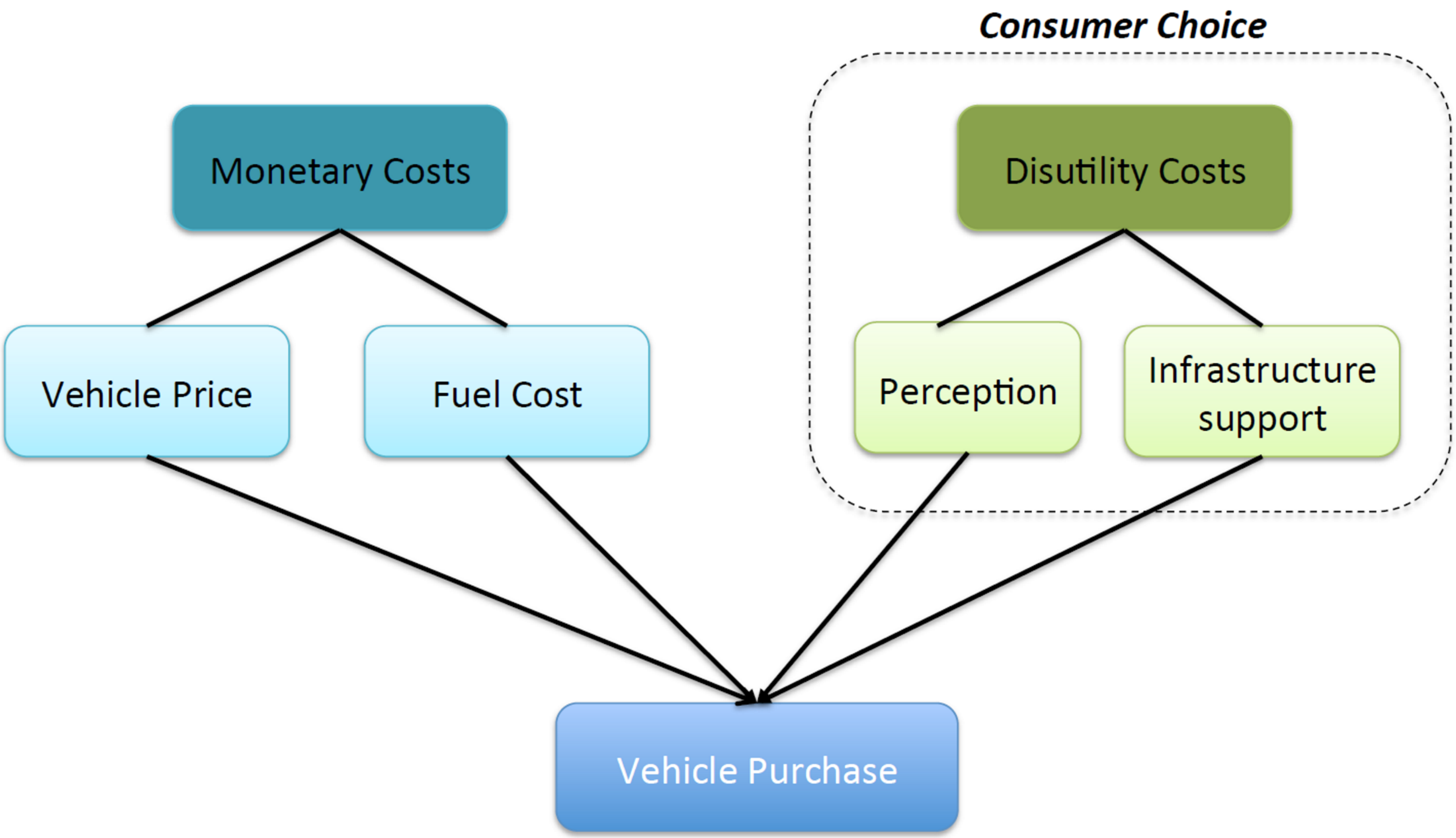
Ramea et al 2015

Vehicle Classifications in the MA^{3}T (Market Allocation of Advanced Automotive Tech) Model



Ramea et al 2015

Vehicle Purchase Choice in the MA^{3}T (Market Allocation of Advanced Automotive Tech) Model



Ramea et al 2015

Disutility Costs in the MA^3T (Market Allocation of Advanced Automotive Tech) Model

- Refueling Inconvenience Cost
  - Cost associated with the lack of access to refueling infrastructure (station availability)
  - Based on various spatial simulation and cluster analysis studies done on acces time to find stations—multipliers are derived
- Range Anxiety Cost
  - Cost to capture the consumer's perception of anxiety associated with the limited range of EVs and infrastructure availability.
  - Based on a daily VMT distribution, model checks whether it meets the range for the day. If not, a $/day penalty is given, which differs across risk groups
- New Technology Risk Premium
  - The consumers' willingness to pay to avoid risk (or gain novelty) approaches zero as cumulative sales of the vehicle technologies increases over time
- Model Availability Cost
  - Make and model diversity is represented in the vehicle choice model as the log of the ratio of the actual number of makes and models available, to the "full diversity" number (conventional vehicles)

MA^{3}T Simulates 1458 US consumer segments Choosing from 40 Light Duty Vehicle Types

- U.S. LDV market divided into 1458 seg., 2005-50
- Buy or no buy decision is now endogenous
- 20 powertrain technologies, cars and light trucks, to be expanded into small cars, midsize cars, large cars, SUVs and pickup
- Vehicle attributes: retail price, fuel economies, acceleration, refueling hassle, range limitation cost, etc
- Infrastructure: hydrogen, natural gas, electricity, diesel; home, work, public charging
- Policies: fuel/carbon tax, feebate, parking or HOV incentives, tax credit or rebate

Looking Forward

- TIME type models are for regional policy analysis
  - ✓ COCHIN-TIME approach tries to induce consumer behaviour within such regional model
  - ✓ However, such model may not reflect on end-users' daily demand dynamics
- Targeted econometric models can allow further investigation of impact of any energy policies on end-users:
  - ✓ Car ownership choice model: Discrete choice model of car type and number of car choices
  - ✓ Choice model of consumer's reaction to energy policies

Questions ?