# Discovering Robust Urban Mobility Futures via Agent Based Simulation in Prototype Cities

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# Mobility of the future: motivation

## Key question

How would

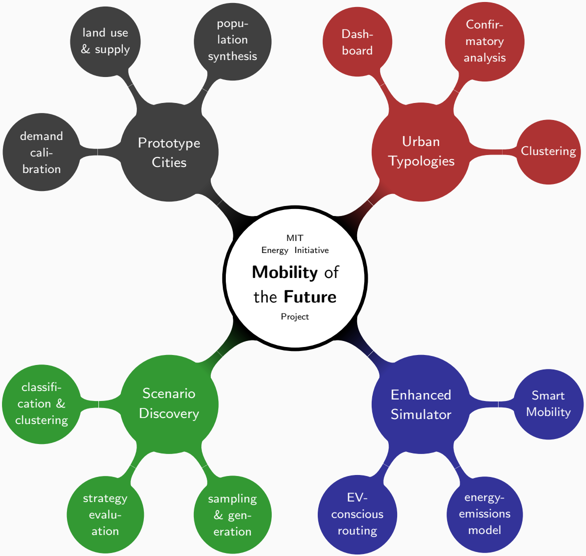
- Smart mobility/autonomous mobility on demand
- Vehicle and fuel technologies
- Energy and environmental policies

affect **future urban mobility**?

## Approach

- Understand and replicate mobility and energy-related urban dynamics in worldwide prototypical metropolitan areas
- Build enhanced urban laboratory to simulate individual traveler reaction and transportation system performance
- Identify efficient policy intersections across various strategies under uncertainty futures

# Research overview



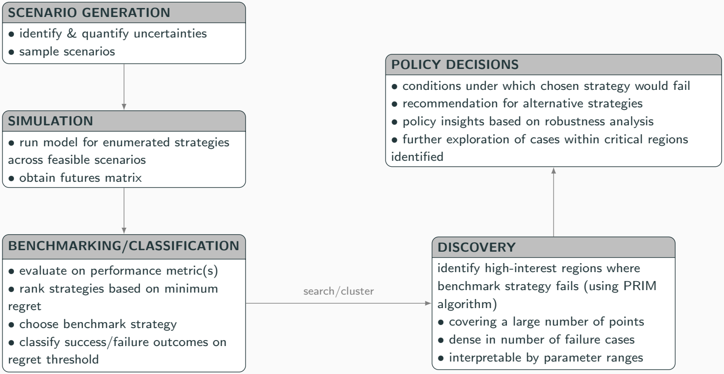
# Motivation for scenario discovery

**Traditional scenario analysis**

- Does not adequately address uncertainties in decision making
- Relies on overly narrow deterministic definition of a small number of scenarios

**Scenario discovery**

- Provides framework for sampling across space of multiple futures
- Allows for identification of clusters of cases where base strategy fails
- These give rise to robust scenarios



# Prior work and significance of current contributions

## Notable academic efforts and key milestones

- Foundations: exploratory modeling[Bankes 1993]
- Development of Patient Rule Induction Method (PRIM) for high dimensional clustering[Friedman and Fisher 1999]
- Formalization of scenario discovery/robust decision making[Lempert et al. 2006]
- Demonstration of scenario discovery concept for robust urban planning[Swartz and Zegras 2013]
- Climate change and resource management; Ethiopia[Shortridge and Guikema 2016], Global[Rozenberg et al. 2014], California[Groves 2006]
- Extensions and improvements: data transformation[Dalal et al. 2013], heterogeneous types[J. H. Kwakkel and Jaxa-Rozen 2016], random bagging[J. Kwakkel and Cunningham 2016]
- Software: exploratory modeling workbench[J. H. Kwakkel 2017], many-objective robust decision making[Hadka et al. 2015]

## Urban mobility arena

- Current work largely dominated by traditional scenario analysis and limited uncertainty analyses
- Bus lane strategy analyses in Marina Bay, Singapore [Song 2013]
- Current: future urban mobility across global urban typologies

# Case study: futures for autonomous mobility on demand (AMOD)

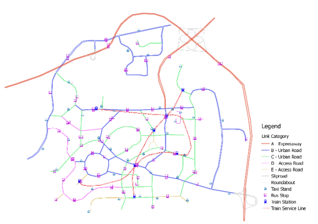
## Scenarios *(each a unique combination of discrete uncertainty factor outcomes)*

| **Uncertainty** | **Levels** / *Probabilities* | | | | |
|---|---|---|---|---|---|
| Household level of motorization | −40%<br>*0.1* | −20%<br>*0.3* | **0**<br>*0.5* | +20%<br>*0.1* | |
| ICEV proportion | 25%<br>*0.1* | 50%<br>*0.2* | 75%<br>*0.3* | **95%**<br>*0.4* | |
| Fuel price change | −50%<br>*0.25* | **0**<br>*0.30* | +50%<br>*0.20* | +100%<br>*0.15* | +150%<br>*0.10* |
| Smart mobility modeshare change | **0**<br>*0.25* | +25%<br>*0.25* | +50%<br>*0.25* | +75%<br>*0.25* | |

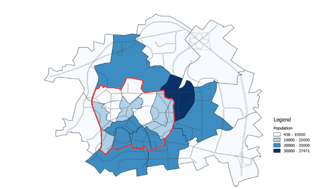
## Strategies *(each corresponds to a fixed policy implementation)*

- **CBD_Restriction**: restriction of AMOD to CBD; Mass Transit included, private cars excluded
- **Do_Nothing**: no AMOD, current on-demand levels
- **Full_AMOD**: full AMOD deployment including first/last mile
- **MOD_PT_Complement**: MOD as Public Transportation Complement (first/last mile)
- **No_PT_AMOD_Substitution**: AMOD as Mass Transit substitute
- **PT_Enhancement** Public Transportation Enhancement (doubling of frequency; first/last mile)

Prototype city testbed: dense public transit-oriented network; 2 rail lines, 5 bus lines, 99 nodes, 127 bidirectional links



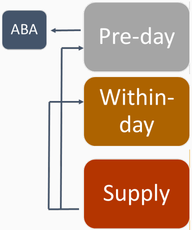

24 zones, population 350 000; CBD encircled in red; darker shades indicate greater population density



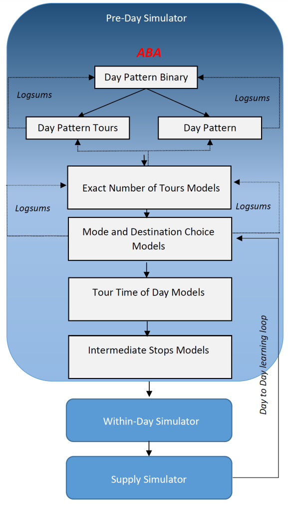
# Case study: Simulation and evaluation framework

Simulation laboratory:
**SimMobility** Mid-Term

Components:




- Integrated agent-based simulator with full feedback loops
- Initial exploration conducted for activity-based model (pre-day component)
- **126 scenarios** generated
- Run across 6 strategies




- The regret is computed for all scenarios based on the benchmark strategy specified

## Regret

For benchmark strategy $s^b \in S$ and a scenario $f \in F$, the regret $r$ is

$$r(f) = Z(s^b, f) - \min_{s \in S} Z(s, f) \quad (1)$$

- Futures are evaluated using the median activity-based accessibility (ABA) measure in terms of time (minutes).

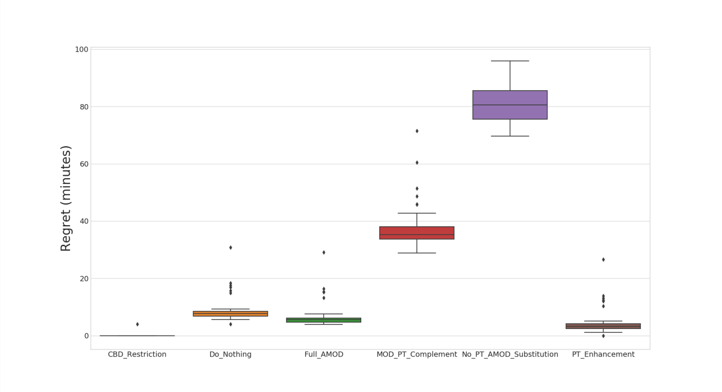
## Performance

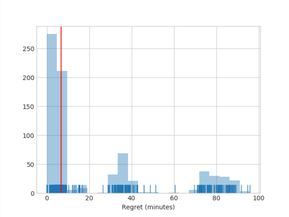
We define cost function $Z(s, f)$ as

$$Z(s, f) = median\,(-ABA_n(f, s)) \quad (2)$$

where $ABA_n$ is the activity-based accessibility for each individual $n$ and $N$ is the population.

# Preliminary results: regret distribution and thresholding

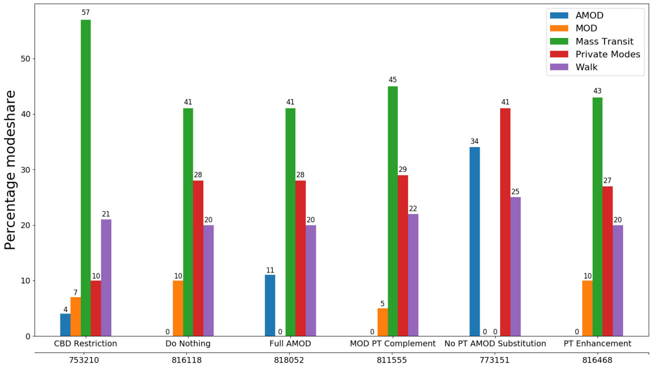



- Median regret across all strategy benchmarks: 6.6 minutes
- Chosen as failure threshold $\theta$
- Strategy used as benchmark for PRIM analyses: **Full_AMOD**
- Number of failure cases: 16/126
- A given scenario is classified a failure if regret is greater than $\theta$

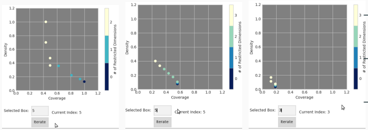
# Modeshare across strategies

- Initially simulate demand for base scenario (no change in any of uncertainty factors) across all six strategies
- Second $x$ axis indicates total number of trips



# Preliminary results: PRIM outcomes

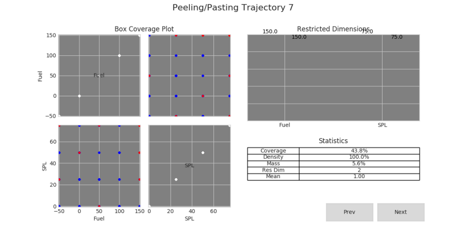
Box-finding sequence and limits:




| | Uncertainty factor | min | max | qp values |
|---|---|---|---|---|
| Box 1 | Fuel price | 150.0 | 150.0 | 0.000741 |
| | Smart mobility preference | 75.0 | 75.0 | 0.037253 |
| Box 2 | Vehicle Ownership | −20.0 | −20.0 | 0.020650 |
| | ICE Proportion | 75.0 | 95.0 | 0.175929 |

⋮

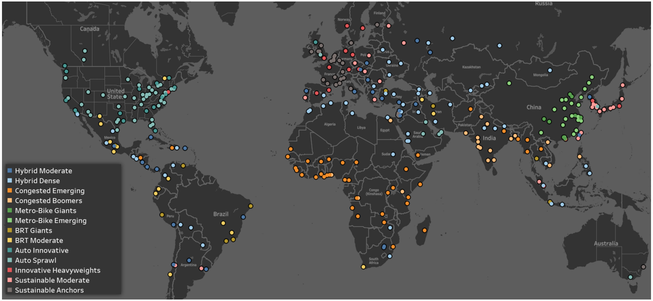
- First box has 50% coverage and 47% density and 1 significant constrained dimension




- Subsequent boxes discovered do not have significant bounds
- "Full_AMOD" strategy is vulnerable under highest fuel price
- Indicates that proper planning must be done to ensure demand is met without lowering performance
- Further exploration required to measure modal shifts and levels of service based on network effects to properly measure impacts of other uncertainty factors

# Outlook

- Current case study performed for only activity-based accessibility outcomes
- Supply to be simulated for energy, network performance outcomes, feedback for ABA iterations
- Further experimental design for discovery across 4 distinct prototype cities representing key urban typologies[1]:
  - **Auto-Sprawl**
  - **Auto-Innovative**
  - **Innovative-Heavyweight**
  - **Sustainable Anchor**
- Key expected result: policy recommendations for robust strategies and efficient outcomes given the urban typology with focus on AMOD implementation[2]




[1] Yafei Han et al. (2018). "Global Urban Typology Discovery with a Latent Class Choice Model". In: Transportation Research Board 97th Annual Meeting. Washington DC, United States.

[2] Rounaq Basu et al. (2018). "Automated Mobility-on-Demand vs. Mass Transit: A Multi-Modal Activity-Driven Agent-Based Simulation Approach". In: *Transportation Research Record* 0.0, p. 0361198118758630. DOI: 10.1177/0361198118758630.