Tri-POP: an online platform for smart mobility with prediction, optimization and personalization

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Tri-POP: an online platform for smart mobility with prediction, optimization and personalization

Smart mobility solutions

- Flexible mobility on demand
- Intelligent online operations

Tri-POP analytics

- Online bi-level optimization
- System-level
- User-level

Tri-POP applications

- Managed lanes
- Sustainability incentives
- Freight on demand

Conclusion

Example: Flexible Mobility on Demand (FMOD)

- Paratransit services
  - **Taxi:** door-to-door, private

  - **Shared-taxi:** door-to-door, shared

  - **Mini-bus:** fixed stops, shared

Personalized FMOD menu

TAXI

DEPARTURE TIME 09:30 AM - 09:40 AM
ARRIVAL TIME 10:00 AM - 10:17 AM
30-37 min
10-12 min > 20-25 min
16 SGD

SHARED-TAXI

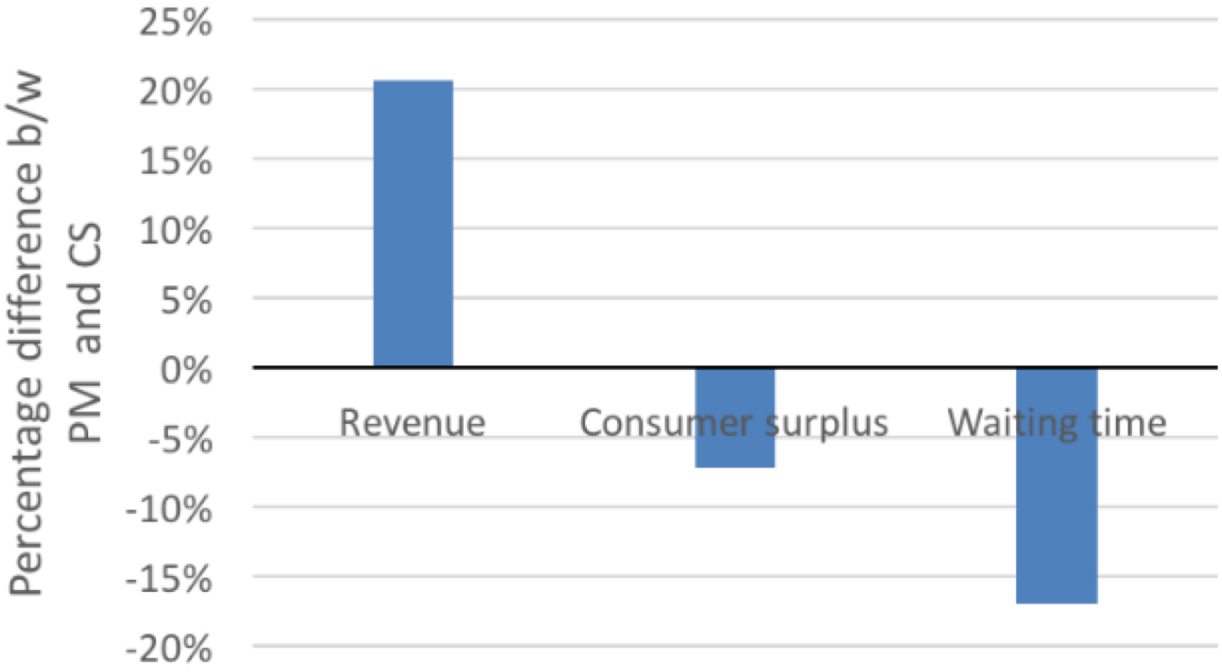
DEPARTURE TIME 09:30 AM - 09:35 AM
ARRIVAL TIME 10:05 AM - 10:16 AM
35-41 min
10-13 min > 25-28 min
8 SGD

MINI BUS

DEPARTURE TIME 09:40 AM - 09:45 AM
ARRIVAL TIME 10:25 AM - 10:38 AM
45-53 min
10 min > 5-8 min > 20-25 min > 10 min
5 SGD

FMOD menu optimization

Maximizing Profit (PM) or Consumer Surplus (CS) (with a fixed fleet size)



*Percentage difference=(PM - CS) / PM *100*

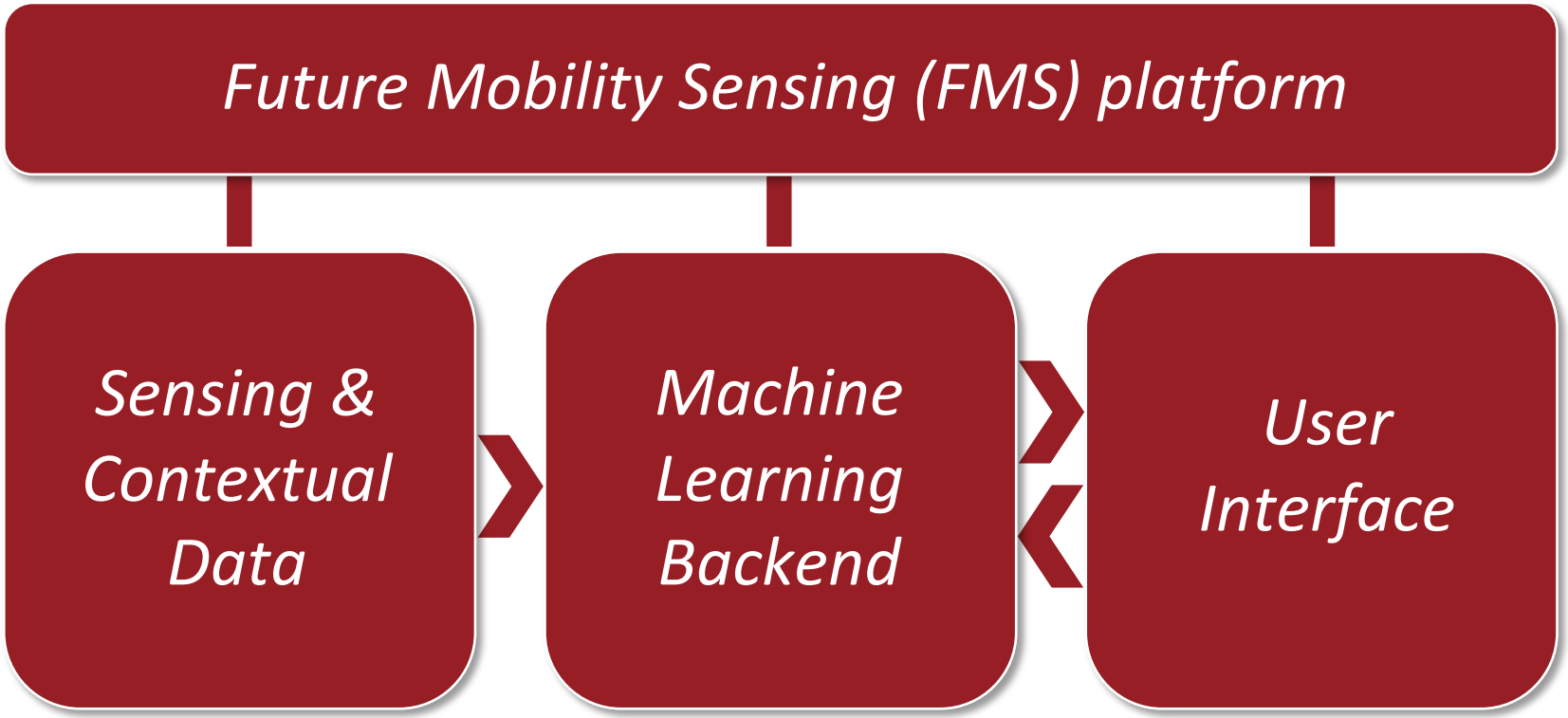
Smart mobility solutions at the ITS Lab

- Mobility on Demand (MOD)
  - Flexible MOD
  - Mobility as a Service (MaaS)
  - Automated MOD
  - Urban air mobility
- Transportation system management
  - Managed lanes
  - Congestion pricing
  - Sustainability incentives
  - Tradable mobility credits
- E-commerce
  - Automated Freight on Demand (AFOD)

What do smart mobility solutions have in common?

- App-based communication
- Advanced sensing
- On-demand
- Real-time operations

User experience via mobile app



What makes these solutions intelligent?

Prediction

- short-term predictions
- e.g. demand, congestion, fleet utilization

Optimization

- efficient use of resources
- e.g. travel time, energy, revenue, consumer surplus

Personalization

- customized options based on individual preferences
- e.g. modes, pick-up times, incentives, discounts

- How do we **combine** these capabilities in **online operations**?

Tri-POP

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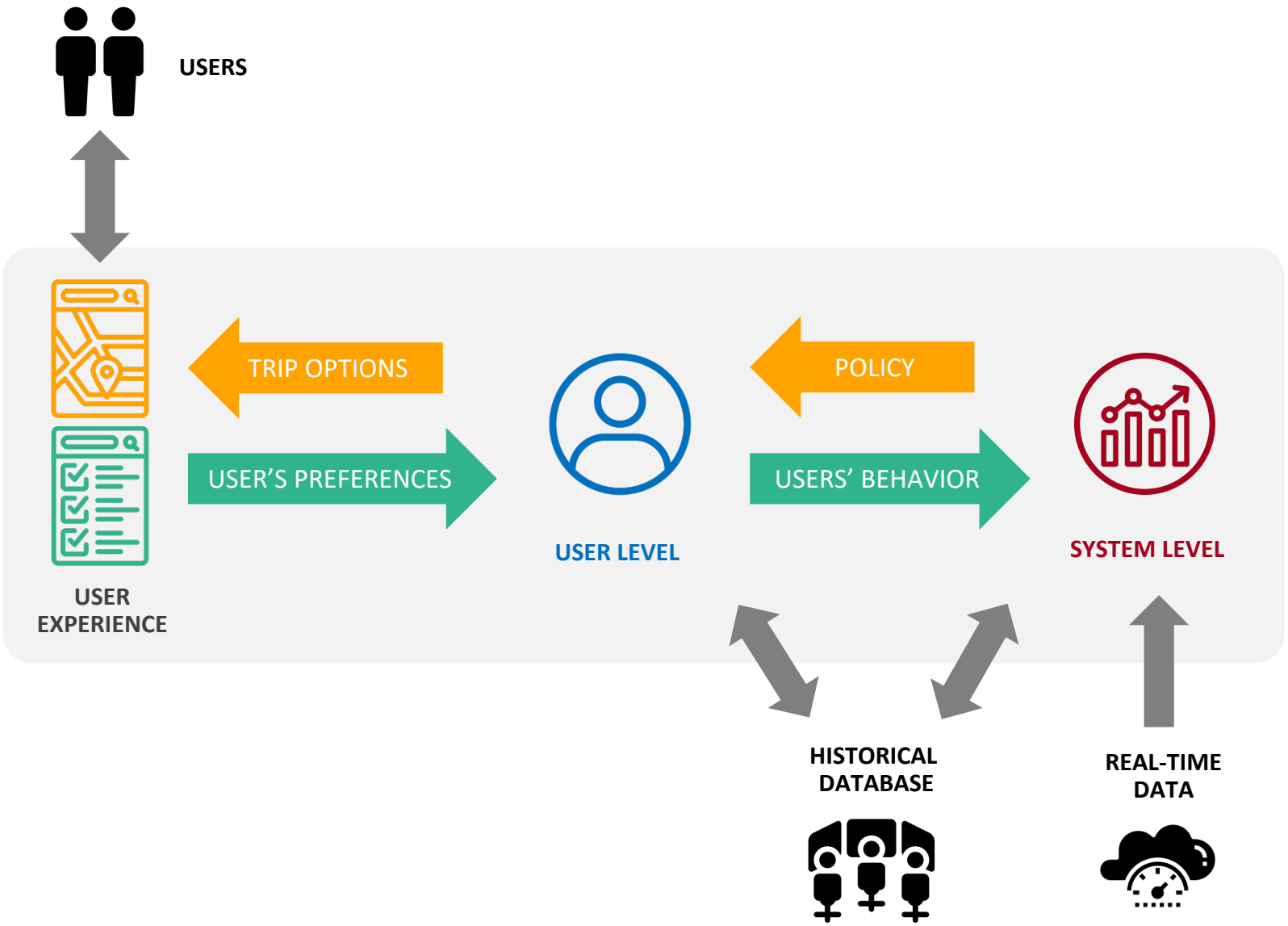
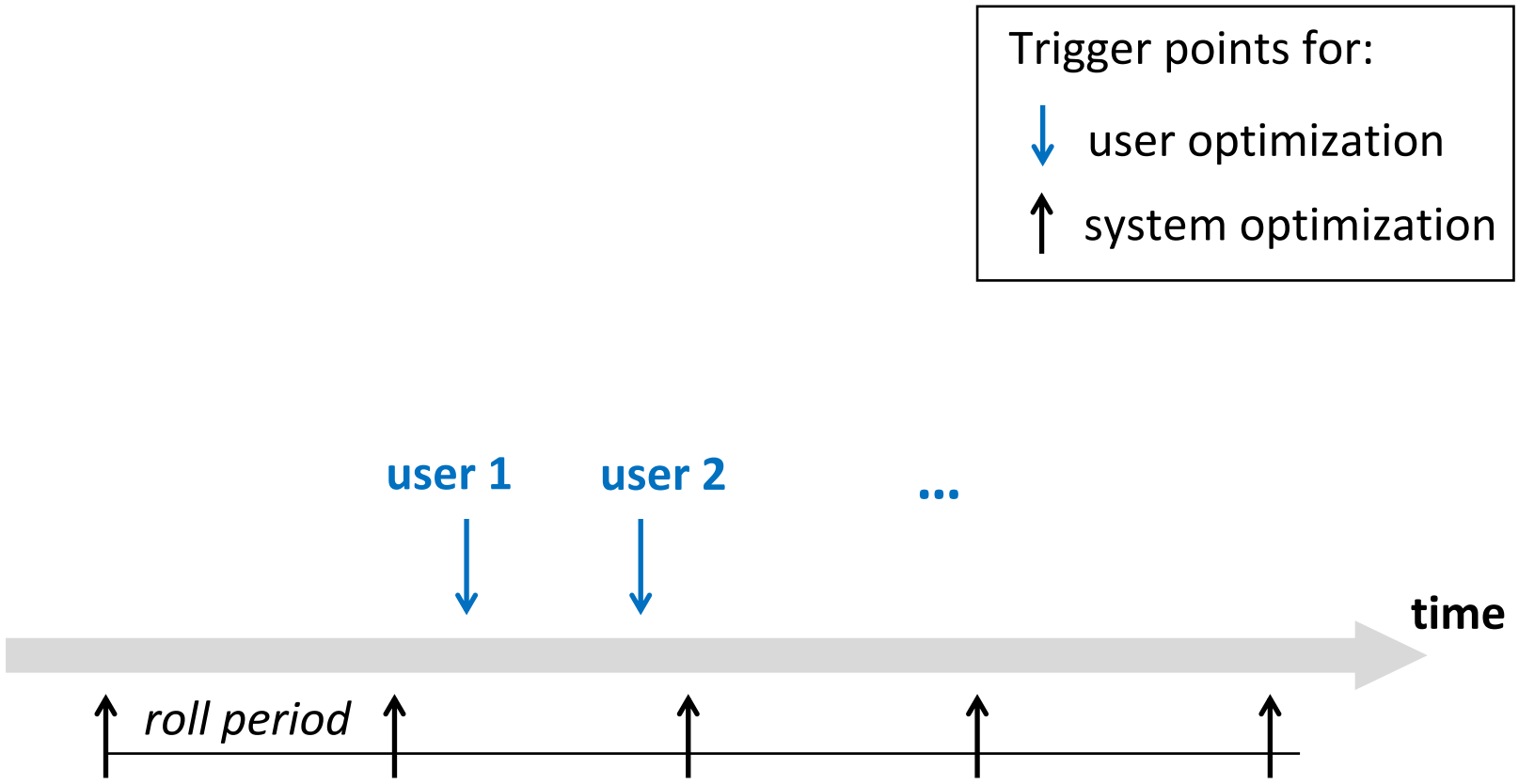
Tri-POP: overall framework



Bi-level optimization: background

- Applied to network/service design problems
- Formulated as two interdependent optimization problems
  - master problem (MP)
  - sub-problem (SP)
- Solved in an iterative manner
  - SP is conditional on MP's solution
  - MP updates its solution based on the performance measures from SP
- **Tri-POP** extends it to ***online*** optimization with
  - a ***rolling horizon*** network model, and
  - a theory-driven ***machine learning*** behavioral model

Tri-POP: rolling horizon



Tri-POP: online bi-level optimization

Personalized

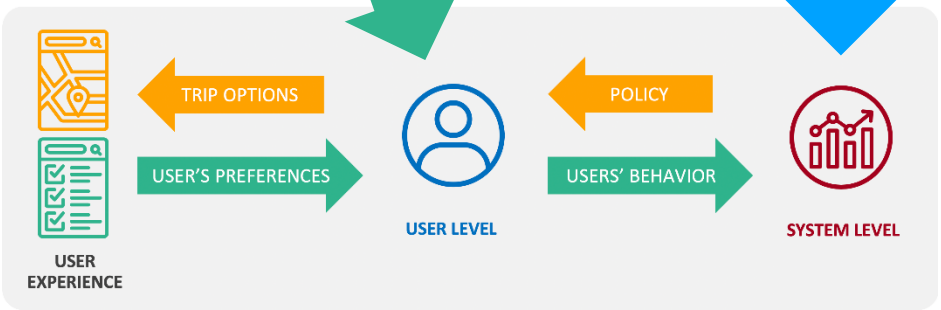
USER optimization

- runs at every query
- determines optimal service (e.g. on-demand) options based on individual preferences (e.g. max. surplus assortment)

Prediction-based

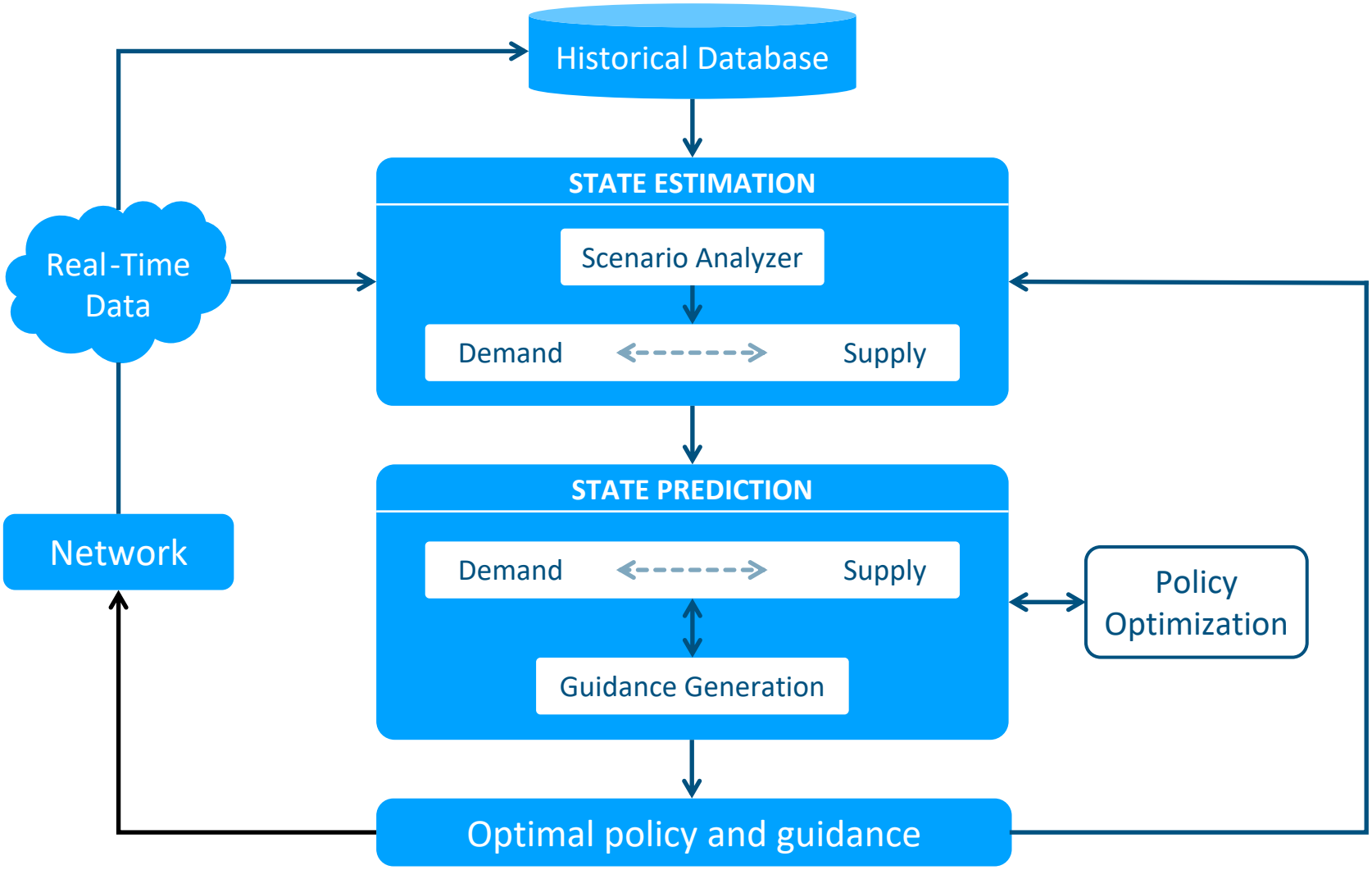
SYSTEM optimization

- runs in real time at every roll period
- determines optimal policy (e.g. surge pricing, incentive allocation) to attain system-level objective (e.g. travel time, welfare)



System level: DynaMIT

- Prediction-based system optimization



User level: overview

Objective:

offer a customized menu that maximizes individual-level objectives given policy in effect

- Updating preferences
- Assortment optimization

Updating preferences

- Individual preferences are modeled with a Logit Mixture with both inter- and intra-consumer heterogeneity
- Preferences are estimated offline and updated online using Hierarchical Bayes and MCMC
- Preferences are
  - stored and identified upon login
  - updated online as choices are made
  - updated offline periodically with pooled data

Assortment optimization

- Maximizes user-level objective (e.g. consumer surplus, social welfare, operator's profit, energy savings, hit rate)
- Subject to system-level policy, available supply, the latest estimates of preferences, and menu size constraint
- Algorithm depends on the application

Tri-POP: summary

- Platform is

User-oriented

  - considers user behavior in determining policy
  - does the best possible for the user

Fair

  - all users subject to the same policy
  - has potential for wider acceptance

- Applications

  - any service that is on-demand and relies on an app
  - e.g. MOD, ride sharing, car-sharing, MaaS

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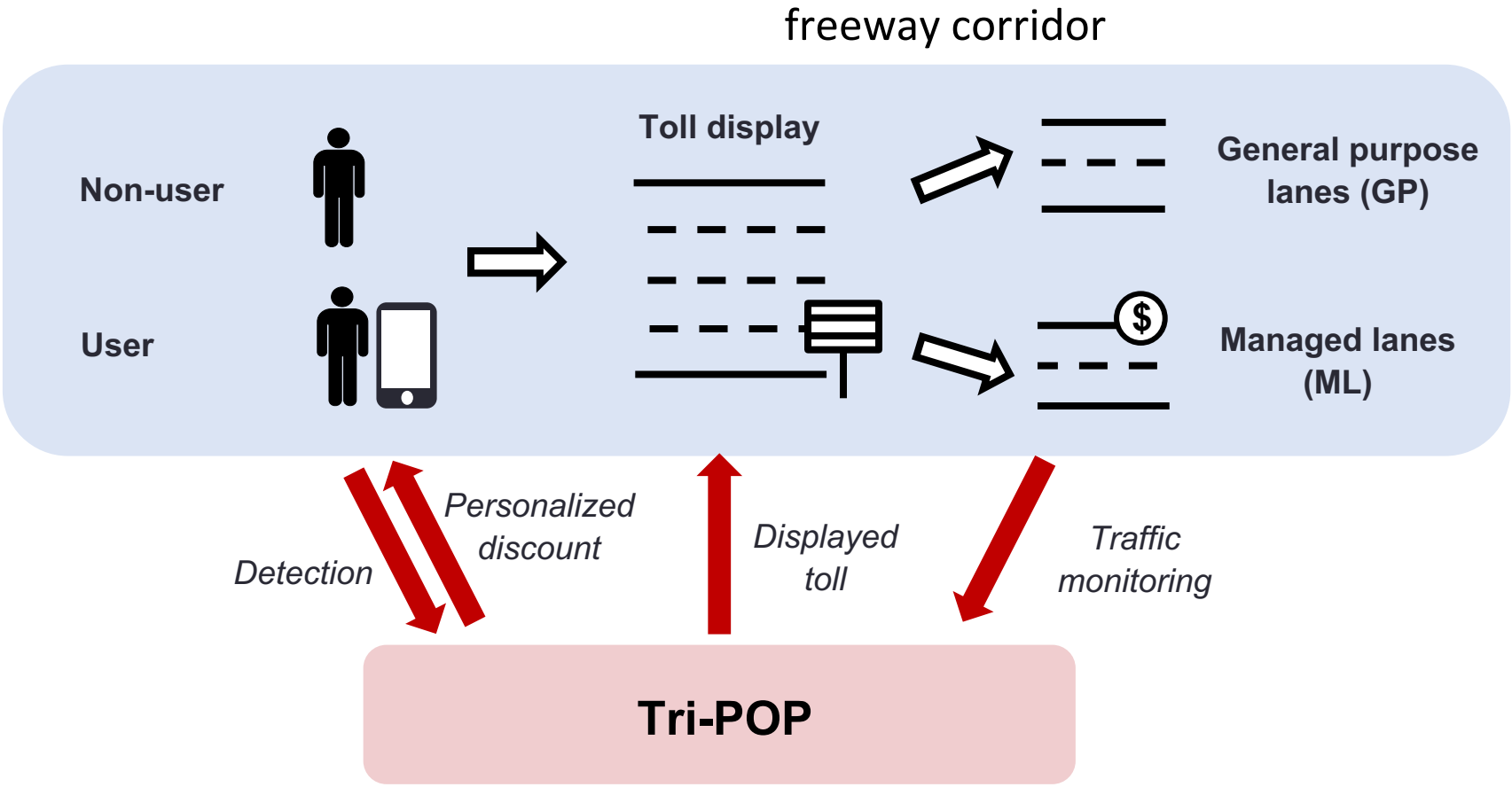
Managed lanes: optimized tolls

- Personalized tolling



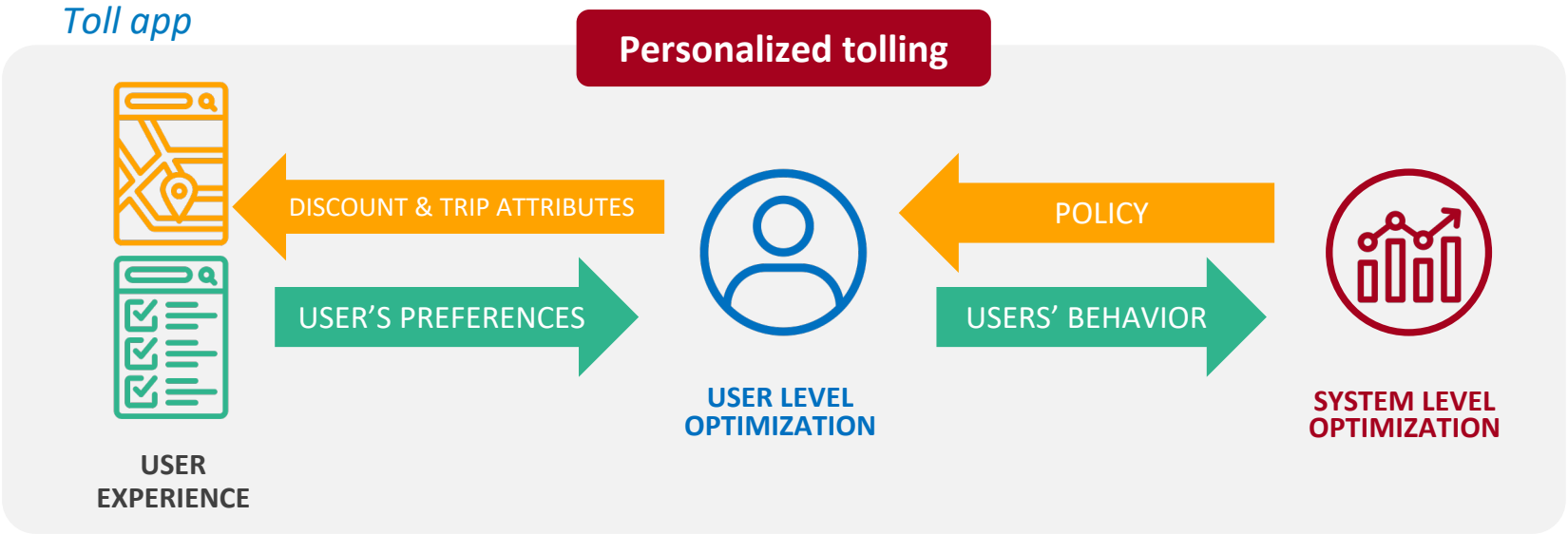
Tri-POP for managed lanes

SYSTEM OPTIMIZATION

- **Objective:** revenue and capture rate
- **Policy:** displayed toll, discount control parameter
- **Constraints:** max toll and min speed

USER OPTIMIZATION

- **Objective:** consistent with system optimization

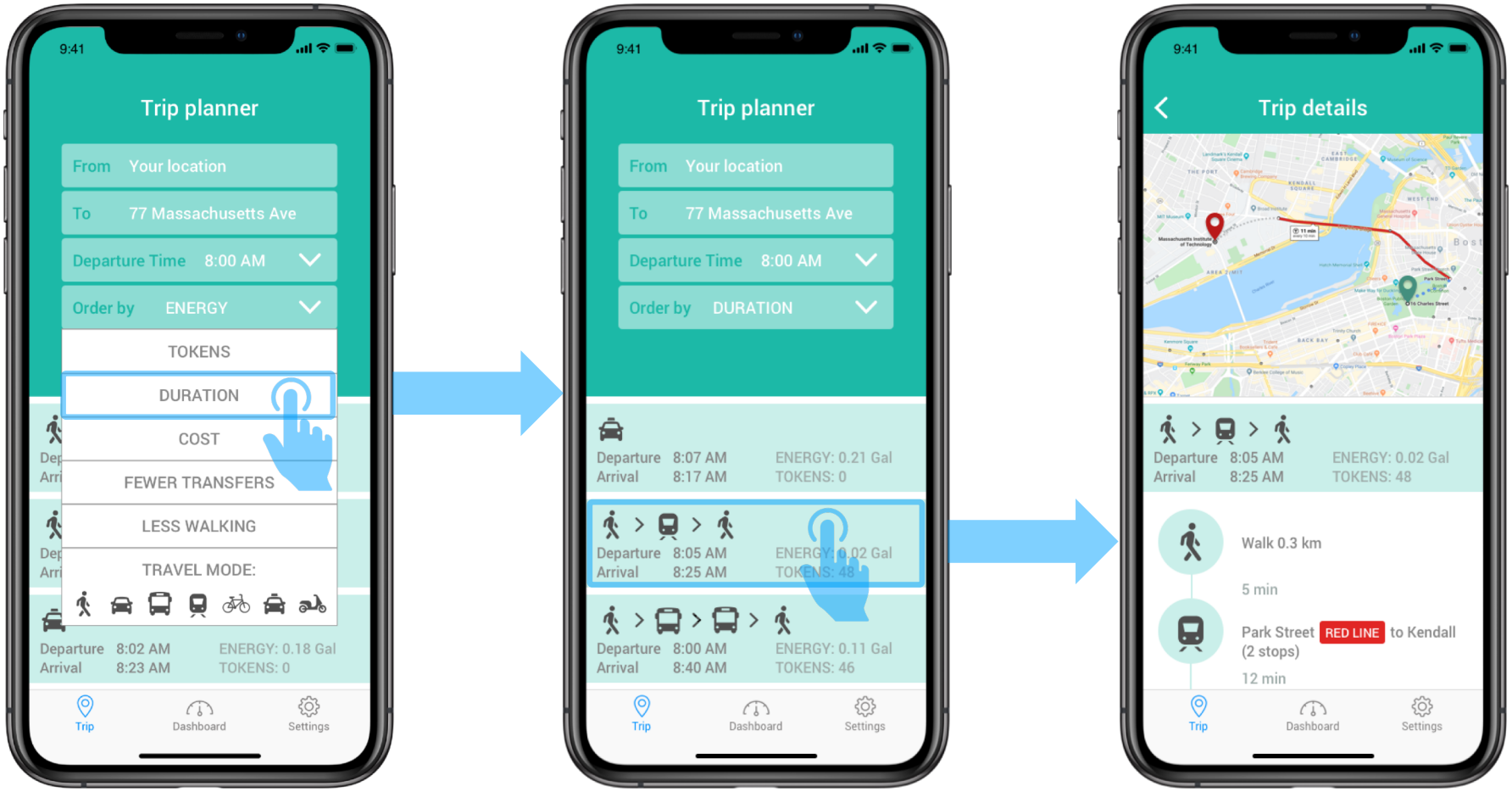


Simulation experiments

- Scenarios
  - Base case (rule-based, no discounts)
  - (A) System optimization (no discounts)
  - (B) Tri-POP (with discounts)
- (A) improves revenue (15-20%) while decreasing capture rate (1-2%) and not affecting significantly GP travel time
- (B) improves revenue (20+%) while increasing capture rate (2+%) and reducing GP peak travel time (5-10%)

Sustainability incentives: Tripod

- Tripod offers personalized incentives for sustainability through a trip planner app



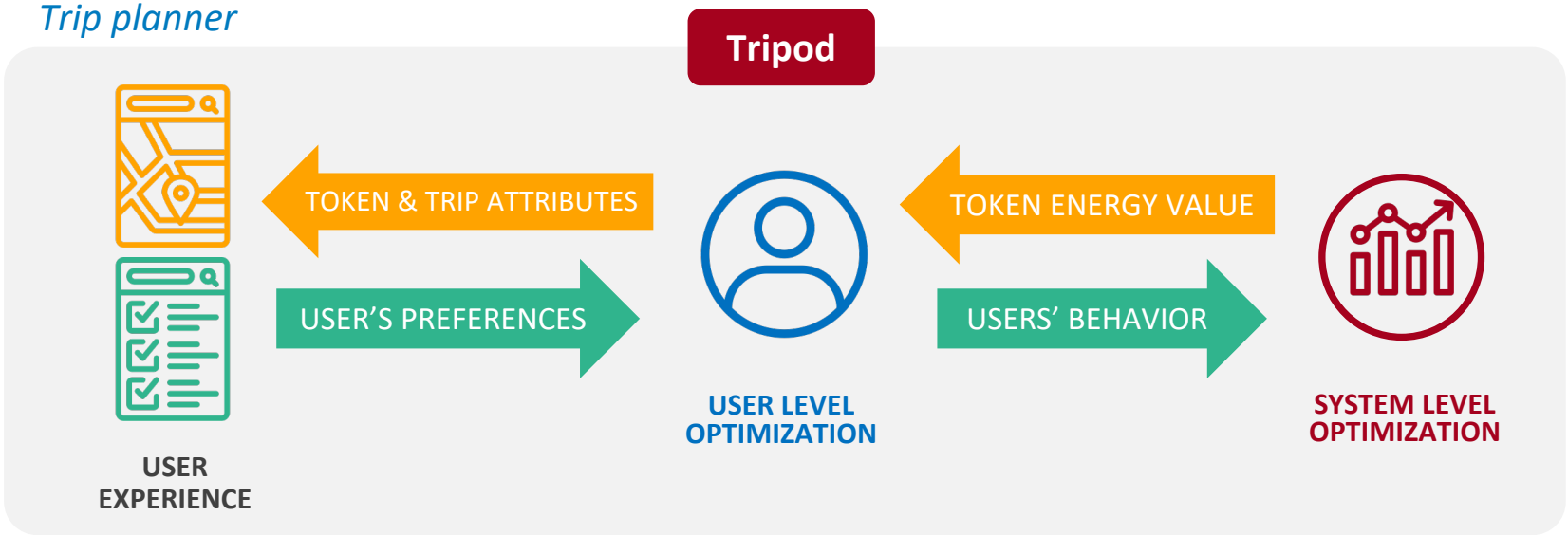
Tri-POP for Tripod

SYSTEM OPTIMIZATION

- **Objective:** system-wide energy consumption
- **Policy:** energy saved per token
- **Constraints:** incentives budget

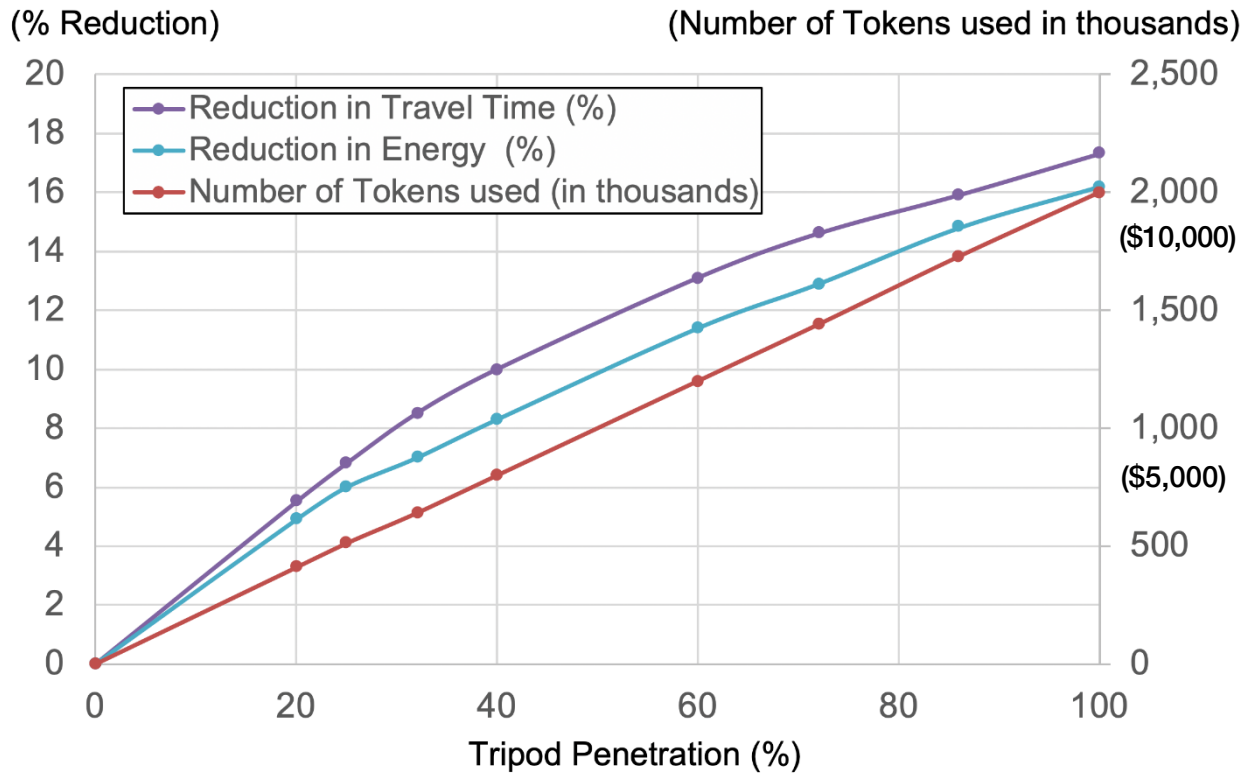
USER OPTIMIZATION

- **Objective:** consumer surplus or hit rate



Simulation experiments

- Central Boston area, 6 – 9 AM (100K trips)
- Budget: 10 cents per Tripod user, 1 token = 0.5 cents
- Reduced travel time and energy



Freight on Demand (FOD): cargo hitching

- FOD: on-demand same-day delivery of e-commerce shipments
- MOD with FOD: assign e-commerce shipments to previously committed and/or idle MOD vehicles

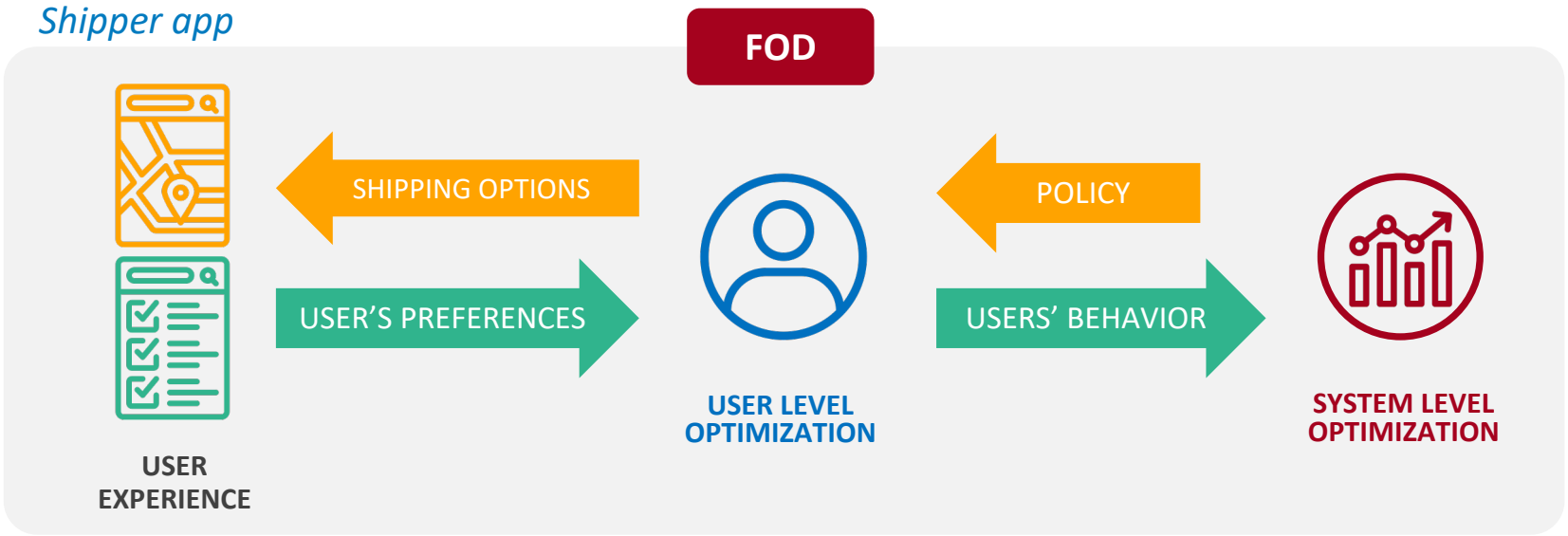
Tri-POP for FOD

SYSTEM OPTIMIZATION

- **Objective:** maximize capacity utilization
- **Policy:** vehicle availability for FOD (schedules)
- **Constraints:** MOD passenger commitments

USER OPTIMIZATION

- **Objective:** sorting FOD availability by waiting time



Simulation experiments

- Singapore 2030 scenarios
  - MOD only (Base)
  - (A) use MOD shared for delivery
  - (B) use MOD shared and idle vehicle for delivery
- Results
  - FOD have minimal effects on MOD in both (A) and (B)
  - FOD performance:
    - (A) delivers ~50% of shipments with long waiting time (20 – 95 min)
    - (B) delivers all shipments with shorter waiting time (15 – 60 min)
  - Reduction (~2%) of VKT (MOD + Freight) in (A) and (B)

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Conclusion

1. Tri-POP: an online platform for smart mobility combining prediction, optimization and personalization

2. Benefits of Tri-POP:

- level of service improvement
- revenue improvement
- efficient use of resources (infrastructure/fleet)
- user satisfaction

Thank you!

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