Smart Mobility: Optimization and Behavioral Modeling

Moshe Ben-Akiva

ITS Lab
Smart Mobility: Introduction

• Mobile technology
• Real-time / on-demand
• Personalized
• Shared
Smart Mobility: Mobile Technology

Autonomous

App-based

Connectivity
Smart Mobility: On-Demand

Uber, Lyft...
Smart Mobility: Personalized

Flexible Mobility On-Demand (FMOD)

Traveler

REQUEST

OFFER

CHOOSE

FMOD server

ALLOCATE

Fleet

Maximizing Profit/Welfare

Mobility as a Service (MaaS)
Smart Mobility: Shared

Car sharing, carpooling lanes, ride sharing, bike sharing....
“Hang on—I’ll Uber us a school bus.”
Research Agenda

Behavioral Data

Behavioral Models/Optimization

Solutions
Designing Effective Smart Mobility Solutions

- Efficiency  optimization
- Personalization  behavioral modeling
- Real-time  app-based platform (FMS) [http://its.mit.edu/future-mobility-sensing](http://its.mit.edu/future-mobility-sensing)
- Testing  SimMobility [http://its.mit.edu/research/simmobility](http://its.mit.edu/research/simmobility)
Research Projects: Solutions

- Real-time Toll Optimization based on Prediction
- Flexible Mobility on Demand (FMOD)
- Autonomous Mobility on Demand (AMOD)
- Mobility Electronic Market for Optimized Travel (MeMOT)
Real-time Toll Optimization based on Prediction
Real-time Toll Optimization based on Prediction

Users → Guidance

Data

Data fusion
Incidents
Self-calibration

Behavioral models (e.g., route choice, departure time choice)
Prediction
Optimization

Control
Rolling Horizon

Time = 20:00. Execution Cycle 1 begins

19:55  20:00  20:05  21:00

Estimation                        Prediction

Time = 20:05. Execution Cycle 2 begins

19:55  20:00  20:05  21:00  21:05

Estimation                        Prediction
DynaMIT 2.0: System Architecture

- Historical Database
- Real Time Data
- Network
- State Estimation
  - Scenario Analyzer
  - Demand ➔ Supply
- State Prediction
  - Demand ➔ Supply
  - Strategy Optimization
- Guidance and control
Case studies

- Area-wide tolling in Singapore
- Managed lanes in Texas
Case Study: Area-wide dynamic tolling

- Minimize total travel time in the network (fixed total demand)
- Historical dataset on incidents/road works (Sept. 15\textsuperscript{th}, 2011)
- Simulation period: 7:30 AM ~ 2:30 PM
- 13 toll gantries
  - Toll rates changing at 5 min interval
Three Scenarios

- **Base case**
  - No guidance

- **Guidance**
  - Predictive guidance with DynaMIT

- **Guidance and toll optimization**
  - DynaMIT guidance and optimized tolls
Reduction in Network Delay

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Travel Time of affected* drivers (veh. hrs)</th>
<th>Total Travel Time (veh. hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>2,184</td>
<td>87,645</td>
</tr>
<tr>
<td>Guidance</td>
<td>1,648 (-25%)</td>
<td>81,626 (-7%)</td>
</tr>
<tr>
<td>Guidance &amp; toll optimization</td>
<td>1,473 (-33%)</td>
<td>79,141 (-10%)</td>
</tr>
</tbody>
</table>

*Affected vehicles are defined as vehicles passing incident locations
Flexible Mobility on Demand (FMOD)
Flexible Mobility on Demand (FMOD)

FMOD provides a **personalized** and **optimized** menu of travel options in **real-time**.

**Dynamic allocation** of vehicles to services
FMOD Services

**Flexibility** to choose from different levels of services

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

![Diagram of door-to-door taxi service]

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

![Diagram of shared-taxi service]

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

![Diagram of mini-bus service]
FMOD User Experience

Request:
Origin: A, Destination: B
Preferred Departure Time: 8:00 – 8:30
/ Preferred Arrival Time: 8:45 – 9:00

Offer:
taxi: DT: 8:25/AT: 8:45, $20
shared-taxi: DT: 8:27/AT: 8:57, $10
as the 4th passenger
mini-bus: DT: 8:14/AT: 8:59, $5
as the 6th passenger

Choice:
service: shared-taxi
DT: 8:27/AT: 8:57, $10

Supply Demand
FMOD Server
Optimization and Preferences
Maximizing profit/welfare
Menu optimization

Phase 1. Feasible product set generation
- Existing commitments
- Capacity constraints
- Scheduling constraints

Phase 2. Assortment optimization
Menu offered to the traveler from the feasible set
- Maximize profit/welfare based on a behavioral model (mode choice)
Simulation Experiments in Singapore

1. Base Case
   Taxi, Private vehicle, MRT, Bus

2. Scenario with FMOD
   Taxi, Private vehicle, MRT, Bus, FMOD

Extended CBD area

- Network configuration:
  - 2706 links - 1294 intersections
  - More than 2000 loop sensors
  - 46 MRT stations

- Simulation setting:
  - 6:00 – 7:00 AM
  - Calibrated demand (08/2013)
  - 10% of all road users have access to FMOD
  - 500 FMOD vehicles
Results: Offer and Choice

- Large share of taxis with ‘Profit maximization’
- Large share of shared-taxi with ‘Consumer surplus’
- Lower reject rate with ‘Consumer surplus’
Results: Operator and User Benefit

Comparison of different strategies (PM and CS)

- **‘Profit Maximization’ (PM)**
  - More revenue for the operator
  - Less waiting time for the user

- **‘Consumer Surplus Maximization’ (CS)**
  - More consumer surplus
Results: Network Performance

Comparison of FMOD (Max. ‘Consumer surplus’) and Base Case with same demand

- Significantly lower V/C ratio in FMOD w/o increasing travel-time
  - 10~20% decrease in average V/C ratio
  - Similar travel-time (avg. difference < 10sec)
Autonomous Mobility on Demand (AMOD)
Autonomous Mobility on Demand (AMOD)

- Bus
- MRT
- Taxi
- Private vehicles

- Bus
- MRT
- Taxi
- Private Vehicles
- Autonomous MOD
Results: Fleet Performance

90% Waiting Time (mins)

Time (AM)

Num Vehicles Rebalanced

Time (AM)

Method
- Baseline
- Rebalancing (1hr)
- Queue (1hr)
Results: Network Performance

<table>
<thead>
<tr>
<th>Path</th>
<th>Length</th>
<th>Travel Time</th>
<th>Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10.6 km</td>
<td>17 min</td>
<td>13.0%</td>
</tr>
<tr>
<td>2</td>
<td>10.1 km</td>
<td>14 min</td>
<td>32.4%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Path</th>
<th>Length</th>
<th>Travel Time</th>
<th>Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>18.7 km</td>
<td>32 min</td>
<td>10.1%</td>
</tr>
<tr>
<td>2</td>
<td>15.4 km</td>
<td>29 min</td>
<td>25.3%</td>
</tr>
</tbody>
</table>
Mobility Electronic Market for Optimized Travel (MEMOT)
MeMOT: Concept

- Optimized and personalized menu with information and incentives in a trip planner app
- Incentives based on real-time system optimization predicting network conditions and energy savings
MeMOT: Framework

- Users
- Travel Choices
- Transportation Network
- Experienced Network Conditions
- Real-time Data
- System Optimization
- User’s preferences
- Token Value & Trip Attributes
- Personalized Menu
- MeMOT
- User Optimization
  - Information & Token Rewards
  - Travel Choices

MeMOT: Framework

Users

Travel Choices

Transportation Network

Experienced Network Conditions

Real-time Data

System Optimization

User’s preferences

Token Value & Trip Attributes

Personalized Menu

MeMOT

User Optimization

MeMOT: 2-Level Optimization

1. A simulation-based **system optimization** framework that predicts traffic, energy consumption and energy efficiency in real-time.

2. A **personalized menu optimization** with information and incentives integrated into an app-based travel diary
MeMOT: 2-Level Optimization Framework

User Optimization

- User Request
- Personalized Menu
- Choices
- Optimal Rewards

System Optimization

- Trip Information & Token Value
- Real-time Data
- Simulation & State Prediction
- Energy Prediction

User Optimization

Choices

System Optimization

Trip Information & Token Value

Optimal Token Allocation

Real-time Data

Simulation & State Prediction

Energy Prediction

Optimal Rewards
Smart Mobility: Optimization and Behavioral Modeling
References (1)

References (2)


APPENDIX
MEMOT
MeMOT: 2-Level Optimization

User Optimization
(user 1, user 2, …)

System Optimization

Pre-trip request
En-route request

roll period
roll period

Disruption

time
System Optimization

**Goal:** Generate reference token value and trip attributes for system-wide optimized scenario

- **Real Time Data**
- **Network, Historical demand/supply parameters**
- **Historical Database**

**State Estimation**
- **Supply Simulator**
- **Demand Simulator**
- **Energy Estimation**
- **Simulated User Optimization**

**State Prediction**
- **Supply Simulator**
- **Demand Simulator**
- **Energy Estimation**
- **Simulated User Optimization**

Predicted network state and optimized token energy value from previous roll period

Average energy savings for the rest of the day

Expected token usage

Expected energy savings

Token energy value
User Optimization

Goal: Generate a personalized menu with trip attributes and token rewards

System Optimization

Database on User Preferences

Predicted trip attributes

System-optimized token value

User's preferences

Back-End

User Optimization

Optimized choice set

Choice

FMS-AdvisorApp

User Behavior Monitor

Info of validated choice & awarded tokens

Choice

Trip tracking

Info of awarded tokens & validated trip

Interface

Trip Menu

Navigation

Dashboard

Marketplace

User
Trip Menu

Scroll down

Click on the Dashboard icon to change page and move to the user token wallet
FMS Platform

SMARTPHONE APP/ TRACKING DEVICES

Sensing Technologies
- GPS
- GSM
- WiFi
- Bluetooth
- Accelerometer

RAW DATA

MACHINE LEARNING BACKEND

Context Info
- Transit Network
- Points of Interest
- Land Use
- Events
- User Info
- …

PROCESS ED DATA

MOBILE/WEB INTERFACE

Activity Diary
- Stops
- Modes
- Activities
- Other info

VERIFIED DATA