MEET IN ASIA PACIFIC FOR THE WORLD’S LEADING TRANSPORT TECHNOLOGY EVENT
ACTIVATING GLOBAL MOBILITY SOLUTIONS
ITS—ENHANCING LIVEABLE CITIES AND COMMUNITIES

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Optimal Automated Booking of On-Demand Transportation
Urban Mobility at Xerox

1. “I want to go from here to B.”

2. App suggests public and private options.

3. Private providers pay fee on rides referred to them, regardless of payment processing.

Private sector fragmented, un-coordinated, confusing
Urban Mobility at Xerox

• GO-LA: Launched in Los Angeles on Jan 27, 2016
• “Xerox Built the Ultimate Transportation App for Los Angeles” - Forbes
Motivation

- MMTPs suggest trip plans that involve private transportation modes on some legs.
- Commuters may have to book these services by themselves.
- This is inefficient. Should be automated.
- Some MMTPs may attempt to automate these bookings. But they will be still very suboptimal.

SUBOPTIMALITY IS DUE TO TRANSFER POINT DELAYS.

*MMTP: Multi-Modal Trip Planner*
Motivation

SUBOPTIMALITY IS DUE TO TRANSFER POINT DELAYS.

• Consequences:
  • Commuter has to wait: bad experience, increased travel time
  • Service has to wait: more cost to the commuter
Our Contribution

Problem: How to optimally and automatically book on-demand transportation services in multi-modal trips to help commuters be cost-efficient?

No solution exists that optimally and automatically books on-demand transportation services.
Solution: Optimal Automated Booking (OAB)

- OAB handles *optimal* booking of private transportation modes to minimize waiting time costs at transfer points.
- Uses ETA of current leg of the journey to destination (NextBus etc)
- Uses forecasted availabilities of services (Uber API etc)
- *Automatically* performs booking and sends confirmation to user
Activity Diagram

Start

MMTP plan

Current & pickup locations, ETA

Is the mode "Auto"

no

Get list of service providers.

Rank based on preference and show.

Update preferences.

yes

Query the ETA of commuter arrival and service availability.

Book according to optimal booking strategy.

Show confirmation.

End.
Layered System Architecture
OAB (Optimal Automated Booking) Strategy

- Discrete time indexed by $t$
- Four quantities of interest:
  - $T$: Estimated Time of Arrival (ETA) of the current mode
  - $S(t)$: Service Availability Time of the on-demand mode
  - $h$: Per unit commuter waiting cost > 0
  - $b$: Per unit on-demand service waiting cost for the commuter > 0

- Intuition: If $T > S(t)$, then the service waits and charges commuter $b$ per unit of time. If $T < S(t)$, then the commuter waits and this costs her/him $h$ per unit of time.

Note: $t$, $T$ and $S(t)$ are absolute times
How does OAB work? Setting I

Stochastic model for ETA and deterministic model for Service Availability is fixed and known

Algorithm 1: It books the on-demand service by computing the optimal booking time when $T$ is a random variable with known distribution function and $S(t)$ is deterministic and invertible.

Result: A confirmation of booking the on-demand transportation

Given: $F(u) = \mathbb{P}(T < u)$; $S(t)$; Waiting costs $b$ and $h$;

Set: $t = 0$; notBooked=True; $t^* = S^{-1}\left(\frac{b}{b+h}\right)$;

while notBooked is True do
    if $t^* \leq t \leq T^{realized} + c$ then
        notBooked,confirmation = BookTransportation();
    end
    if notBooked is False or $t > T^{realized} + c$ then
        Break;
    end
    $t += 1$;
end

Analytical formula for the optimal booking time
How does OAB work? Setting II

Stochastic models for ETA and Service Availability are fixed and known

Algorithm 2: It books the on-demand service by computing the optimal booking time when $T$ is a random variable with known fixed distribution function and $\Delta = S(t) - t$ is i.i.d categorically distributed with fixed known parameter $p$.

Result: A confirmation of booking the on-demand transportation

Given: $G(u) = P(T - \Delta < u)$; Waiting costs $b$ and $h$;
Set: $t = 0$; notBooked=True; $t^* = G^{-1}\left(\frac{b}{b+h}\right)$;
while notBooked is True do
  if $t^* \leq t \leq T_{realized} + c$ then
    notBooked, confirmation = BookTransportation();
  end
  if notBooked is False or $t > T_{realized} + c$ then
    Break;
  end
  t += 1;
end

Analytical formula for the optimal booking time
How does OAB work? Setting III

Stochastic models for ETA and Service Availability are not known beforehand and are time varying.

Result: A confirmation of booking the on-demand transportation

Given: \( t_{-1}(u) = \mathbb{P}(t' \leq u) \); \( Q_{-1}(v) = \mathbb{P}(\Delta(-1) \leq v) \);
Waiting costs \( b \) and \( h \);
Set: \( t = 0 \); notBooked=True; \( S_{-1} = \emptyset \);

while notBooked is True do
\[
\hat{T}_t = \text{queryETA}(t); \ S_t = \text{queryServiceAvailability}(t);
\]
\[
F_t = \text{updateDistribution}(F_{t-1}, \hat{T}_t); \ Q_t = \text{updateDistribution}(Q_{t-1}, S_t - t);
\]
\[
G_t = \text{getDistribution}(F_t, Q_t); \ w^*_t = G_t^{-1}\left(\frac{h}{b+h}\right);
\]
\[
S_t = S_{t-1} \cup \{w^*_t\}; \ // \text{Adding new optimal booking time}
\]
\[
Q_t = \{w^*_u \in S_t : \|F_t - F_u\|_{tv} \geq \epsilon_F \text{ or } \|Q_t - Q_u\|_{tv} \geq \epsilon_Q\};
\]
if \( t \geq \min(S_t \setminus Q_t) \) then
\[
\text{notBooked, confirmation} = \text{BookTransportation}();
\]
end

if notBooked is False or \( t > T_{\text{realized}} + c \) then
\[
\text{Break};
\]
end

\( t += 1; \)
Experiment: Setting I

Arrival Model: Uni-modal distribution (green) with mean ETA 200 minutes and standard deviation 20 minutes

Service Availability Model: Always available with deterministic delay of 5 minutes

User waiting cost is same as service waiting cost
Experiment: Setting I

Arrival Model: Uni-modal distribution (green) with mean ETA 200 minutes and standard deviation 20 minutes

Service Availability Model: Always available with deterministic delay of 5 minutes

User waiting cost is half the service waiting cost
Experiment: Setting I

Arrival Model: Uni-modal distribution (green) with mean ETA 200 minutes and standard deviation 20 minutes

Service Availability Model: Always available with deterministic delay of 5 minutes

User waiting cost is double the service waiting cost
Experiment: Setting III (time varying data)

Arrival Model: Uni-modal distribution (green) with mean ETA 200 minutes and standard deviation 20 minutes.

Service Availability Model: Stochastic with mean delay of 5 minutes and standard deviation 5 minutes.

User waiting cost is same as service waiting cost.
Experiment: Setting III (time varying data)

Arrival Model: Uni-modal distribution (green) with mean ETA 200 minutes and standard deviation 20 minutes
Service Availability Model: Stochastic with mean delay of 5 minutes and standard deviation 5 minutes

User waiting cost is half the service waiting cost

User waiting cost is double the service waiting cost
Experiment: Setting III (Boston Data)

Arrival Model: From NextBus
Service Availability Model: From Uber

Note: User waiting cost is same as service waiting cost
Benefit for Commuters: Single-Source App

- **Convenient** single-source for all public and private mobility options
- **Personalized** to user’s preference (e.g., health, environment, cost, time)
- **Unified** account-based payments
- **Trusted** official mobility app of city
- **Dynamic** re-routing options

Point-to-point trip planning: *bridging first and last mile*
Optimization across all mobility activity for load balancing and reduced congestion:

- Nudging people to use public transportation, ride sharing
- Automated demand-based service provision (e.g. shared shuttle)
- A city dashboard provides real-time insight for capacity planning
Summary

• Multi-modal journeys have travel point delays
• We have proposed online algorithms that book on-demand modes based on predicted delays
• This saves “costs” and minimizes inconvenience for the user
• Is a building block towards more convenient multi-modal trip experiences.

Please refer to the paper for variants and extensions of the modeling setting.