Organization-Based Taxi-Sharing: Demand, Service Design, and Policy Analysis

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Research Team

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Outline

• Introduction
• Evaluation framework
• Demand models
• Service design
• Viability for operator
• Institutional support
• Conclusion
Introduction
Introduction

• Urban commuting challenges
  – High motorization rates / congestion
  – Parking shortage
  – Limited public transport services

• Large institutions in urban areas are major generators of traffic in their neighborhoods
Parking Provision

• It is widely recognized that building more parking is costly and promotes the role of the private car as a preferred mode of transport


<table>
<thead>
<tr>
<th>Cost of subsidizing transit</th>
<th>Cost of providing parking</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1.27 per eligible rider per month</td>
<td>$223 per month per space</td>
</tr>
</tbody>
</table>

→ Significantly lower cost of subsidizing transit service compared to building new parking spaces
Transport Demand Management

• Institutions need to consider strategies to reduce parking demand (and reliance on private autos)

• Transport demand management strategies include:
  – Compressed workweek
  – Pricing / disincentives / subsidies
  – Ridesharing / taxi-sharing
  – More affordable housing nearby
  – And others…

focus of this presentation
Shared-Ride Taxi: Concept

• A Shared-Ride Taxi (SRT) is a door-to-door vehicle that enables two or more individuals to be served simultaneously based on spatial and temporal matching.

• Organization-based: Customers are constituents of an organization.
Properties

• Door-to-door comfort of the private car
• Shared ride advantage of public transport
• Different modes and vehicles (taxi, minivan, etc.) may be used
• Technology-enabled (dynamic scheduling, reservations through web or SMS, location awareness through GPS, etc.)
• SRT involves deviation relative to direct trip
Concept of Deviation

- Deviation for person A = \((tt_{AB} + tt_{BC}) - tt_{AC}\)
- Generally, travelers are not willing to accept a large deviation \(\Rightarrow\) impose max. deviation constraint:
  \((tt_{AB} + tt_{BC}) - tt_{AC} \leq \text{Max. deviation}\)
SRT Is a Form of Ridesharing

Source: Chan and Shaheen (2012)
SRT Example: Google Shuttle Bus

• Corporate tech shuttles that transport company employees in the SF Bay area to work (Google, Facebook, Apple, Yahoo,...)

• Shuttle attributes:
  – Comfortable air-conditioned ride
  – Real-time location information
  – Wi-Fi
  – Bike racks

• Ridership:
  – Google: 6400 per day (Google website)
  – 47% of riders would drive if it weren’t for the shuttles (SF Municipal Transportation Agency)
The Case of the American University of Beirut (AUB)

• AUB is a private university with around 8000 students (from mostly wealthy families) and 4400 employees

• It is located in a dense and congested urban area in Ras Beirut
AUB Context (cont.)

Main Issues

• High reliance on the private car and parking shortage
  – AUB contributes about 21% of peak hour trips and 21% of carbon emissions in its neighborhood (Kassab, 2011)
  – AUB’s parking demand is nearly 3,000 external parking spaces in addition to the 1,105 parking spaces on campus (Aoun et al., 2013)

• Low quality public transport options with limited coverage outside Beirut
Public Transport in Beirut, Lebanon

- Jitneys (‘service’)
  - Unregulated by the government
  - No fixed stops/bus shelters
  - Poor quality and stigmatized image
  - Limited coverage outside the city

- Buses

- Minibuses
AUB Context (cont.)

Vision

• Main challenges:
  – How to apply public transport measures without existing public transport systems?
  – How to shift high-income users away from private, low-occupancy modes?

• A shared-taxi service for AUB students was identified as a promising TDM option that adapts the conventional public transport model to suit the target population (Aoun et al., 2013)
Shared-Taxi Evaluation Framework
Problem Statement

• The objective is to design an organization-based SRT and assess its feasibility
• Research focus: demand and service design
Evaluation Framework
(Al-Naghi, 2014)
Research Program

• Demand and policy analysis (Al-Ayyash, 2015; Al-Ayyash et al., 2016)
  – Econometric demand models for SRT in an organization-based context

• Service design and feasibility (Al-Naghi, 2014)
  – Vehicle routing algorithms and simulation of the operation of SRT for evaluation purposes

• Case study application to AUB
Demand Models
(Source: Al-Ayyash, 2015; Al-Ayyash et al., 2016)
Factors Influencing Ridesharing Demand

- In-vehicle time / deviation and waiting time
- Cost and incentives
- Availability of computer and cell phone messaging
- Safety and security (background checks)
- User awareness
- Perceived flexibility, convenience, and privacy
- Age, employment status, difficulty in walking, etc.

Source: Amey, 2010; Ben-Akiva et al., 1996; Benjamin et al., 1998; Chan and Shaheen, 2012; Deakin et al., 2010; Takeuchi et al., 2003
Demand Models

• **Aim**: assess the market share of SRT and elasticity w.r.t. time, fare, comfort, etc.

• Since the SRT isn’t an existing mode of transport, use **stated preference surveys** with hypothetical scenarios
Example of a Choice Scenario

<table>
<thead>
<tr>
<th>One-way fare</th>
<th>Change in travel time</th>
<th>Maximum allowable waiting time for pick-up &amp; early drop-off</th>
<th>Maximum number of passengers sharing a ride in a vehicle (including you)</th>
<th>Mobile application for reservation and tracking &amp; free Wi-Fi connectivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,500 L.L.</td>
<td>10 min. more than your current travel time using your current travel mode</td>
<td>0 to 5 min</td>
<td>4 to 6 (Minivan)</td>
<td>Not available</td>
</tr>
</tbody>
</table>

How many days per week will you use the shared-ride taxi service?

- [ ] None
- [ ] 1
- [ ] 2
- [ ] 3
- [ ] 4
- [ ] 5

Dependent variable
Modeling Framework

• Disaggregate random utility choice model
  – 6 alternatives: 0, 1, 2, 3, 4, 5 days per week of using SRT
  – Utility of each alternative is function of:
    • Attributes: travel time difference, cost difference, max. allowed waiting time, vehicle type, and presence of Wi-Fi in vehicle/mobile app for reservation
    • Individual characteristics: Gender, attitude towards ride-sharing (latent)

• Model predicts the probability of each alternative
Framework: Hybrid Choice Model

Latent variable model:
ride-sharing attitude

Observed exogenous variables:
Socioeconomic characteristics and shared-ride taxi service attributes \( X \)

Observed choice from SP data \( y \)

Choice model: SRT usage

Delta utility \( \Delta U \)

Latent variables \( F \)

Attitudinal indicators \( I \)

I like sharing rides with others. I don’t mind if the Shared-Ride Taxi makes several stops...

Structural relationship

Measurement relationship
Main Findings

<table>
<thead>
<tr>
<th>Variable</th>
<th>Effect on SRT ridership</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel time deviation</td>
<td></td>
</tr>
<tr>
<td>Additional cost</td>
<td></td>
</tr>
<tr>
<td>Minivan (compared to taxi)</td>
<td></td>
</tr>
<tr>
<td>Max. allowed waiting time for pick-up/drop-off</td>
<td></td>
</tr>
<tr>
<td>Wi-Fi in vehicle</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>(for PT users)</td>
</tr>
<tr>
<td>Favorable ride-sharing attitude</td>
<td></td>
</tr>
</tbody>
</table>

- Model was estimated separately for students who commute by car and those who commute by public transport

- Car users are more time sensitive than PT users, while PT users are more cost sensitive than car users
Policy Analysis

Different SRT Service Types

**Premium Service**
- SRT One-way Fare
  - HIGH
- Delta Time
  - LOW
- SRT MAWT
  - LOW
- Vehicle Size
  - SMALL VEHICLE
- Free Wi-Fi Connectivity
  - AVAILABLE

**Basic Service**
- SRT One-way Fare
  - MEDIUM
- Delta Time
  - MEDIUM
- SRT MAWT
  - MEDIUM
- Vehicle Size
  - SMALL VEHICLE
- Free Wi-Fi Connectivity
  - UNAVAILABLE

**Economy Service**
- SRT One-way Fare
  - LOW
- Delta Time
  - HIGH
- SRT MAWT
  - HIGH
- Vehicle Size
  - MINIVAN
- Free Wi-Fi Connectivity
  - UNAVAILABLE
Policy Analysis (cont.)

SRT Ridership by Type

- Different service types can be offered to cater for different types of users.
Service Design

(Source: Al-Naghi, 2014)
Problem

- **Aim**: formation of vehicle tours based on spatial and temporal matching

**Input**
- Origins and destinations
- Schedule
- Mode of commute
- Socioeconomic characteristics
- Road network

**Output**
- Assignment of students on tours from different origins to a single destination, and then back (2-way)
- Number of cars needed and car occupancy
Optimization Problem

• Special case of Vehicle Routing Problems (VRP)
  – Capacitated vehicle routing problem with time windows

• **Objective function**: minimize total operating cost

• **Constraints**:
  – Deviation from direct path is below a certain threshold
  – Arrival/departure time is within a certain window
  – Vehicle capacity
Optimization Problem (cont.)

• Known to be NP-Hard, and thus exact algorithms cannot solve large problems in real time

• Known heuristic algorithms: Branch-and-Bound, Clarke and Wright's Savings, Nearest Neighbor (Greedy), Column Generation, Genetic, and the Ant Colony

• Research contribution: develop computationally efficient heuristics for large-scale problems
Algorithms

• Basic intuition: construct a tree rooted at the depot and solve the VRP on the tree

• Tree illustration:

• Spatial hierarchy of a tree is intuitive for the sequence of packing of individuals into vehicles
Algorithms (cont.)

- Algorithms developed consist of three stages:
  1. Cost matrix formation
  2. Tree formation
     - Construct **Hierarchical spanning trees**, rooted at the depot, from the cost matrix to structure the search of feasible ride matches.
  3. Tree traversal
     - Implement enumerated **tree traversal algorithm** to pack the feasible nodes in the tree into cars
Algorithms (cont.)

- Two heuristics are developed
  - **Proximity cluster tree (PCT)**
    - Idea: Groups students spatially based on the proximity of their residences to each other
  - **Minimum deviation tree (MDT)**
    - Idea: Groups students spatially based on minimum deviations (i.e. students on the way)
Algorithms (cont.): Tree Formation

• **Proximity cluster tree (PCT)**
  – Each node \(i\) is linked to its parent node \(j\), where \(j\) is the closest to \(i\) and is closer to the depot than \(i\).

• **Minimum deviation tree (MDT)**
  – Each node \(i\) is linked to its parent node \(j\), where \(j\) has the least route deviation for \(i\), and is closer to the depot than \(i\).
### PCT and MDT Examples

<table>
<thead>
<tr>
<th>Type</th>
<th>Network Diagram</th>
<th>Chart Diagram</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PCT</strong></td>
<td><img src="image1" alt="Network Diagram" /></td>
<td><img src="image2" alt="Chart Diagram" /></td>
</tr>
<tr>
<td><strong>MDT</strong></td>
<td><img src="image3" alt="Network Diagram" /></td>
<td><img src="image4" alt="Chart Diagram" /></td>
</tr>
</tbody>
</table>
Simulation Results for AUB

Sample

• Sample considered for simulation:
  – 2788 students who live in Greater Beirut and commute by motorized modes
Simulation Results for AUB (cont.)

Temporal Partitioning (One-Way)

- Hourly distribution of start/end of classes (of 2393 students who come on a Monday)

![Graph showing start and end times of classes]

- Each hourly group of students is solved separately
  - E.g. consider next the 8 AM group of students – potential SRT users: 574
Simulation Results for AUB (cont.)

Number of Required Cars (MDT)

- Higher fare $\rightarrow$ Lower demand $\rightarrow$ fewer cars needed
- Higher maximum deviation $\rightarrow$ fewer cars needed and lower demand

- Fare is computed as a fraction of the Private Taxi fare.
Simulation Results for AUB (cont.)

Average Car Occupancy

• Average car occupancy increases with car capacity.

ST fare is taken as 40% of private taxi fare.
Computational Efficiency

• Small problems (24 nodes):
  – MDT/PCT: Less than 5 seconds
  – CPLEX: 20-60 minutes

• Large problems (~600 students):
  – MDT/PCT: Tree Derivation < 50 sec., Tree Traversal < 30 sec./scenario
Viability for Operators
Viability for Operators

• Two options may be considered:
  – **Option 1**: Commissioning the SRT service to one or more existing private taxi companies
  – **Option 2**: Commissioning the SRT service to a new and exclusive operator for AUB

• Testing several scenarios of maximum deviation and fare:
  – Option 2 was always infeasible *(large investment cost in vehicles, many of which remain idle in off-peak hours)*
  – Option 1 was feasible for fares exceeding 30% of private taxi fares and car capacities equal to 4
Options for Increasing the Viability for Operators

• **Reducing vehicle fleet size** by commissioning extra demand to private taxi operators

• **Denying requests** matching fewer than 3 passengers in the peak hours

• **Imposing a higher acceptable deviation** during peak hours to achieve full packing of the vehicles

• **Increasing the vehicle capacity** (at least during peak periods) using a heterogeneous fleet of cars and vans
Institutional Support
Institutional Context

• Institutional support is crucial for enhancing the viability of the SRT through:
  – Increasing awareness
  – Providing supporting policies (e.g. policies regarding parking subsidies)
  – Financial subsidy
Effect of Subsidy on Demand

• Using the estimated demand models, 2 levels of subsidy were tested for AUB:
  – 750 LL (0.5$)
  – 1,500 LL (1$) per one-way trip for a Basic service

• Subsidy increases demand by 5-20%
Financial Burden of Subsidy

• When a 1$ per one-way trip is offered:
  – The total monthly subsidy granted to every student is 24,000 LL ($16) – assuming three round trips to AUB per week
  – The annual subsidy burden would be approximately $290,000 (for around 1800 switching students).
Conclusion
SRT Impacts

• Students:
  – Cost savings for current car users and time savings for current PT users
  – Reduced parking needs and auto ownership (long term)

• Community:
  – Less congestion in the neighborhood by reducing auto dependency and vehicle miles traveled
  – Reduction in noise and air pollution

• Institution:
  – Reduced need for parking expansion
  – Supporting sustainable transport solutions
SRT Impacts (cont.)

• Reduction in peak hour trips and parking spaces:

<table>
<thead>
<tr>
<th>Fare</th>
<th>Peak Hour Trip Reduction</th>
<th>Mid-day Parking Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>30%</td>
<td>166</td>
<td>800</td>
</tr>
<tr>
<td>40%</td>
<td>123</td>
<td>592</td>
</tr>
<tr>
<td>50%</td>
<td>70</td>
<td>336</td>
</tr>
</tbody>
</table>

– Reduction in peak hour trips represents around 5-13% of the peak hour traffic volume on a busy street bordering the university

– Reduction in parking demand is about 11-27% of AUB’s demand
Important Factors for SRT Success

• Market studies
• Proper costing and incentives
  – E.g. Enoch et al. (2006) state that “DRT projects are often not realistically costed or designed with a full understanding of the market they are to serve”.
• Technology-based systems
• Phased operation
• Cooperation of different stakeholders
Research Contribution

• Comprehensive framework for organization-based SRT evaluation

• Development of computationally efficient routing heuristics for organization-based SRT:
  – unit demand, asymmetric network, narrow time windows at departure, common arrival time at destination, etc.

• Demand models for organization-based SRT, including qualitative attributes and attitudes

• Methodology can be used by other universities or institutions considering SRT
Extensions

- Feedback between demand and service design
- Testing other well-known VRP heuristics in the literature
- Service design and simulation for multiple institutions (many-to-many vehicle routing problem)
References


References (cont.)


