Impacts of Autonomous Vehicles on Parking and Congestion

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AVs legislation and policy

USA TODAY

First ride in driverless car is a bit jerky, but still 'pretty cool'

The New York Times

Wielding Rocks and Knives, Arizonans Attack Self-Driving Cars
Speed up the integration of AVs
Conventional Car-parks
AV Car-parks

Street Access

Building

STREET

AV Car-parks

Street Access

Building

STREET
Optimal Parking Facility Geometry

1- Design Demand
2- Plot Dimensions
Relocation Policy

Any vehicle can be discharged at any given point in time
Vehicle Relocation in Larger Islands
Expected Relocations Per Vehicle Retrieval

\[ P_{iv}(d_i) = \frac{(d_i/2y)^v / v!}{\sum_{t=0}^{x_i} (d_i/2y)^t / t!}. \]

\[ R_v = \frac{1}{v} \left[ \sum_{a=1}^{v} a + \sum_{a=1}^{v} (a - 1) \right] = \frac{1}{v} \left[ \frac{v(v + 1)}{2} + \frac{(v - 1)v}{2} \right] = v \]

\[ E[R] = \sum_{i=1}^{S} \sum_{v=0}^{x_i} \frac{d_i}{2yD} P_{iv}(d_i) R_v. \]
Solution Methodology

- A mixed integer program with a non-linear objective function.
- The purpose of the [MP] is to iteratively generate different layouts until the best layout is found.
- The [SP] finds the optimal allocation of the demand between the islands.
Impact of Demand on Optimal Layout

$D=600$

$D=640$

$D=680$

$D=720$

$D=760$

$D=780$
Plot Shape Analysis

Capacity 540

Capacity 560

Capacity 500
Parking capacity increase

Spatial efficiency ratio vs. Plot width W

- A1 = 5330
- A2 = 6890
- A3 = 8650
Where to park?

16:00

14:00

18:00  17:00

15:00

1 2 3
Full information scenario

- All arrival and departure times are known in advance.
- The problem is modelled as an integer program.
Full information scenario

\[A_1, A_2, A_3, A_4, A_5, D_4, A_6, A_7, A_8, A_9, A_{10}, A_{11}, D_9, A_{12}, D_7, D_2, D_3, D_5, D_8, D_1, D_{12}, D_6, D_{10}, D_{11}\]
Partial information scenario

- Sequential stochastic optimization model
  \[
  \min_{\pi \in \Pi} \mathbb{E}^{\pi} \sum_{t=0}^{T} C(S_t, X^{\pi}(S_t)),
  \]
  \[
  S_{t+1} = S^M(S_t, x_t, W_{t+1})
  \]

- Infinite state space

- Test and compare different policies using a simulation model
Allocation policies

- Arrival time
  - Only considers the arrival time

- Clustering based on dwell time
  - Cluster AVs as short term vs long term

- Blockage probability
  - Blockage probability based on average dwell times
Key operational findings

- Blocking probability is the best scenario when all the islands are sizeable or arrival rate is high.
- Arrival policies compete with blockage probability because they consider future arrivals.
- Considering Retrieving vehicles from the rear side does not reduce the number of relocations.
Regular Vehicle Parking

Conventional Vehicle Driver

![Diagram showing the process of regular vehicle parking with icons for work, home, and parking.]

Work  Home  Parking
Parking options

- **Home**
  - $C_h = 2x_h c_t$

- **Car-park**
  - $C_p = 2x_p c_t + r_p(t_p - 2x_p)$

- **Cruise**
  - $C_c = t_p c_t$

where:
- $x$ Travel time
- $c$ Travel cost
- $r$ Parking rate
- $t$ Activity time
Hypothetical city
Base case scenario with $r_p = 3\left[\frac{\$}{hr}\right]$ and $t_p = 12\left[\frac{\$}{hr}\right]$. 

(a) Daily link traffic flow. 

(b) Daily spatial distribution of cruising. 

(c) Daily spatial distribution of parking at parking lots. 

(d) Daily spatial distribution of parking at homes.
Parking cost sensitivity analysis
Travel cost sensitivity analysis

$c_t = 4$

$c_t = 6$

$c_t = 8$

$c_t = 10$

$c_t = 12$

$c_t = 14$

$c_t = 16$

$c_t = 18$
Parking location analysis

Daily spatial distribution of cruising

Daily spatial distribution of Parking
### Key findings

#### 5 pm traffic flow snapshot

<table>
<thead>
<tr>
<th></th>
<th>No policy</th>
<th>Same parking price</th>
<th>Zero-occupant toll</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum cruising time</td>
<td>18 min</td>
<td>30 min</td>
<td>15 min</td>
</tr>
<tr>
<td>Average travel time to car-parks</td>
<td>12 min</td>
<td>10 min</td>
<td>11.5 min</td>
</tr>
<tr>
<td>Maximum travel time to car-parks</td>
<td>47 min</td>
<td>50 min</td>
<td>43 min</td>
</tr>
<tr>
<td>Change in VKT</td>
<td>-</td>
<td>+1 %</td>
<td>- 3.5 %</td>
</tr>
</tbody>
</table>
Capacity enhancement

Vehicle to Vehicle

Vehicle to Infrastructure
Relation between link capacity and AV proportion

\[ C = C_{HV} + (C_{AV} - C_{HV})r^2 \]
The Equilibrium Condition

- The equilibrium condition can be formulated as NCP.
- The UE does not have a unique solution because the travel time function changes regarding HV and AV flows is not symmetric.
A simple example

\[ (t^0, C^0) = (0, 1) \]

\[ (t^0, C^0) = (0, 1) \]

(a) \((g_{AV}, g_{HV}) = (1, 1)\).

(c) \((g_{AV}, g_{HV}) = (2.5, 1)\).
Best User Equilibrium flow
Traffic management policies

- HV exclusive, AV exclusive, or shared links.
- There are $3^{|A|}$ different scenarios for a network $G(V, A)$.
- System optimal traffic assignment is used as the lower bound.
- For a real size network, policies can decrease the gap between user equilibrium and system optimal to less than 1%.
Review

Parking Design
- Car-park dimensions
- Design demand
- Optimal car-park layout Design

Parking Choice
- Location and price of each car-park
- Arrival and departure information of each individual

Parking and Network Policy
- Optimal parking policies
- Optimal traffic management policies

Optimal operation of the car-park

Parking Operation
Thank You!

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