Impacts of Autonomous Vehicles on Parking and Congestion

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AVs legislation and policy

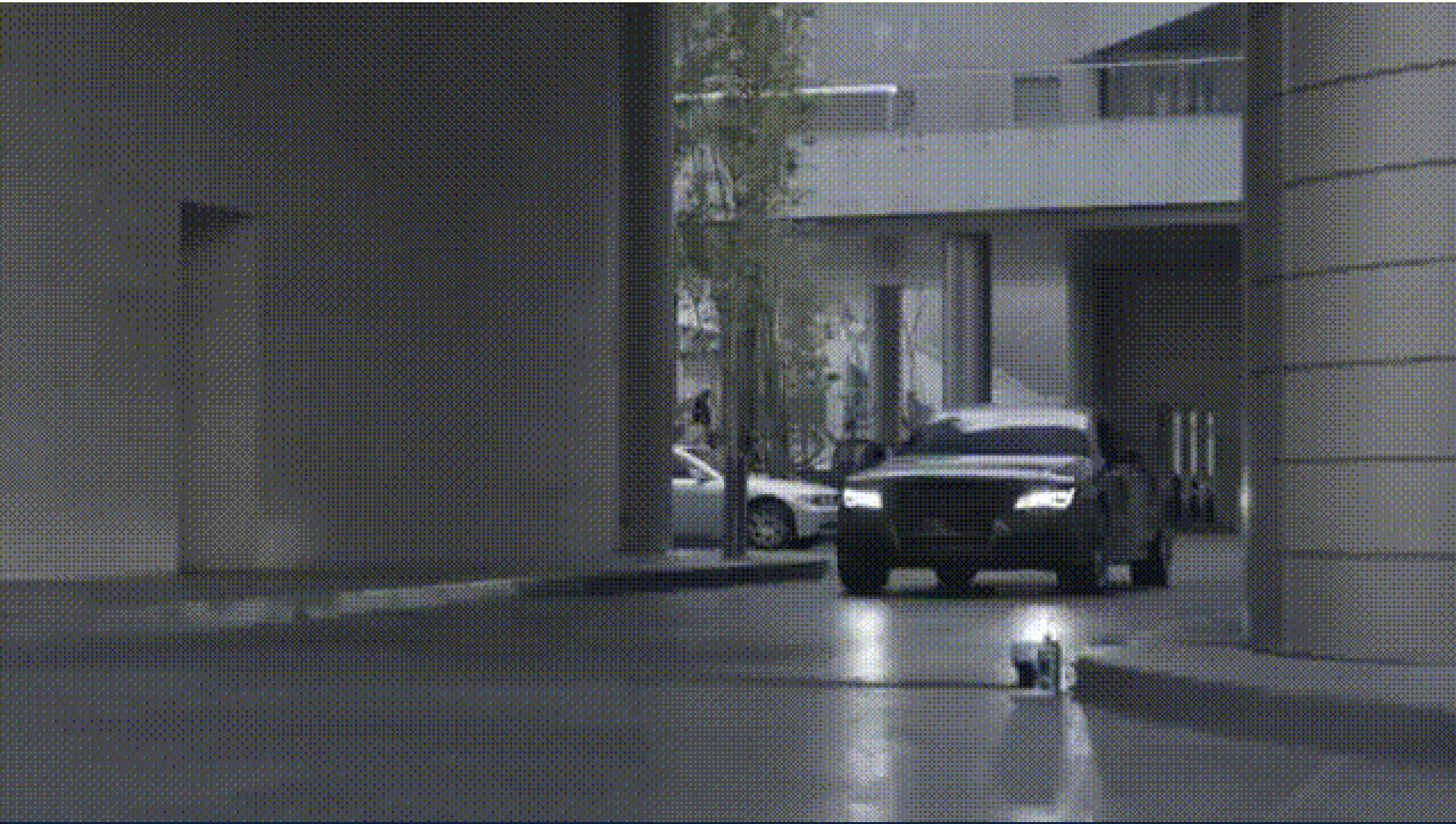
USA TODAY

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

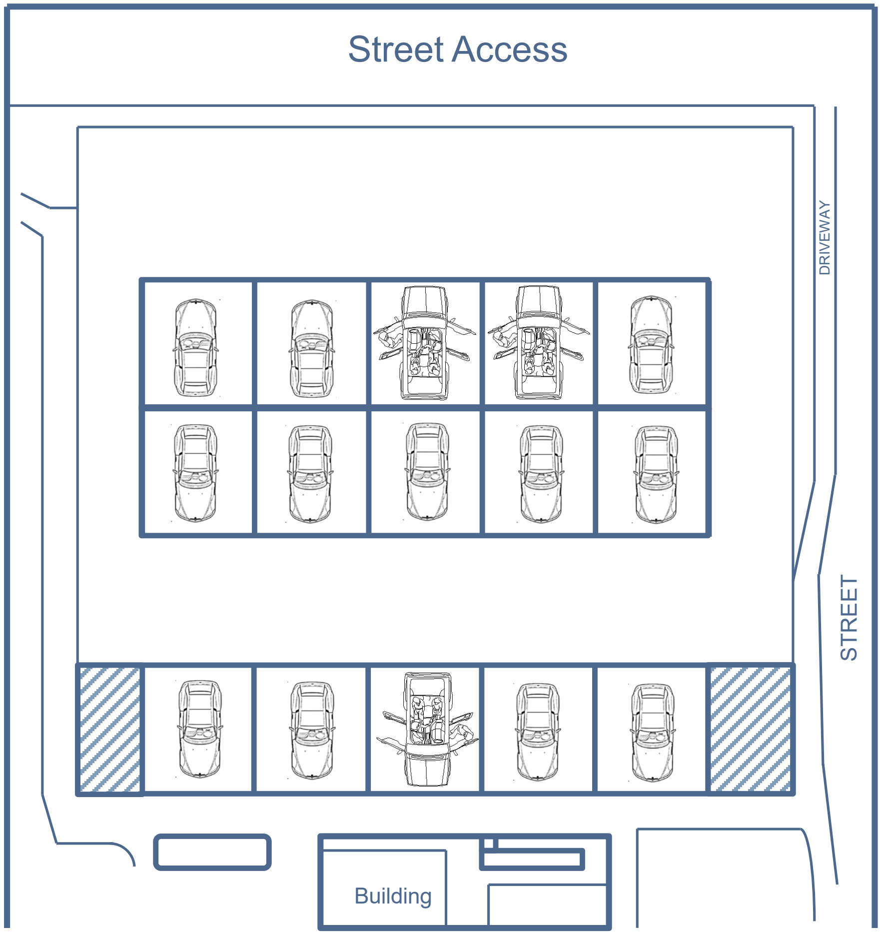
The New York Times

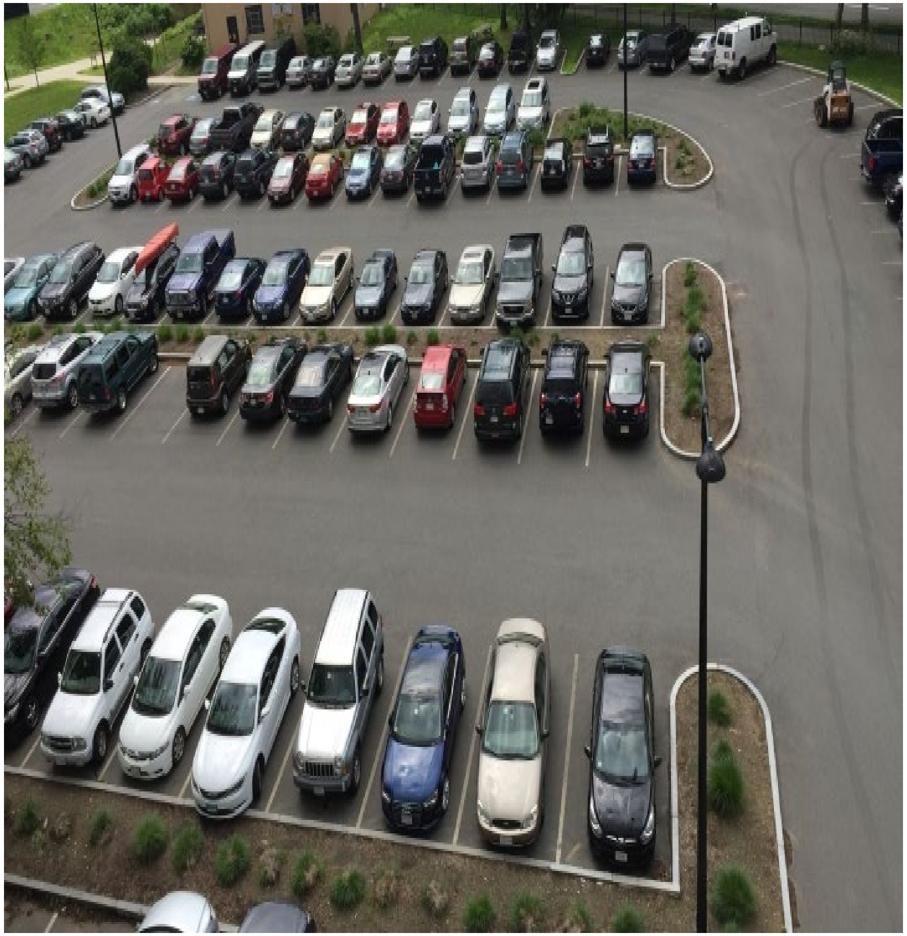
Wielding Rocks and Knives, Arizonans Attack Self-Driving Cars

Speed up the integration of AVs

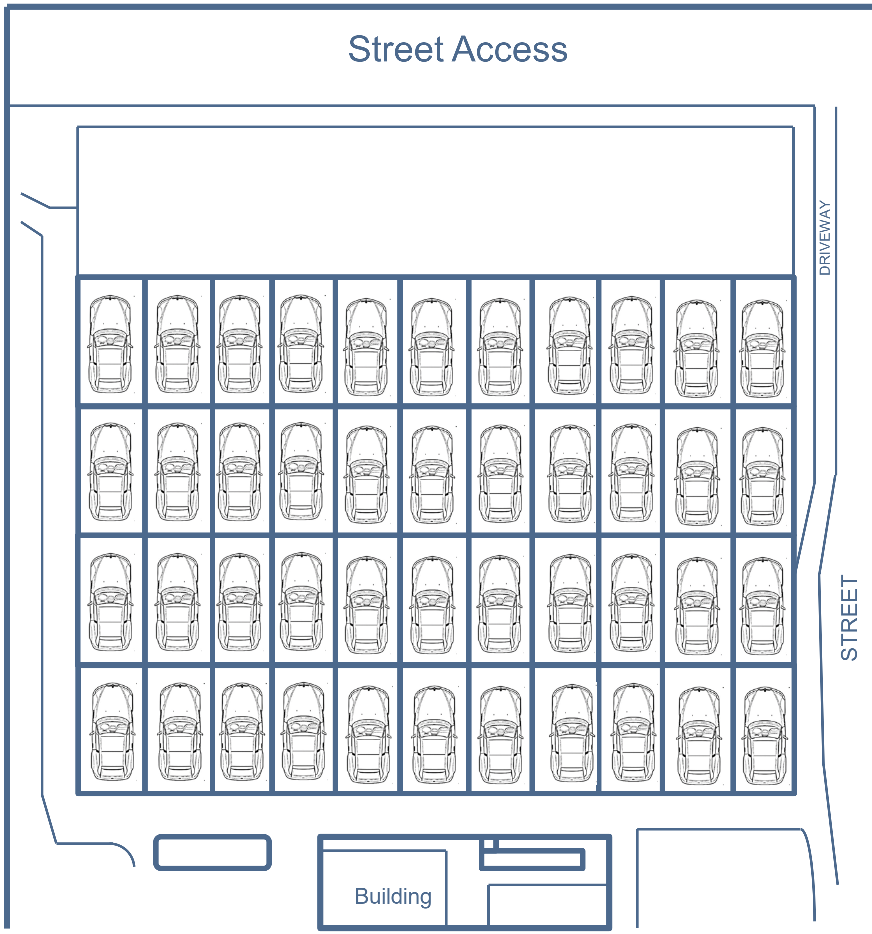


Conventional Car-parks



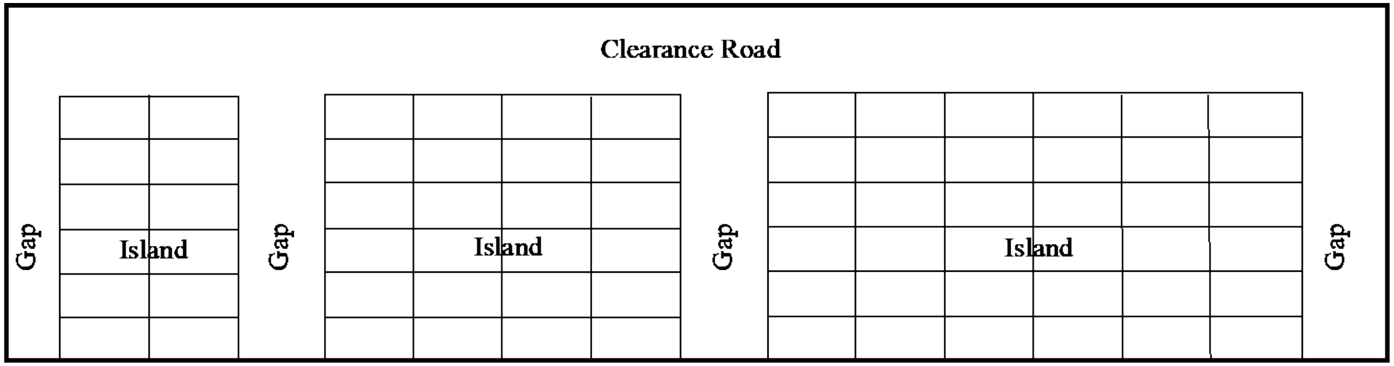


AV Car-parks

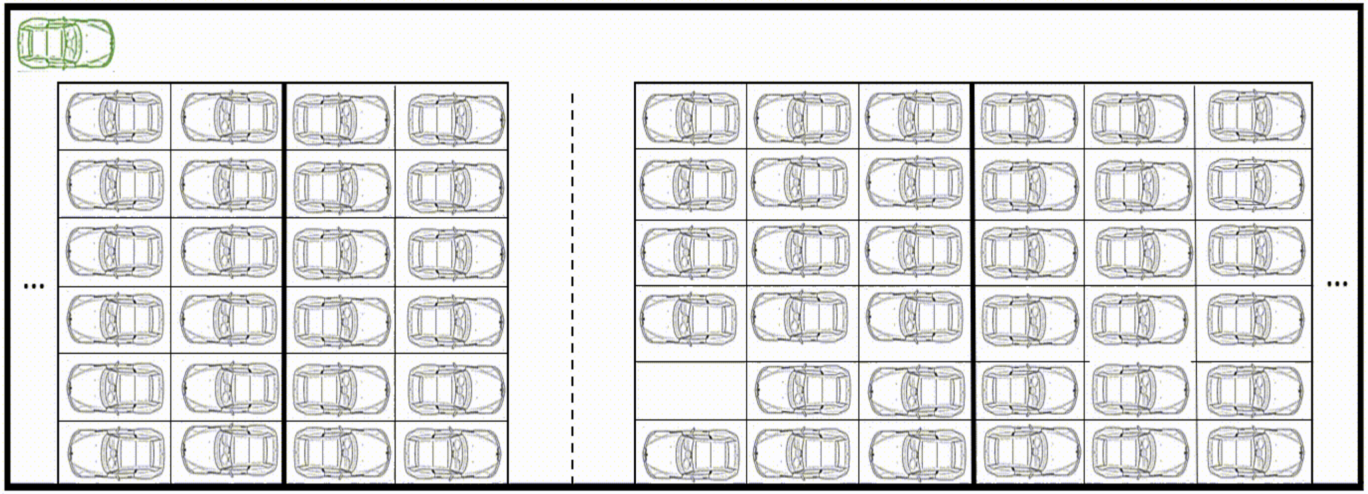


Optimal Parking Facility Geometry

1- Design Demand
2- Plot Dimensions

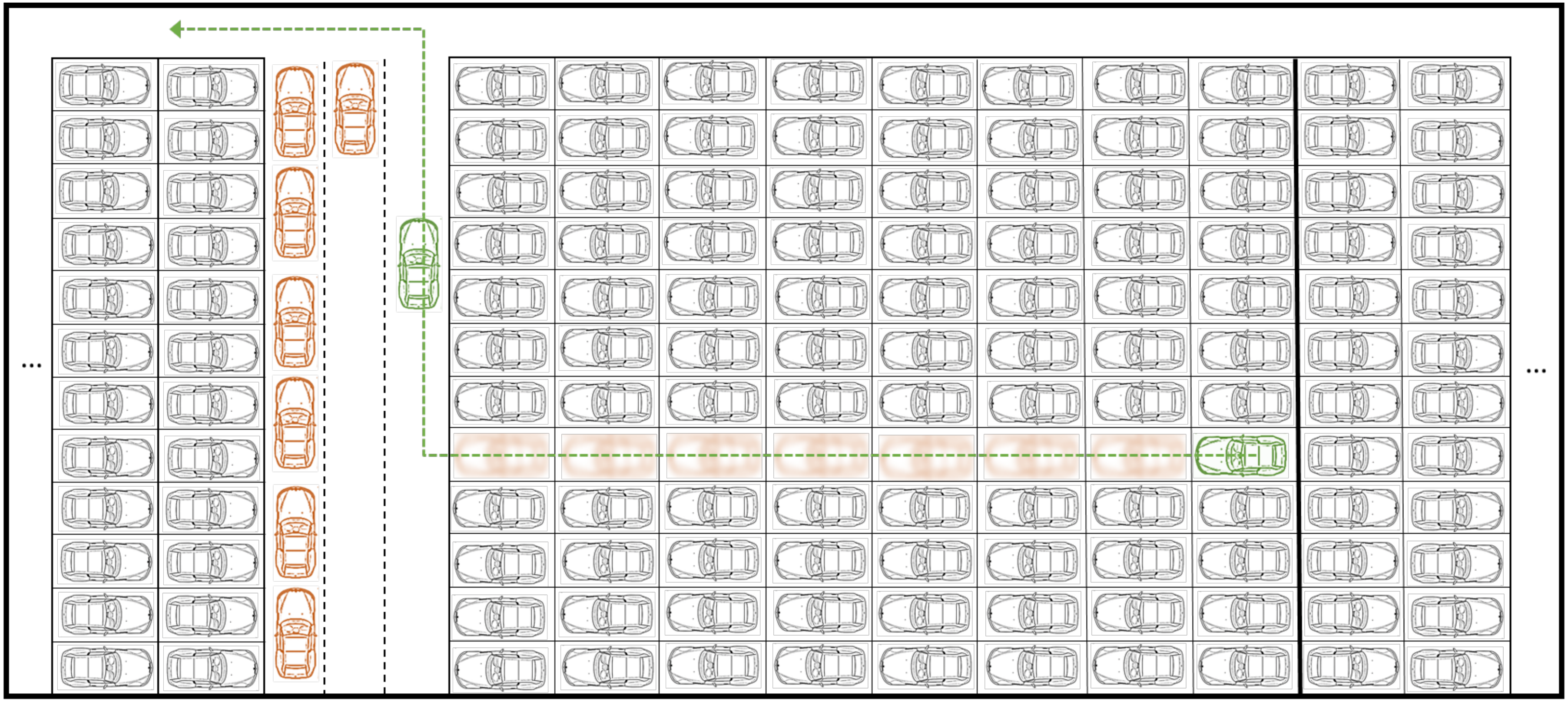


Relocation Policy



Any vehicle can be discharged at any given point in time

Vehicle Relocation in Larger Islands

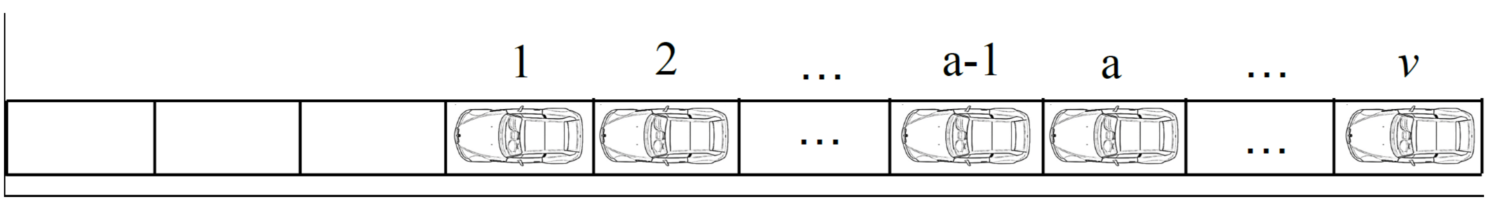


Expected Relocations Per Vehicle Retrieval

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

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

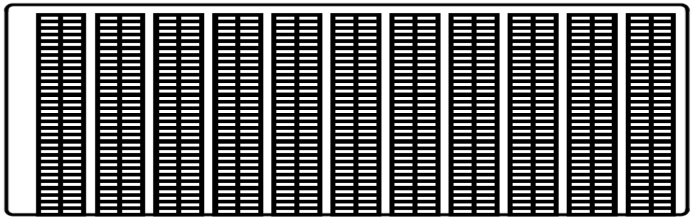
$$E[R] = \sum_{i=1}^{S}\sum_{v=0}^{x_i}\frac{d_i}{2yD}P_{iv}(d_i)R_v.$$



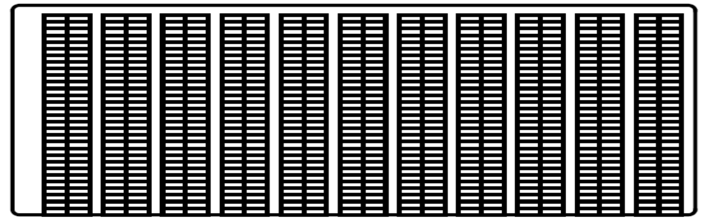
Solution Methodology

- 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



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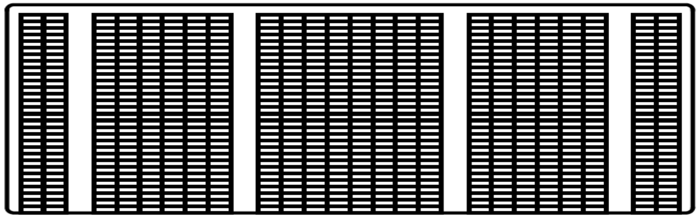
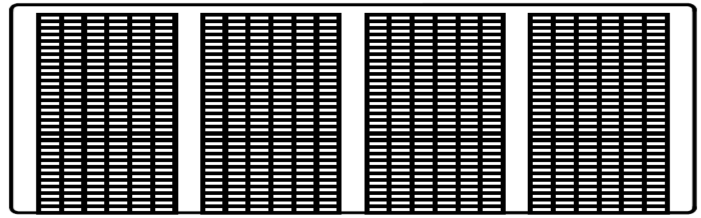


D=680



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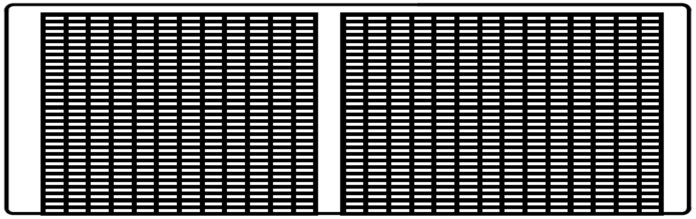
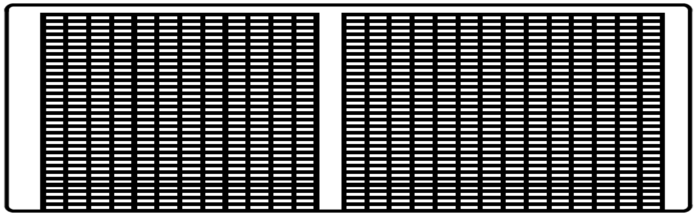
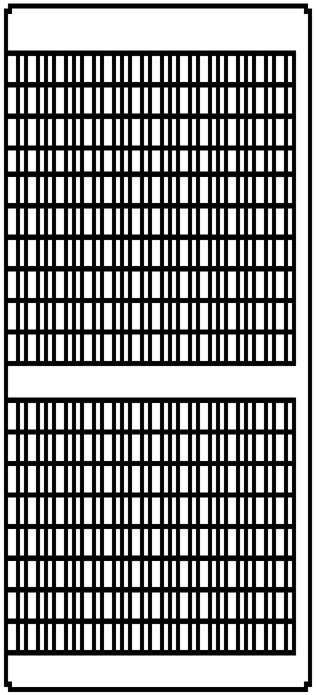


D=760

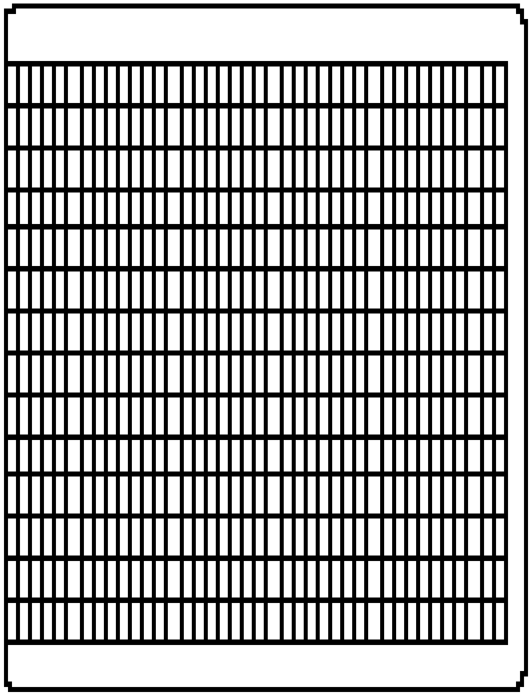


D=780

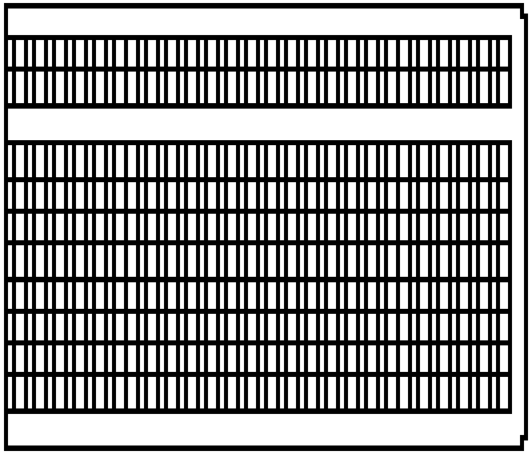
Plot Shape Analysis



Capacity
540

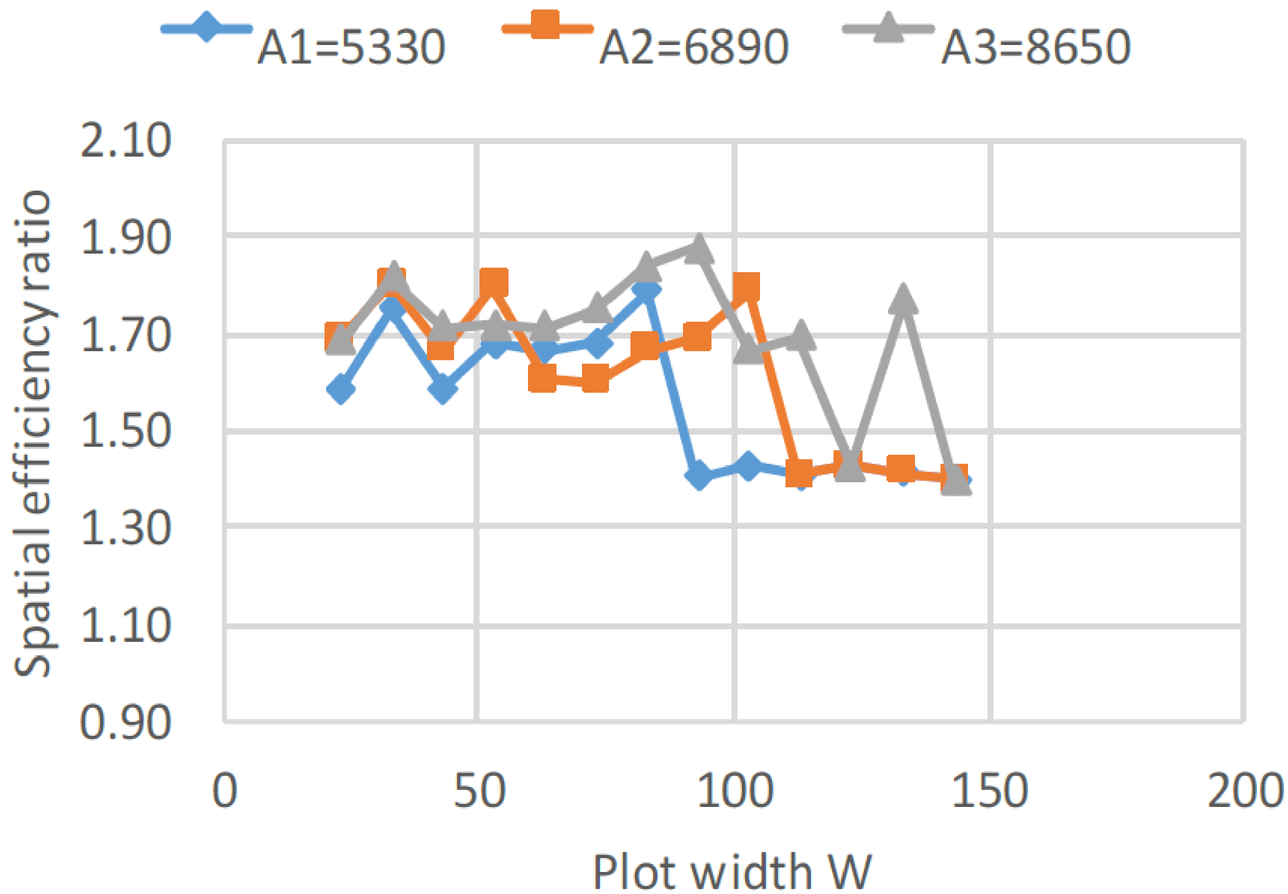


Capacity
560

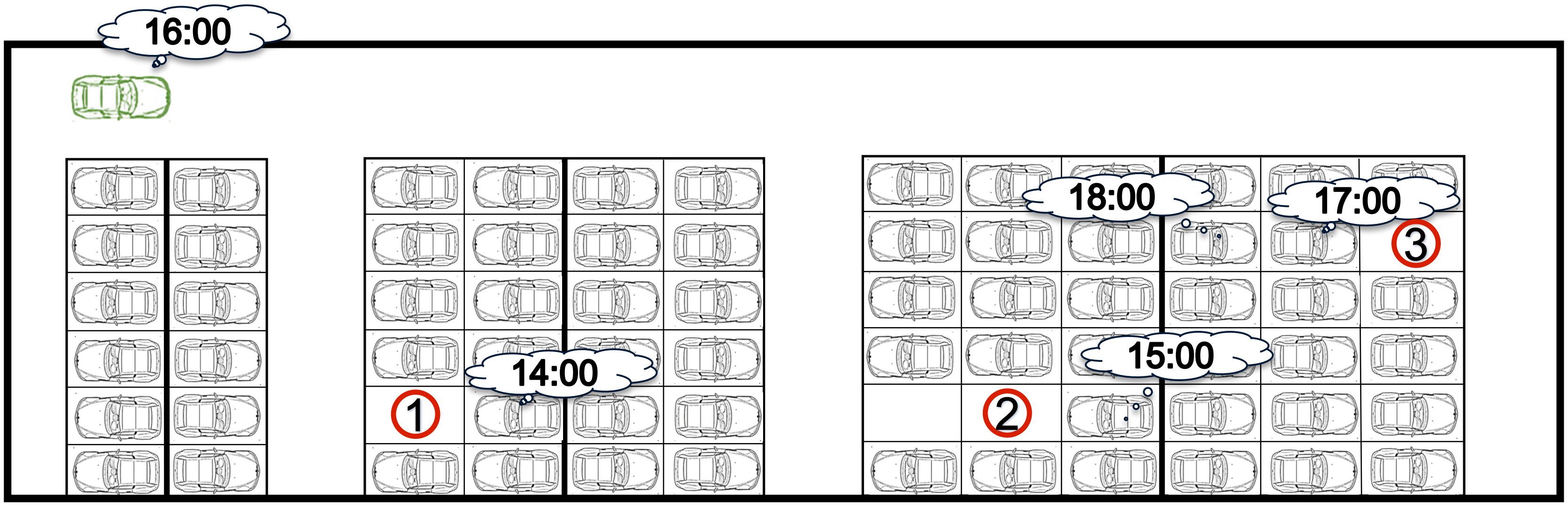


Capacity
500

Parking capacity increase



Where to park?

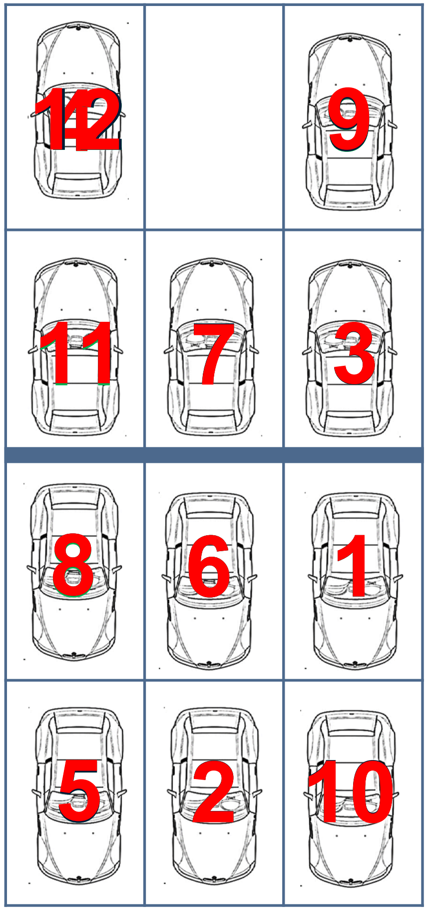


Full information scenario

- 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

$$min_{\pi \in \Pi} E^{\pi} \sum_{t=0}^{T} C(S_t, X^{\pi}(S_t)),$$

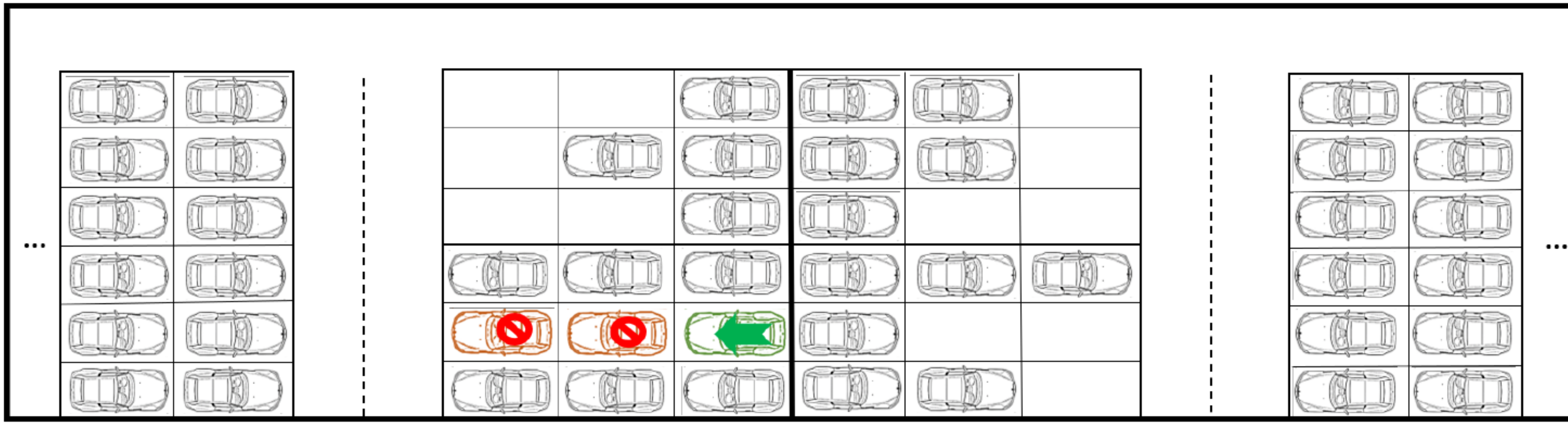
$$S_{t+1} = S^M(S_t, x_t, W_{t+1})$$

- 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

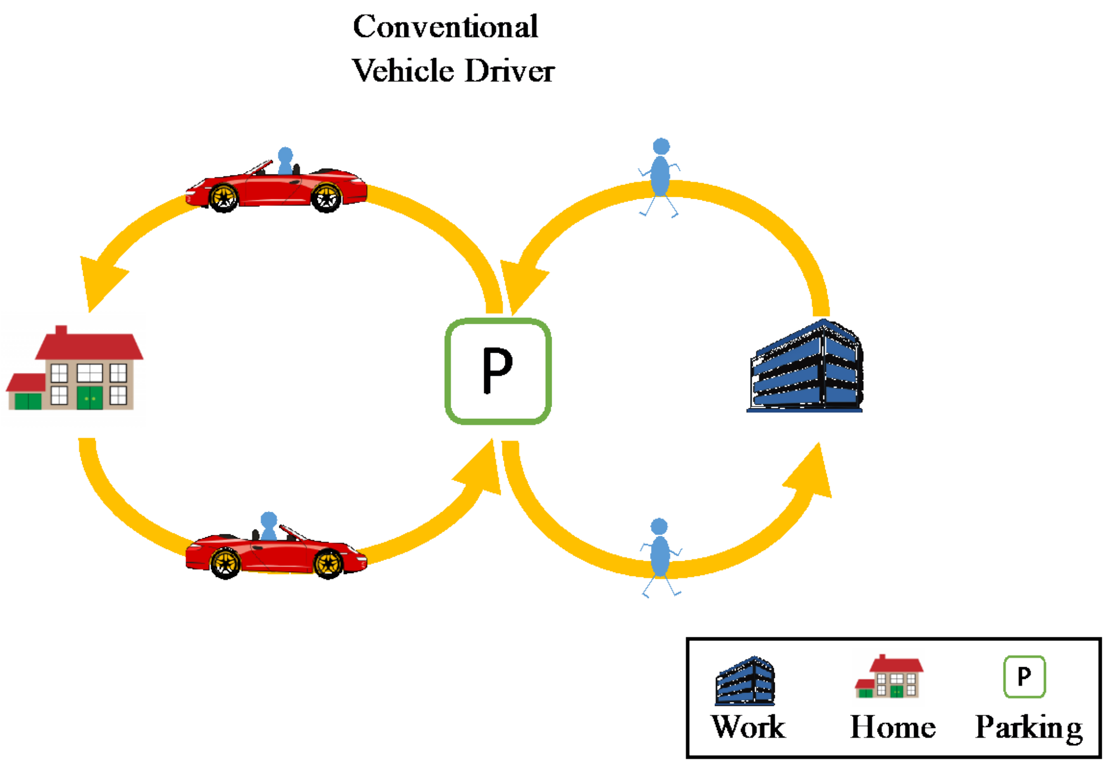
Key operational findings



arrivals.

- Considering Retrieving vehicles from the rear side does not reduce the number of relocations.

Regular Vehicle Parking

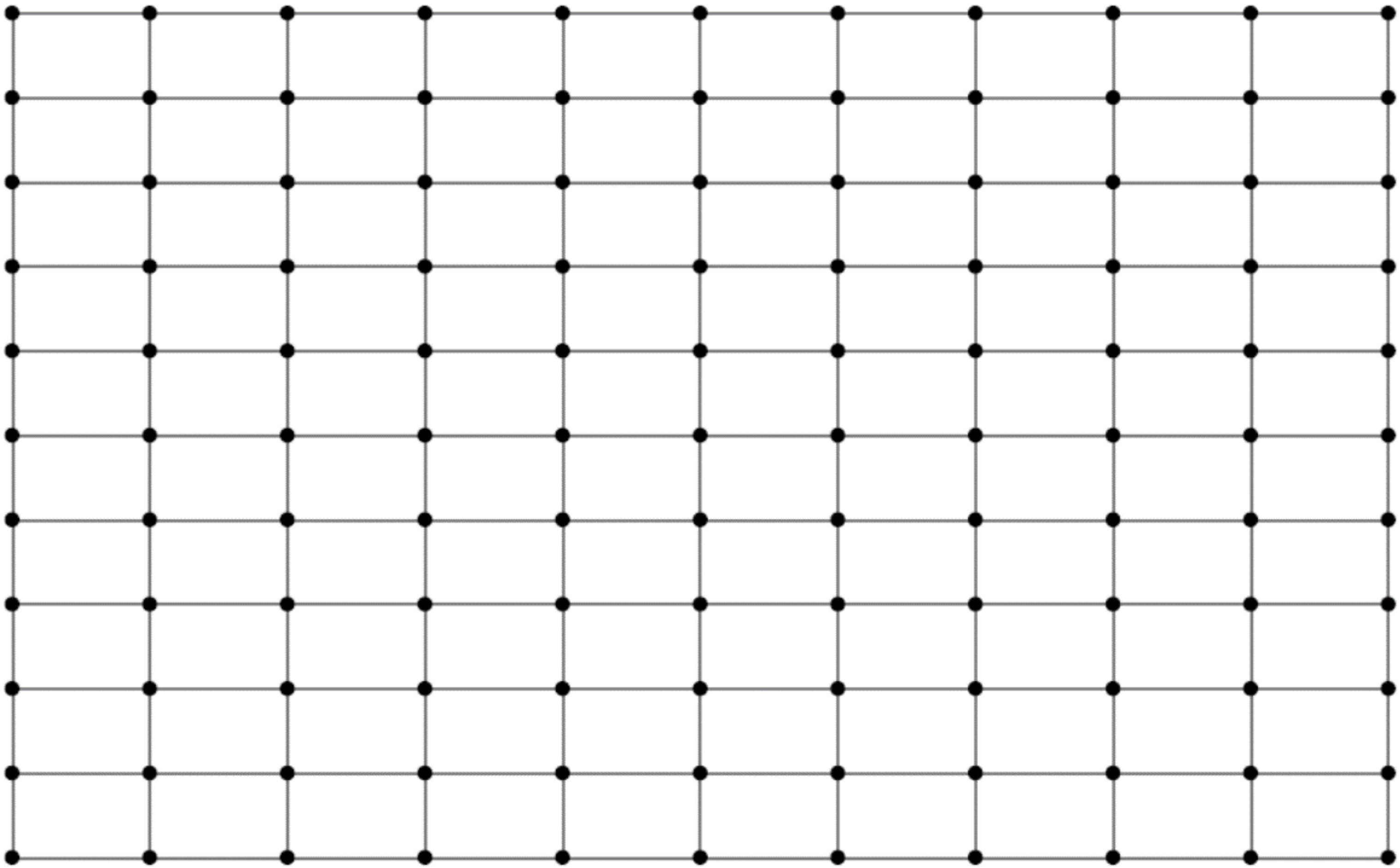


Parking options

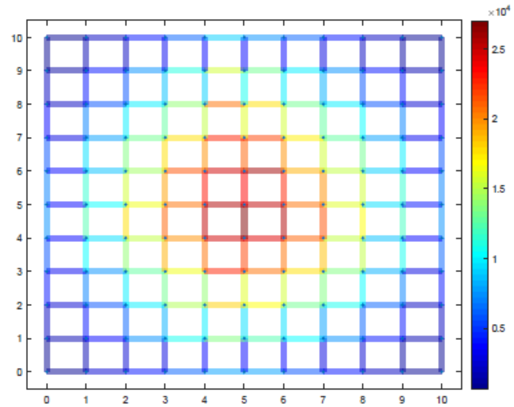
- Home
  - $C_h = 2x_h c_t$
- Car-park
  - $C_p = 2x_p c_t + r_p(t_p - 2x_p)$
- Cruise
  - $C_c = t_p c_t$

x	Travel time
c	Travel cost
r	Parking rate
t	Activity time

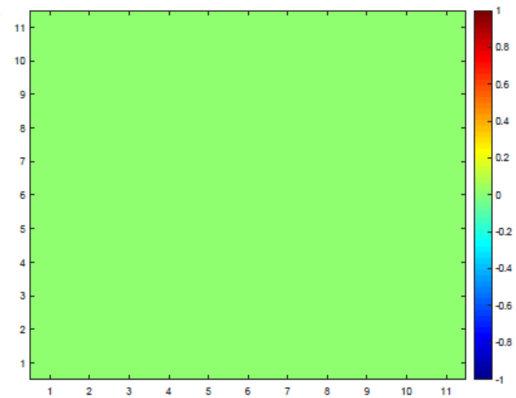
Hypothetical city



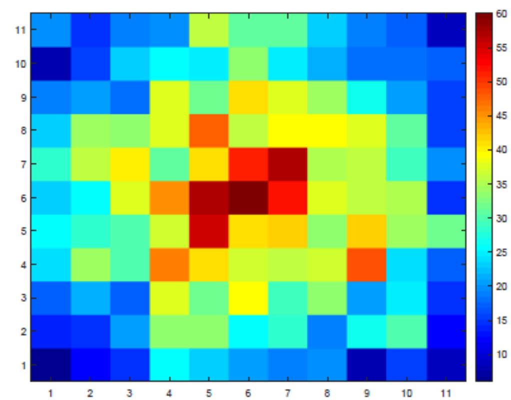
Base case scenario with $r_p = 3[\frac{\$}{hr}]$ and $t_p = 12[\frac{\$}{hr}]$



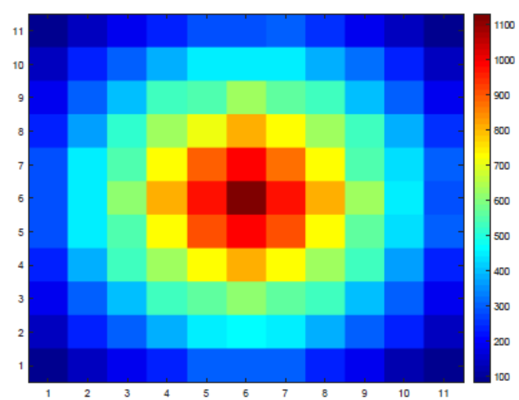
(a) Daily link traffic flow.



(b) Daily spatial distribution of cruising.



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



(d) Daily spatial distribution of parking at homes.

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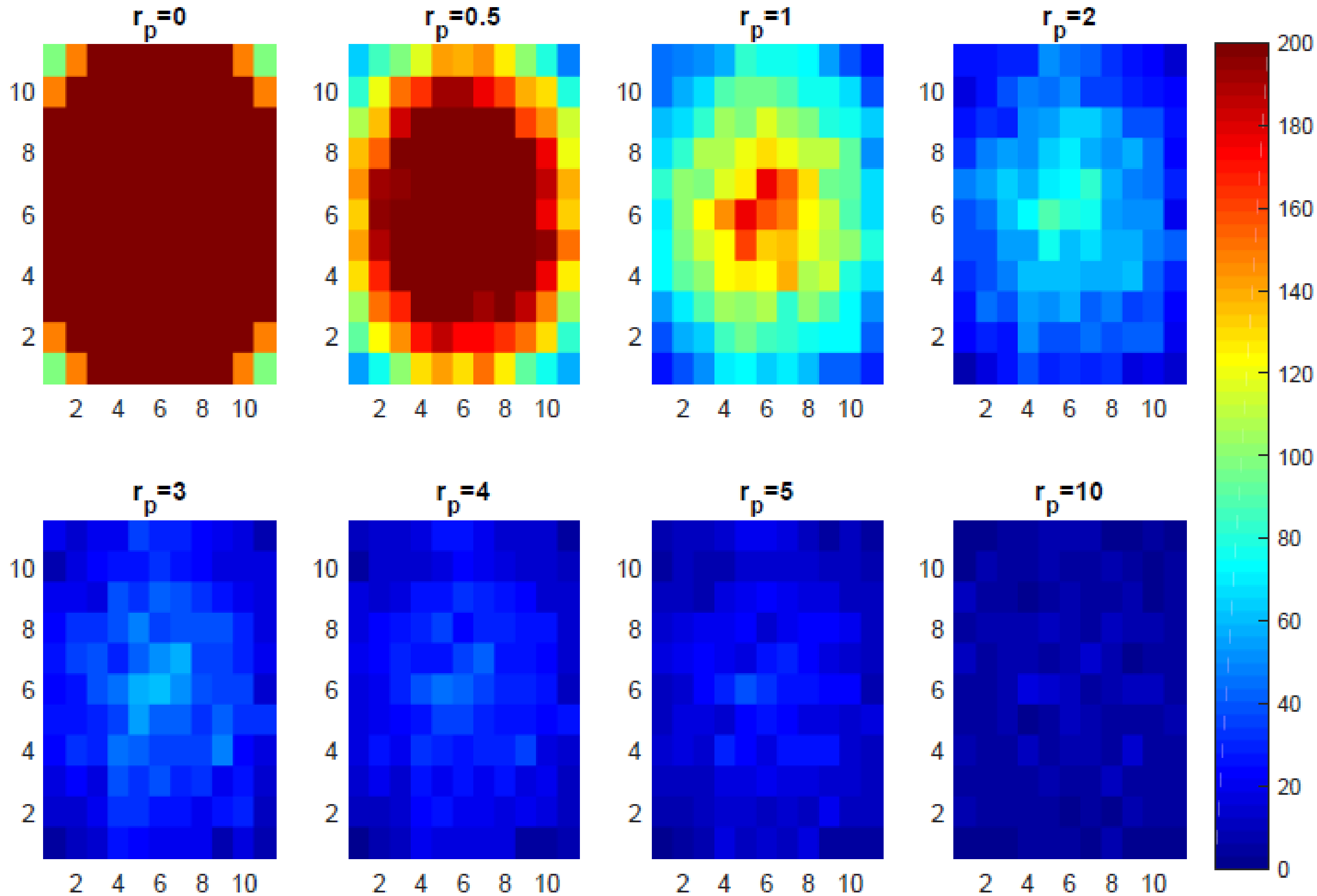
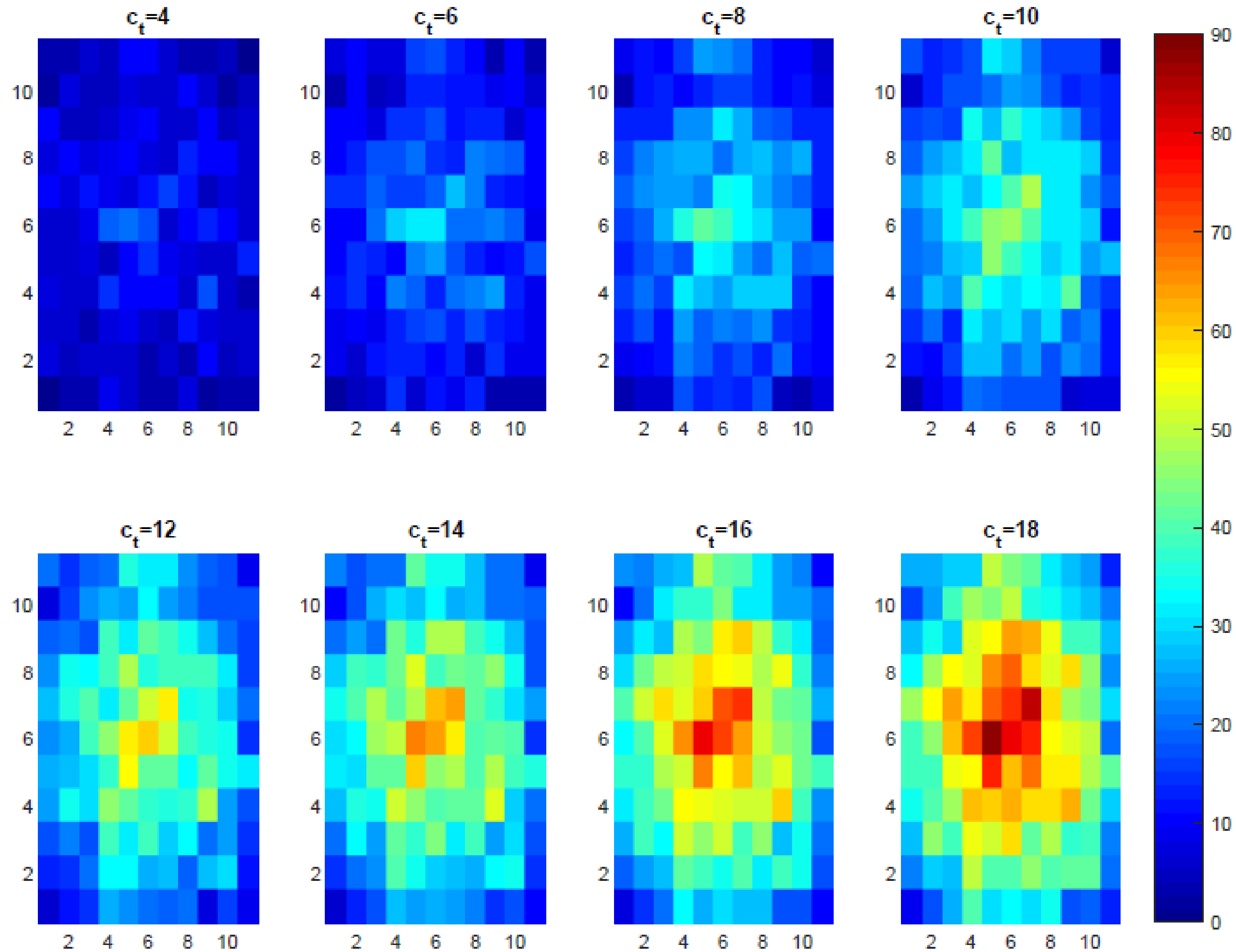
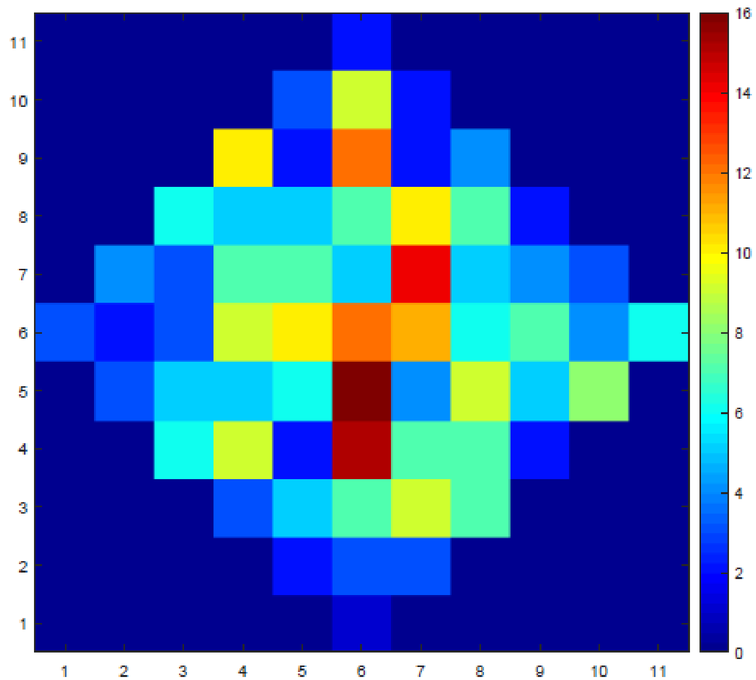
Parking cost sensitivity analysis



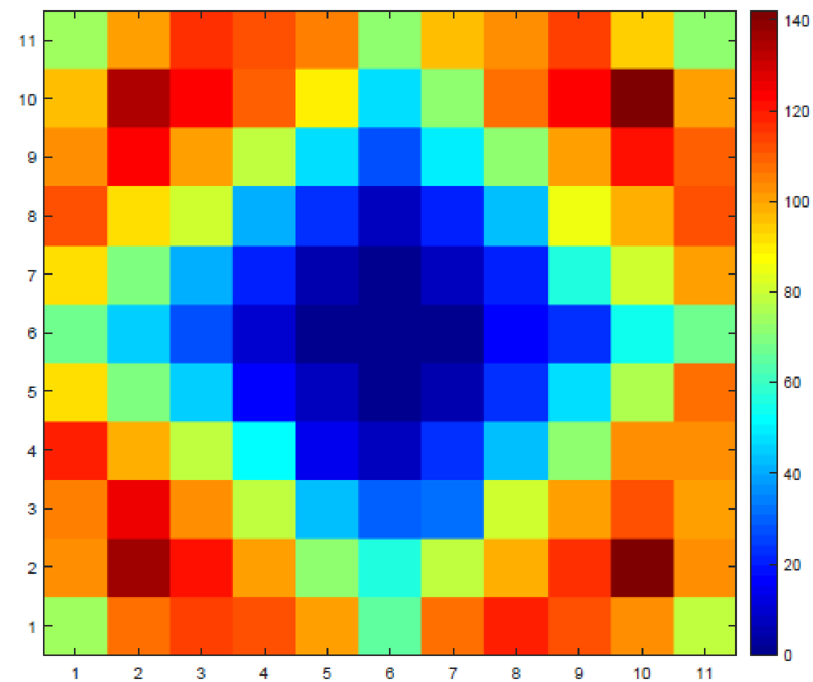
Travel cost sensitivity analysis



Parking location analysis



Daily spatial distribution of cruising



Daily spatial distribution of Parking

Key findings

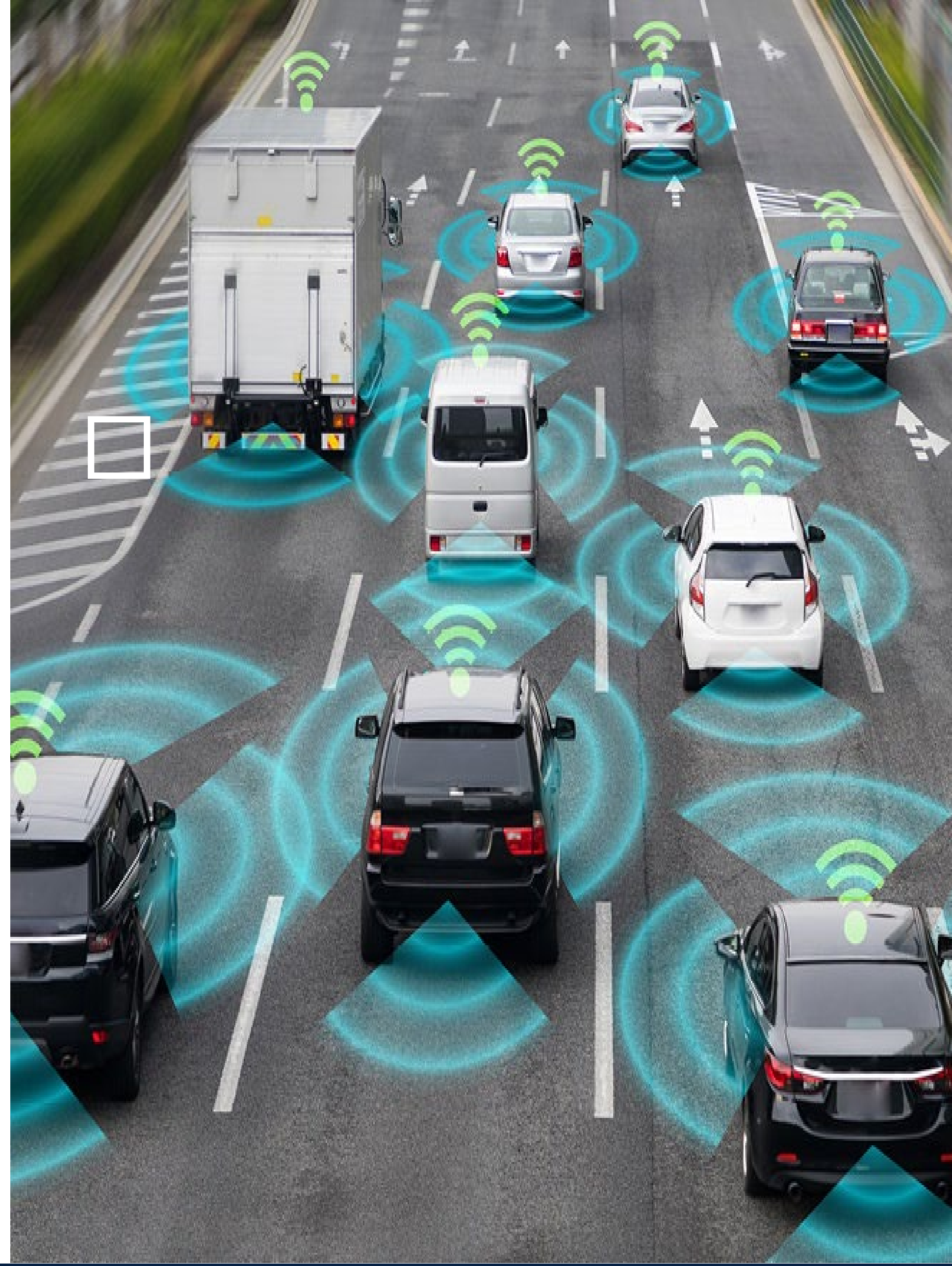
5 pm traffic flow snapshot

	No policy	Same parking price	Zero-occupant toll
Maximum cruising time	18 min	30 min	15 min
Average travel time to car-parks	12 min	10 min	11.5 min
Maximum travel time to car-parks	47 min	50 min	43 min
Change in VKT	-	+1 %	- 3.5 %

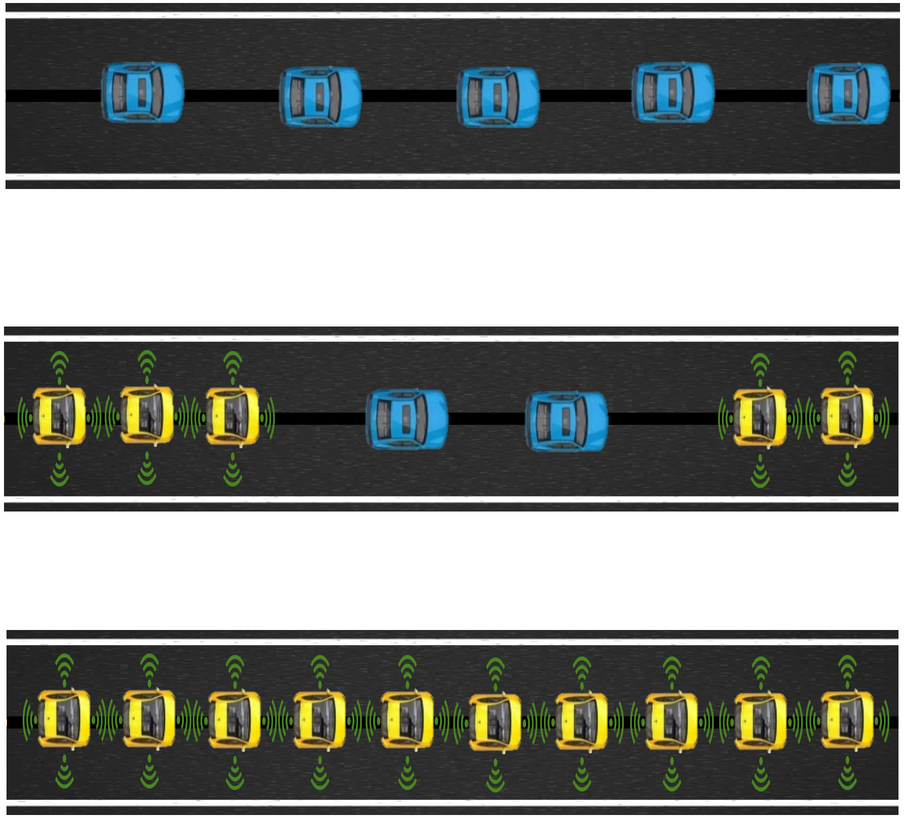
Capacity enhancement

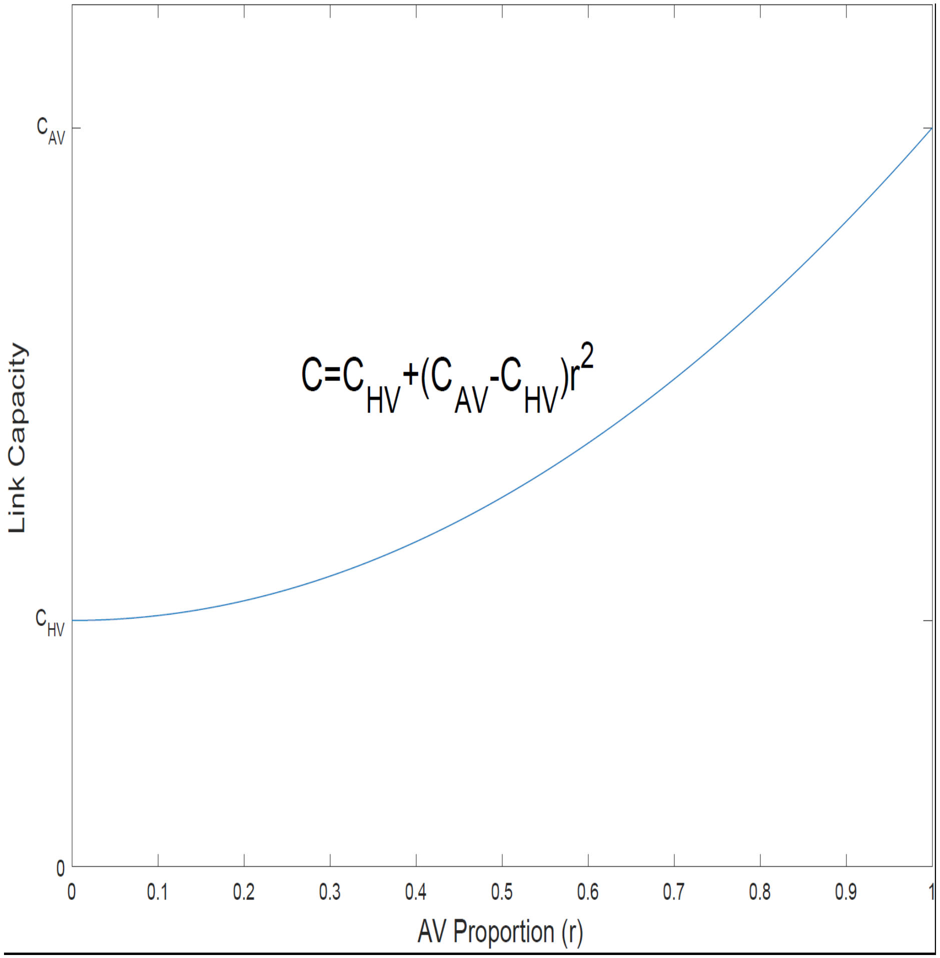
Vehicle to Vehicle

Vehicle to Infrastructure



Relation between link capacity and AV proportion

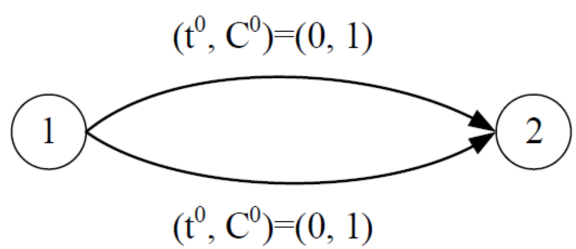


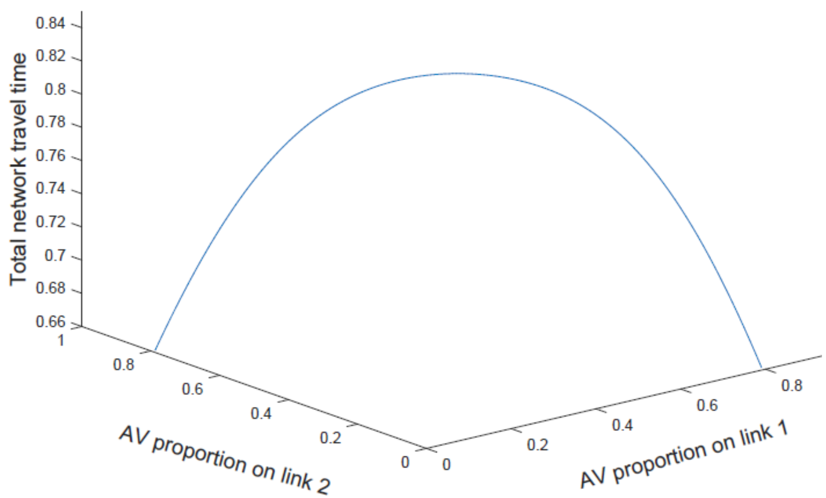


The Equilibrium Condition

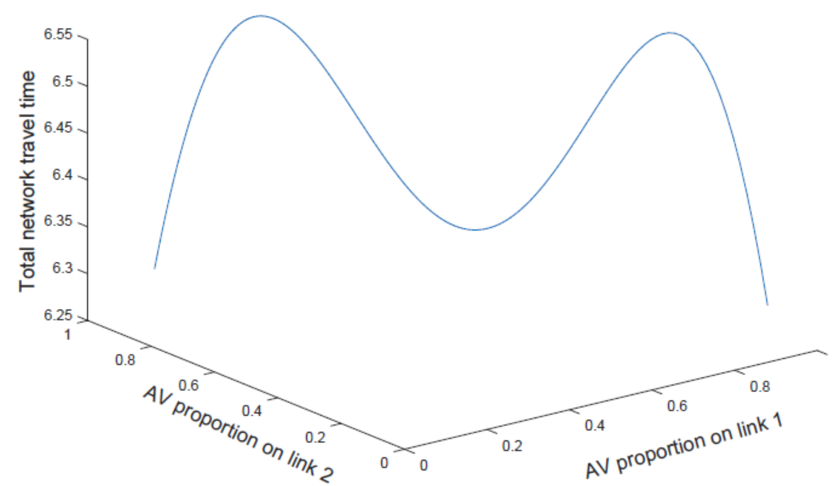
- The equilibrium condition can be formulated as NCP.
- The UE does not have a unique solution because the travel time function changes regarding HV and AV flows is not symmetric.

A simple example



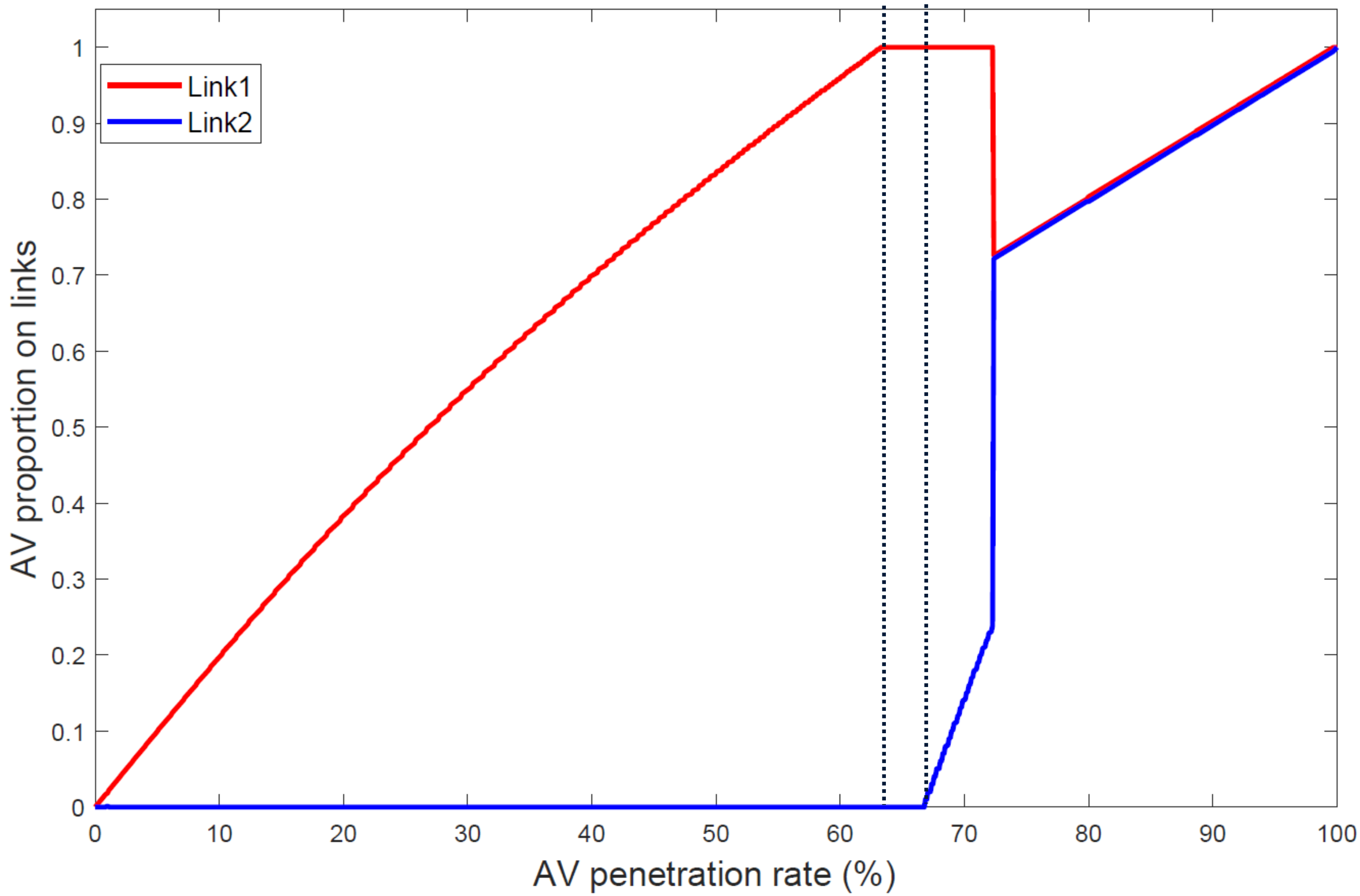


(a) $(g_{AV}, g_{HV}) = (1, 1)$.



(c) $(g_{AV}, g_{HV}) = (2.5, 1)$.

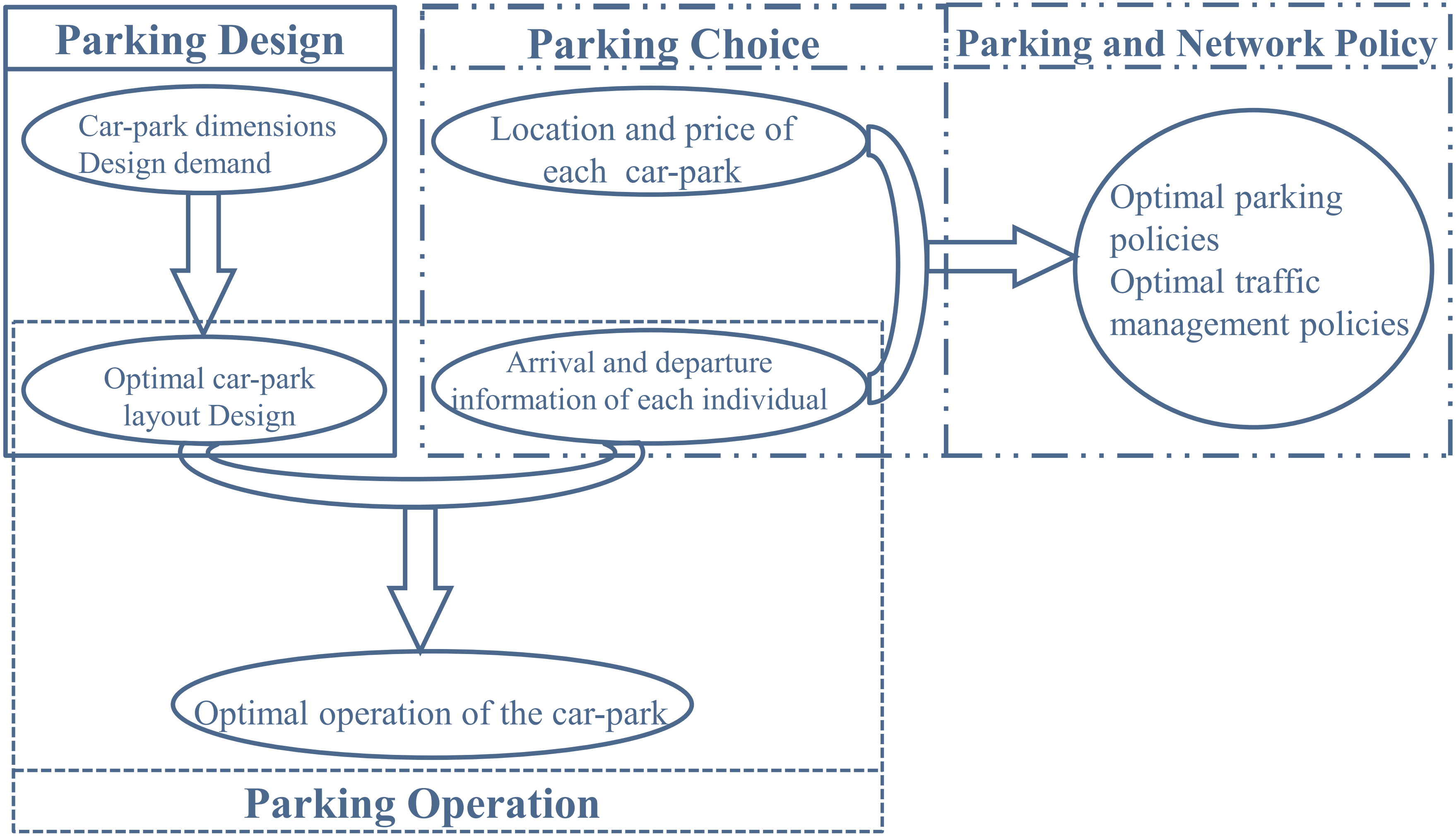
Best User Equilibrium flow



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
Parking Choice
Parking and Network Policy
Car-park dimensions
Design demand
Location and price of
each car-park
Optimal parking
policies
Optimal traffic
management policies
Optimal car-park
layout Design
Arrival and departure
information of each individual
Optimal operation of the car-park
Parking Operation

Thank You!

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