Carsharing Fleet Location Design with Mixed Vehicle Types for CO2 Emission Reduction

Joy Chang
Joint work with Siqian Shen (U of Michigan IOE)
and Ming Xu (U of Michigan SNRE)

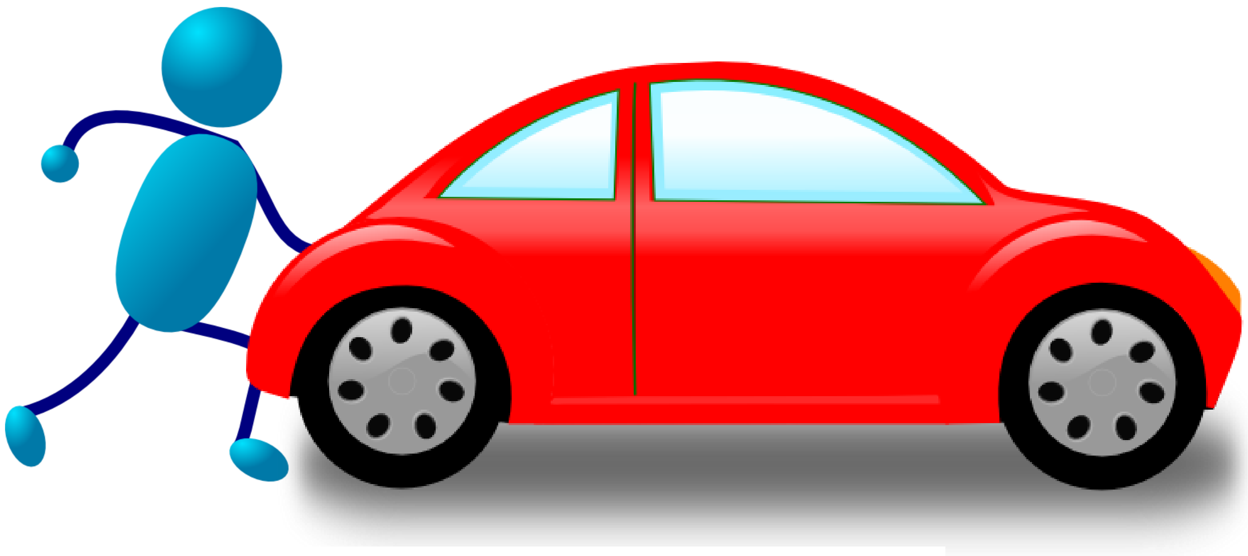
INFORMS Annual Meeting Nashville
November 13, 2016

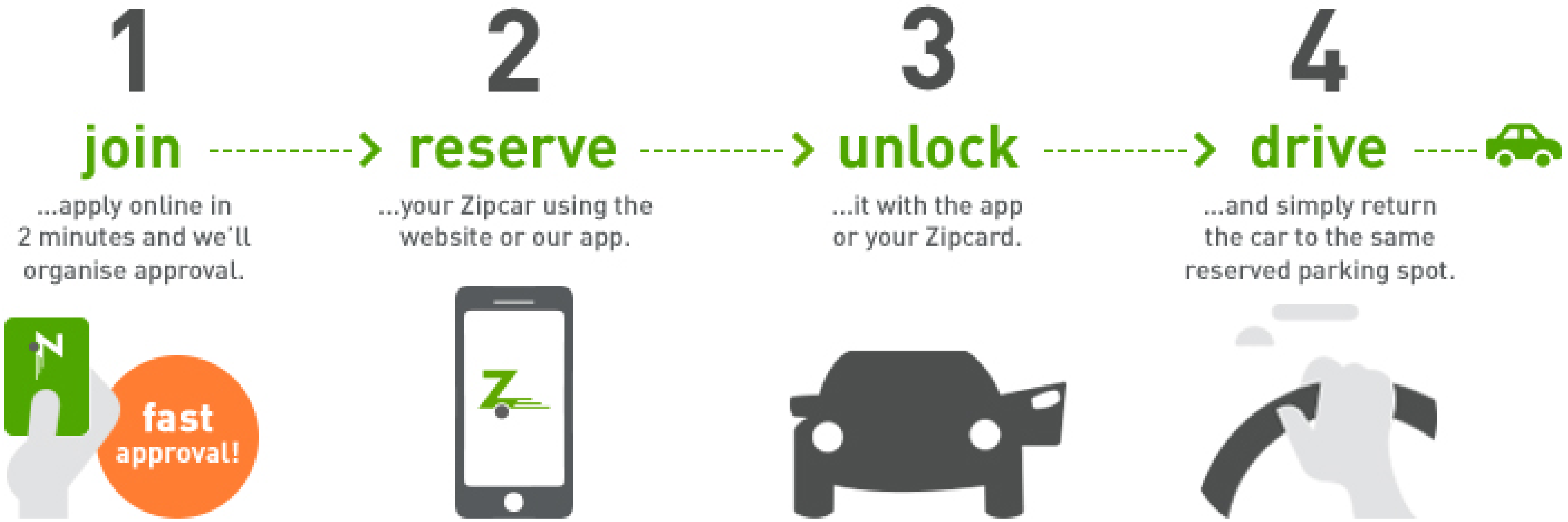
Outline

- **Introduction**
- Mathematical Models
- Computational Results
- Conclusions

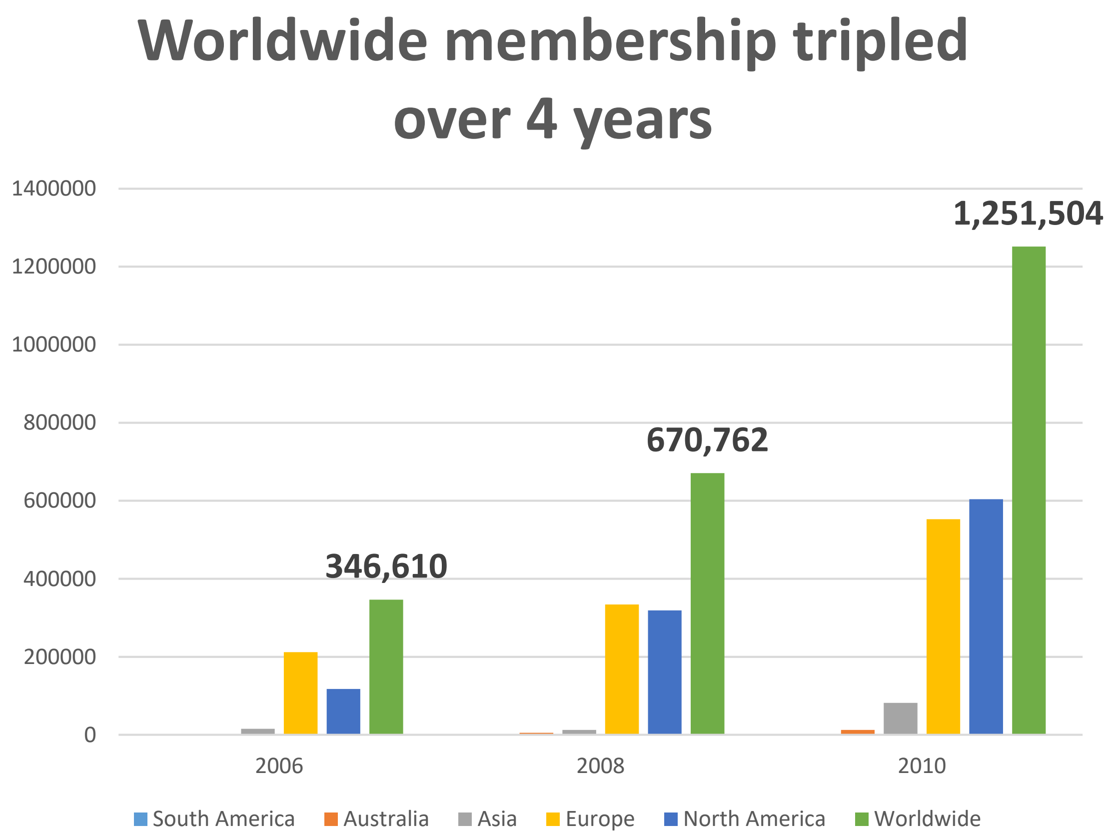
What is carsharing?

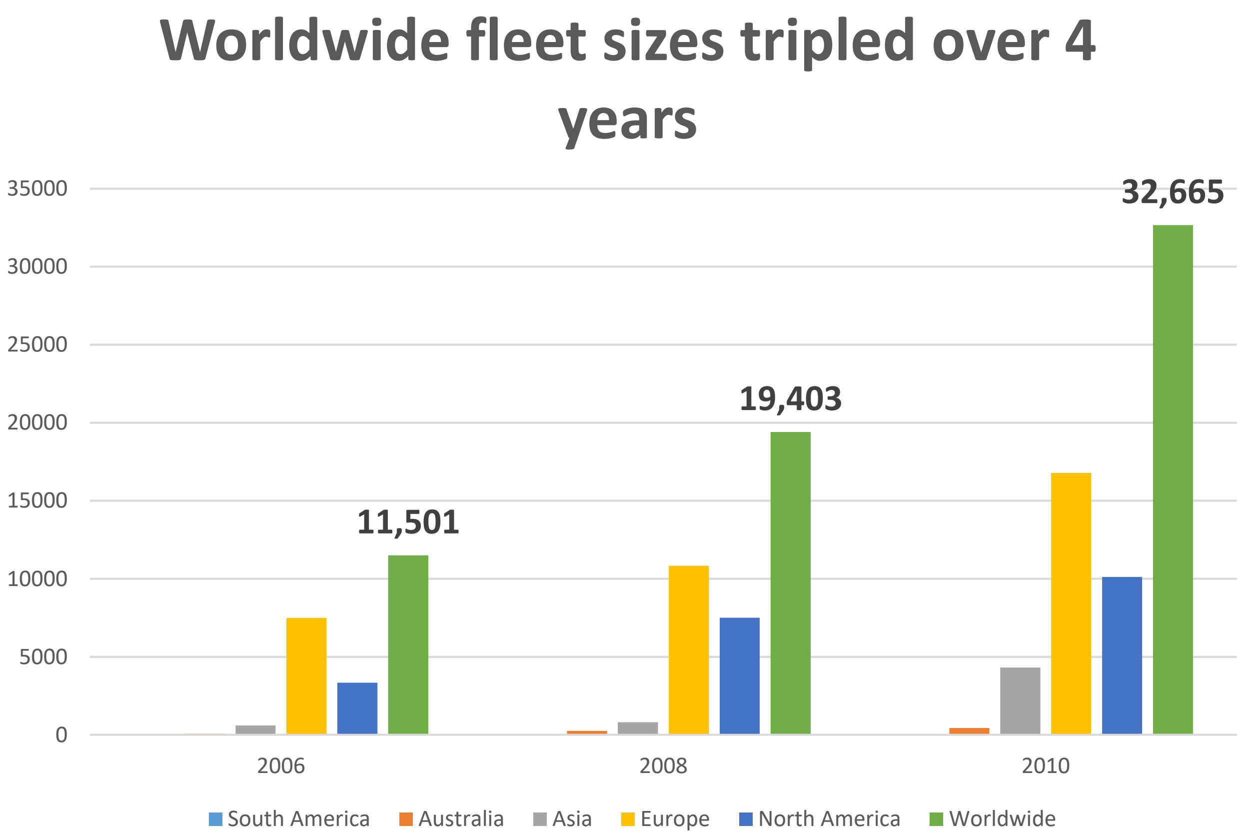
- Short-term car rentals
- One-way or round-trip





Industry growth





Adapted from "Carsharing and personal vehicle services: worldwide market developments and emerging trends", S.A. Saheen.

Carsharing providers

	Private companies	Nonprofit	Government
Entity	Zipcar	City CarShare	Seattle
Vehicles removed (foregone buying or sold)	15 privately owned vehicles for every Zipcar	17,000	1,200 – 1,600
Reduced vehicle miles	90% of members drive 5,500 less miles	140 million miles	N/A

Carshare design and optimization

- Consider strategic decisions
  - Car types to purchase to appeal to larger customer base?
  - Carbon emissions limit?

- Evaluate the impact
  - Case study (Zipcar Boston)
  - Mathematical modeling

- Optimize profitability and quality of service via models that
  - Incorporate round-trip and one-way demands
  - Incorporate carbon emissions constraint
  - Make strategic decisions about diverse portfolio of vehicle types

Outline

- Introduction
- **Mathematical Models**
- Computational Results
- Conclusions

Framing the problem

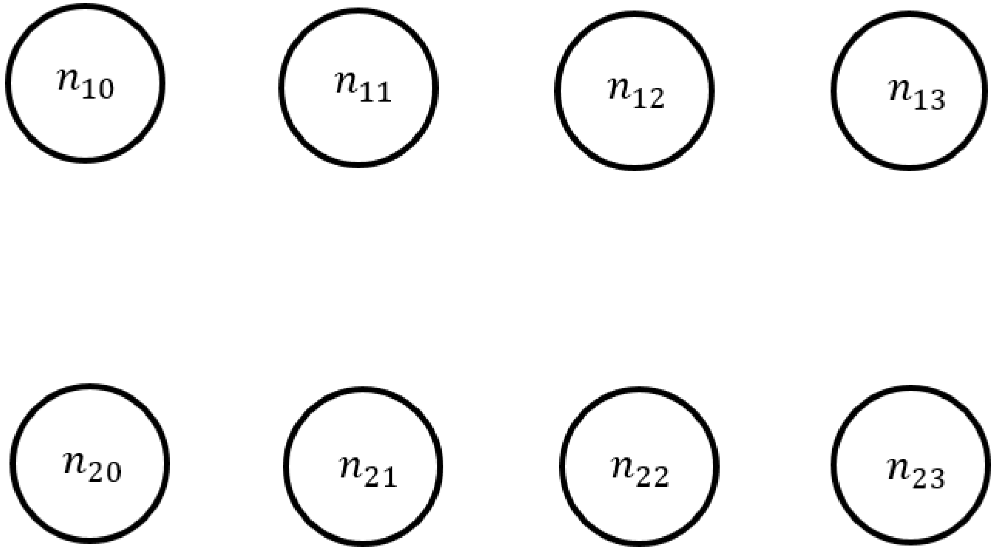
Carsharing companies need a diverse vehicle portfolio

How does demand for different vehicle types affect:

- Profitability
- Quality of service
  - One-way and round-trip
  - Denied trip
  - Trip fulfillment
- Purchasing decisions
- Carbon emissions

Building the spatial-temporal network

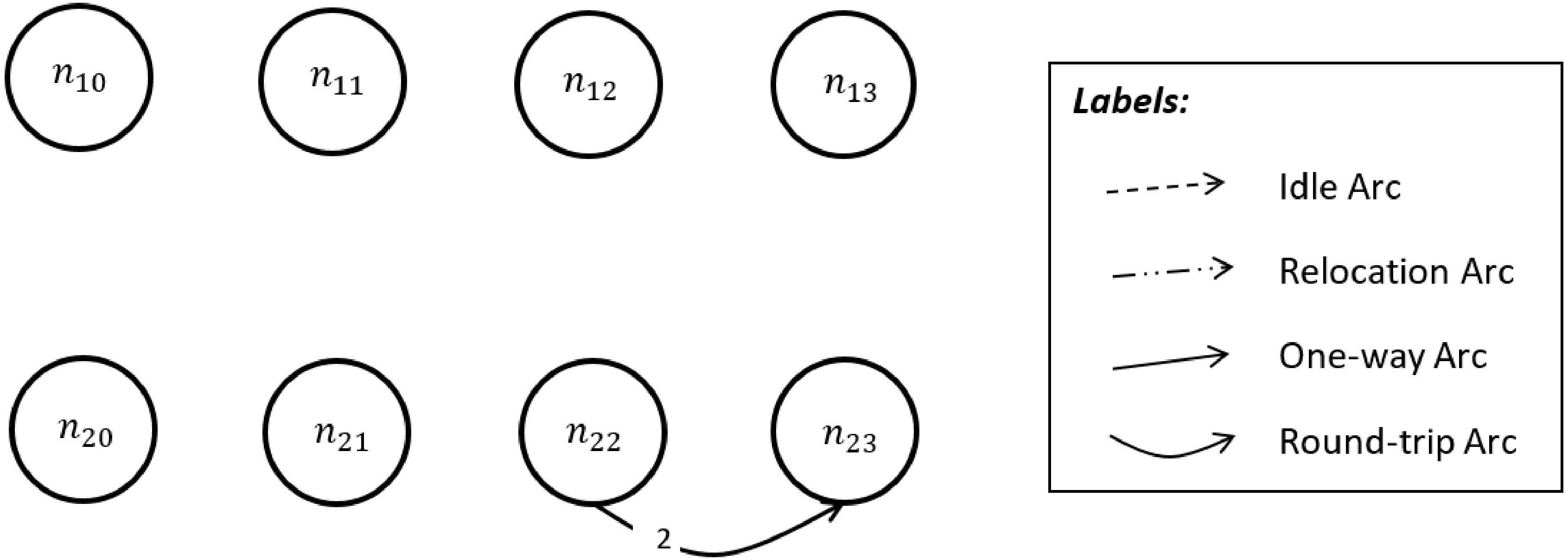
- Example:
  - Zones 1, 2
  - Time periods 0, 1, 2, 3
  - n_{it}: Zone *i* at time *t*



Round-trip arcs

- Example:
  - Zones 1, 2
  - Time periods 0, 1, 2, 3
  - n_{it}: Zone *i* at time *t*

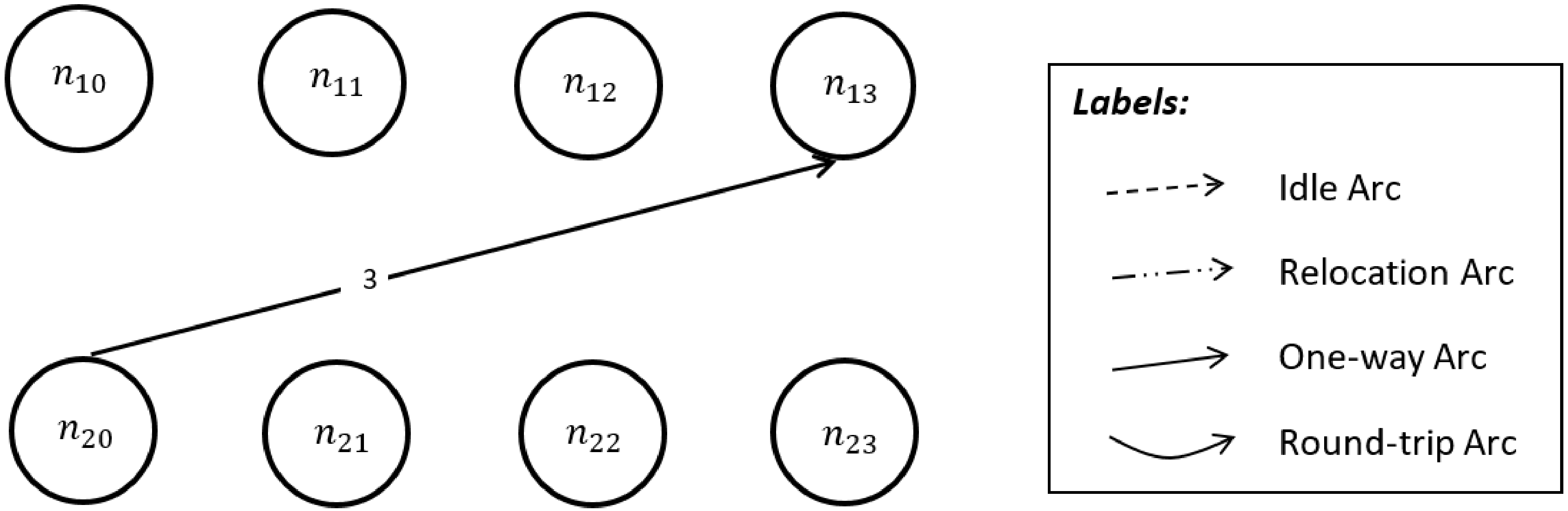
Type	Volume	Origin	Destination	Start	End
One-way	3	2	1	0	3
Round-trip	2	2		2	3



One-way arcs

- Example:
  - Zones 1, 2
  - Time periods 0, 1, 2, 3
  - n_{it}: Zone *i* at time *t*

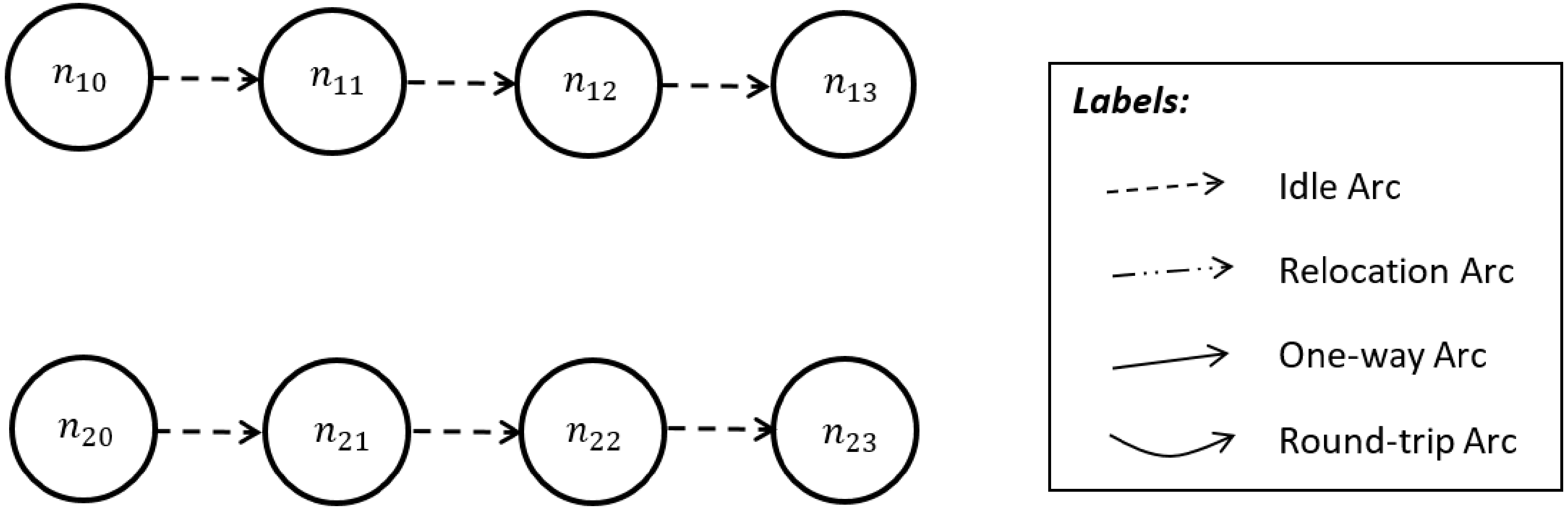
Type	Volume	Origin	Destination	Start	End
One-way	3	2	1	0	3
Round-trip	2	2		2	3



Idle arcs

- Example:
  - Zones 1, 2
  - Time periods 0, 1, 2, 3
  - n_{it}: Zone *i* at time *t*

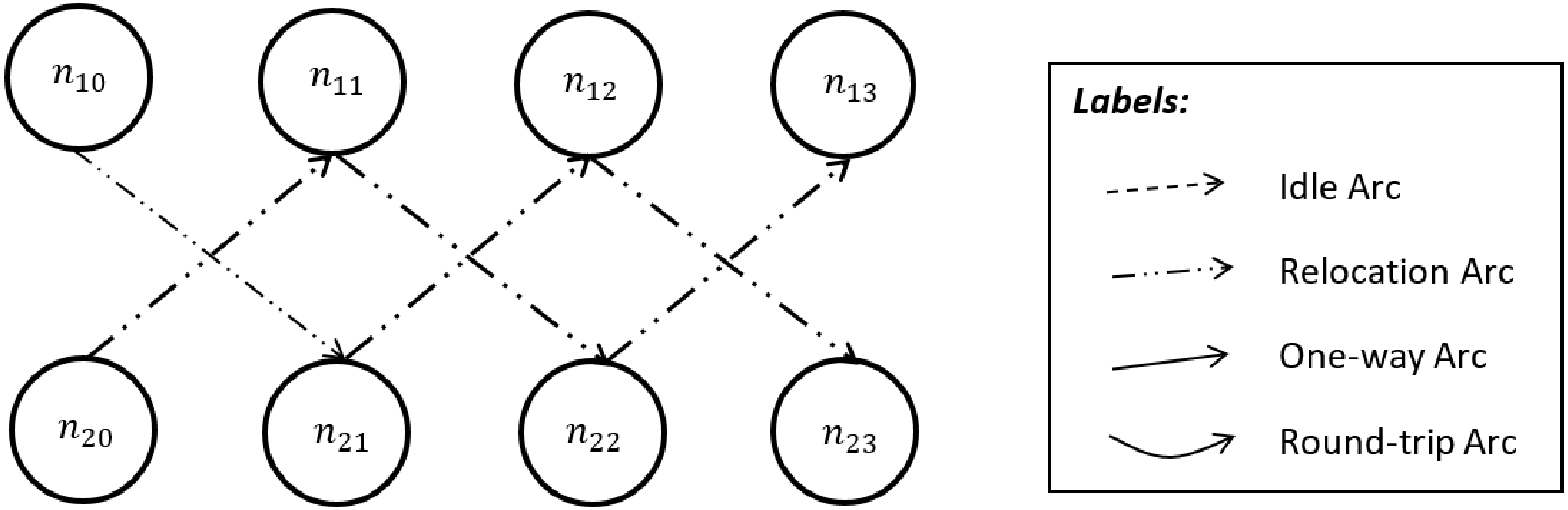
Type	Volume	Origin	Destination	Start	End
One-way	3	2	1	0	3
Round-trip	2	2		2	3



Relocation arcs

- Example:
  - Zones 1, 2
  - Time periods 0, 1, 2, 3
  - n_{it}: Zone *i* at time *t*

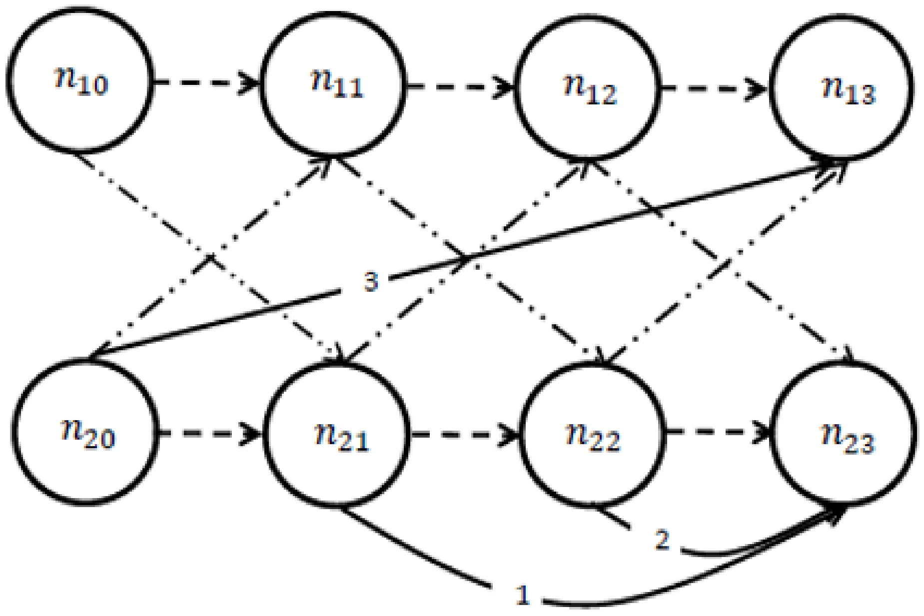
Type	Volume	Origin	Destination	Start	End
One-way	3	2	1	0	3
Round-trip	2	2		2	3

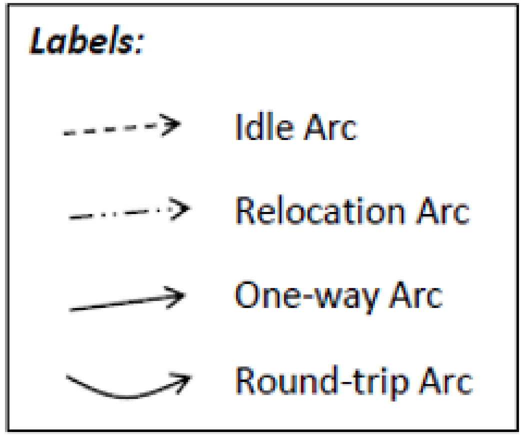


Final spatial-temporal network

- Example:
  - Zones 1, 2
  - Time periods 0, 1, 2, 3
  - n_{it}: Zone *i* at time *t*

Type	Volume	Origin	Destination	Start	End
One-way	3	2	1	0	3
Round-trip	2	2		2	3





Defining Model 1

Inputs

- Car purchase cost and emissions generated
- Car rental price
- Arc capacity (demand)

Objective

- Maximize total revenue of operating cars over set time

Defining Model 1

Decision variables

- Number and type of cars purchased at each zone
- Number of cars to route along each arc

Constraints

- Number of cars entering each node equals number of cars leaving
- Carbon emission produced does not exceed limit
- Car purchase cost does not exceed limit

Assumptions

- A set of service zones and a finite number of service periods
- Serve one-way and round-trip rentals
- Cars can be relocated, to balance vehicle distributions
- Unsatisfied demand is immediately lost

Network arc parameters

Type of Arc	Capacity u_{aj}	CO_2 emission e_{aj}
Idle arcs $a = (n_{it}, n_{i,t+1}) \in A^I$	$v_j^{\max}$	0
Round-trip arc $a = (n_{it}, n_{is}) \in A^R$	d_{ijts}	$c_j(s-t)$
One-way arc $a = (n_{it}, n_{i's}) \in A^O$	$d_{ii'jts}$	$c_j(s-t)$
Relocation arc $a = (n_{it}, n_{i',t+l_{ii'}}) \in A^{REL}$	$v_j^{\max}$	$c_j l_{ii'}$

Type of Arc	Maintenance	Idle	Relocation	Profit	Arc Revenue k_{aj}
Idle arc $a = (n_{it}, n_{i,t+1}) \in A^I$	b_{jt}	p_{jt}	0	0	$-(b_{jt} + p_{jt})$
Round-trip arc $a = (n_{it}, n_{is}) \in A^R$	$\sum_{\ell=t}^{s-1} b_{j\ell}$	0	0	r_{ijts}	$r_{ijts} - \sum_{\ell=t}^{s-1} b_{j\ell}$
One-way arc $a = (n_{it}, n_{i's}) \in A^O$	$\sum_{\ell=t}^{s-1} b_{j\ell}$	0	0	$r_{ii'jts}$	$r_{ii'jts} - \sum_{\ell=t}^{s-1} b_{j\ell}$
Relocation arc $a = (n_{it}, n_{i',t+l_{ii'}}) \in A^{REL}$	$\sum_{\ell=t}^{t+l_{ii'}-1} b_{j\ell}$	0	$c^{\text{rel}} l_{ii'}$	0	$-c^{\text{rel}} l_{ii'} - \sum_{\ell=t}^{t+l_{ii'}-1} b_{j\ell}$

Network arc parameters

Type of Arc	Capacity u_{aj}	CO_2 emission e_{aj}
Idle arcs $a = (n_{it}, n_{i,t+1}) \in A^I$	$v_j^{\max}$	0
Round-trip arc $a = (n_{it}, n_{is}) \in A^R$	d_{ijts}	$c_j(s-t)$
One-way arc $a = (n_{it}, n_{i's}) \in A^O$	$d_{ii'jts}$	$c_j(s-t)$
Relocation arc $a = (n_{it}, n_{i',t+l_{ii'}}) \in A^{REL}$	$v_j^{\max}$	$c_j l_{ii'}$

Type of Arc	Maintenance	Idle	Relocation	Profit	Arc Revenue k_{aj}
Idle arc $a = (n_{it}, n_{i,t+1}) \in A^I$	b_{jt}	p_{jt}	0	0	$-(b_{jt} + p_{jt})$
Round-trip arc $a = (n_{it}, n_{is}) \in A^R$	$\sum_{\ell=t}^{s-1} b_{j\ell}$	0	0	r_{ijts}	$r_{ijts} - \sum_{\ell=t}^{s-1} b_{j\ell}$
One-way arc $a = (n_{it}, n_{i's}) \in A^O$	$\sum_{\ell=t}^{s-1} b_{j\ell}$	0	0	$r_{ii'jts}$	$r_{ii'jts} - \sum_{\ell=t}^{s-1} b_{j\ell}$
Relocation arc $a = (n_{it}, n_{i',t+l_{ii'}}) \in A^{REL}$	$\sum_{\ell=t}^{t+l_{ii'}-1} b_{j\ell}$	0	$c^{\text{rel}} l_{ii'}$	0	$-c^{\text{rel}} l_{ii'} - \sum_{\ell=t}^{t+l_{ii'}-1} b_{j\ell}$

Network arc parameters

Type of Arc	Capacity u_{aj}	CO_2 emission e_{aj}
Idle arcs $a = (n_{it}, n_{i,t+1}) \in A^I$	$v_j^{\max}$	0
Round-trip arc $a = (n_{it}, n_{is}) \in A^R$	d_{ijts}	$c_j(s-t)$
One-way arc $a = (n_{it}, n_{i's}) \in A^O$	$d_{ii'jts}$	$c_j(s-t)$
Relocation arc $a = (n_{it}, n_{i',t+l_{ii'}}) \in A^{REL}$	$v_j^{\max}$	$c_j l_{ii'}$

Type of Arc	Maintenance	Idle	Relocation	Profit	Arc Revenue k_{aj}
Idle arc $a = (n_{it}, n_{i,t+1}) \in A^I$	b_{jt}	p_{jt}	0	0	$-(b_{jt} + p_{jt})$
Round-trip arc $a = (n_{it}, n_{is}) \in A^R$	$\sum_{\ell=t}^{s-1} b_{j\ell}$	0	0	r_{ijts}	$r_{ijts} - \sum_{\ell=t}^{s-1} b_{j\ell}$
One-way arc $a = (n_{it}, n_{i's}) \in A^O$	$\sum_{\ell=t}^{s-1} b_{j\ell}$	0	0	$r_{ii'jts}$	$r_{ii'jts} - \sum_{\ell=t}^{s-1} b_{j\ell}$
Relocation arc $a = (n_{it}, n_{i',t+l_{ii'}}) \in A^{REL}$	$\sum_{\ell=t}^{t+l_{ii'}-1} b_{j\ell}$	0	$c^{\text{rel}} l_{ii'}$	0	$-c^{\text{rel}} l_{ii'} - \sum_{\ell=t}^{t+l_{ii'}-1} b_{j\ell}$

Network arc parameters

Type of Arc	Capacity u_{aj}	CO_2 emission e_{aj}
Idle arcs $a = (n_{it}, n_{i,t+1}) \in A^I$	$v_j^{\max}$	0
Round-trip arc $a = (n_{it}, n_{is}) \in A^R$	d_{ijts}	$c_j(s-t)$
One-way arc $a = (n_{it}, n_{i's}) \in A^O$	$d_{ii'jts}$	$c_j(s-t)$
Relocation arc $a = (n_{it}, n_{i',t+l_{ii'}}) \in A^{REL}$	$v_j^{\max}$	$c_j l_{ii'}$

Type of Arc	Maintenance	Idle	Relocation	Profit	Arc Revenue k_{aj}
Idle arc $a = (n_{it}, n_{i,t+1}) \in A^I$	b_{jt}	p_{jt}	0	0	$-(b_{jt} + p_{jt})$
Round-trip arc $a = (n_{it}, n_{is}) \in A^R$	$\sum_{\ell=t}^{s-1} b_{j\ell}$	0	0	r_{ijts}	$r_{ijts} - \sum_{\ell=t}^{s-1} b_{j\ell}$
One-way arc $a = (n_{it}, n_{i's}) \in A^O$	$\sum_{\ell=t}^{s-1} b_{j\ell}$	0	0	$r_{ii'jts}$	$r_{ii'jts} - \sum_{\ell=t}^{s-1} b_{j\ell}$
Relocation arc $a = (n_{it}, n_{i',t+l_{ii'}}) \in A^{REL}$	$\sum_{\ell=t}^{t+l_{ii'}-1} b_{j\ell}$	0	$c^{\text{rel}} l_{ii'}$	0	$-c^{\text{rel}} l_{ii'} - \sum_{\ell=t}^{t+l_{ii'}-1} b_{j\ell}$

Model 1

Maximize total revenue

Max $\sum_{a \epsilon A} \sum_{j \epsilon J} k_{aj} y_{aj}$

s.t.

$$\sum_{a \epsilon \delta^+(n_{it})} y_{aj} - \sum_{a \epsilon \delta^-(n_{it})} y_{aj} = \begin{cases} x_{ij} & \text{if } t = 0 \\ 0 & \text{if } t \,\epsilon\, \{1, \dots, T-1\} \end{cases} \quad \forall \quad n_{it} \,\epsilon\, N, j \,\epsilon\, J$$

$$\sum_{a \epsilon A} \sum_{j \epsilon J} e_{aj} y_{aj} \leq \mathcal{H}$$

$$\sum_{i \epsilon I} \sum_{j \epsilon J} m_j x_{ij} \leq \mathcal{F}$$

$$y_{aj} \leq u_{aj} \quad \forall \quad a \,\epsilon\, A, \; j \,\epsilon\, J$$

$$x_{ij} \,\epsilon\, \mathbb{Z}_+, y_{aj} \,\epsilon\, \mathbb{Z}_+ \quad \forall \quad a \,\epsilon\, A, \; j \,\epsilon\, J$$

Model 1

Flow balance constraint

Max $\sum_{a \epsilon A} \sum_{j \epsilon J} k_{aj} y_{aj}$

s.t. $\sum_{a \epsilon \delta^+(n_{it})} y_{aj} - \sum_{a \epsilon \delta^-(n_{it})} y_{aj} = \begin{cases} x_{ij} & \text{if } t = 0 \\ 0 & \text{if } t \epsilon \{1, \dots, T-1\} \end{cases} \quad \forall \quad n_{it} \epsilon N, j \epsilon J$

$\sum_{a \epsilon A} \sum_{j \epsilon J} e_{aj} y_{aj} \leq \mathcal{H}$

$\sum_{i \epsilon I} \sum_{j \epsilon J} m_j x_{ij} \leq \mathcal{F}$

$y_{aj} \leq u_{aj} \quad \forall \quad a \epsilon A, \ j \epsilon J$

$x_{ij} \epsilon \mathbb{Z}_+, y_{aj} \epsilon \mathbb{Z}_+ \quad \forall \quad a \epsilon A, \ j \epsilon J$

Model 1

Max $\sum_{a \epsilon A} \sum_{j \epsilon J} k_{aj} y_{aj}$

s.t.

$$\sum_{a \epsilon \delta^+(n_{it})} y_{aj} - \sum_{a \epsilon \delta^-(n_{it})} y_{aj} = \begin{cases} x_{ij} & \text{if } t = 0 \\ 0 & \text{if } t \epsilon \{1, \dots, T-1\} \end{cases} \quad \forall \quad n_{it} \epsilon N, j \epsilon J$$

$$\sum_{a \epsilon A} \sum_{j \epsilon J} e_{aj} y_{aj} \leq \mathcal{H}$$

Budget limit

$$\sum_{i \epsilon I} \sum_{j \epsilon J} m_j x_{ij} \leq \mathcal{F}$$

$$y_{aj} \leq u_{aj} \quad \forall \quad a \epsilon A, \; j \epsilon J$$

$$x_{ij} \epsilon \mathbb{Z}_+, y_{aj} \epsilon \mathbb{Z}_+ \quad \forall \quad a \epsilon A, \; j \epsilon J$$

Model 1

Max $\sum_{a \epsilon A} \sum_{j \epsilon J} k_{aj} y_{aj}$

s.t.

$$\sum_{a \epsilon \delta^{+}(n_{it})} y_{aj} - \sum_{a \epsilon \delta^{-}(n_{it})} y_{aj} = \begin{cases} x_{ij} & \text{if } t = 0 \\ 0 & \text{if } t \epsilon \{1, \dots, T-1\} \end{cases} \quad \forall \quad n_{it} \epsilon N, j \epsilon J$$

$$\sum_{a \epsilon A} \sum_{j \epsilon J} e_{aj} y_{aj} \leq \mathcal{H}$$

$$\sum_{i \epsilon I} \sum_{j \epsilon J} m_j x_{ij} \leq \mathcal{F}$$

Carbon emissions limit

$$y_{aj} \leq u_{aj} \quad \forall \quad a \epsilon A, \ j \epsilon J$$

$$x_{ij} \epsilon \mathbb{Z}_+, y_{aj} \epsilon \mathbb{Z}_+ \quad \forall \quad a \epsilon A, \ j \epsilon J$$

Model 1

Max $\sum_{a \epsilon A} \sum_{j \epsilon J} k_{aj} y_{aj}$

s.t.

$$\sum_{a \epsilon \delta^{+}(n_{it})} y_{aj} - \sum_{a \epsilon \delta^{-}(n_{it})} y_{aj} = \begin{cases} x_{ij} & \text{if } t = 0 \\ 0 & \text{if } t \epsilon \{1, \ldots, T-1\} \end{cases} \qquad \forall \quad n_{it} \epsilon N, j \epsilon J$$

$$\sum_{a \epsilon A} \sum_{j \epsilon J} e_{aj} y_{aj} \leq \mathcal{H}$$

$$\sum_{i \epsilon I} \sum_{j \epsilon J} m_j x_{ij} \leq \mathcal{F}$$

$$y_{aj} \leq u_{aj} \qquad \forall \quad a \epsilon A, \; j \epsilon J$$

Capacity constraint

$$x_{ij} \epsilon \mathbb{Z}_{+}, y_{aj} \epsilon \mathbb{Z}_{+} \qquad \forall \quad a \epsilon A, \; j \epsilon J$$

Model 1

Max $\sum_{a \epsilon A} \sum_{j \epsilon J} k_{aj} y_{aj}$

s.t.

$$\sum_{a \epsilon \delta^{+}(n_{it})} y_{aj} - \sum_{a \epsilon \delta^{-}(n_{it})} y_{aj} = \begin{cases} x_{ij} & \text{if } t = 0 \\ 0 & \text{if } t \epsilon \{1, \dots, T-1\} \end{cases} \quad \forall \quad n_{it} \epsilon N, j \epsilon J$$

$$\sum_{a \epsilon A} \sum_{j \epsilon J} e_{aj} y_{aj} \leq \mathcal{H}$$

$$\sum_{i \epsilon I} \sum_{j \epsilon J} m_j x_{ij} \leq \mathcal{F}$$

$$y_{aj} \leq u_{aj} \quad \forall \quad a \epsilon A, \; j \epsilon J$$

$$x_{ij} \epsilon \mathbb{Z}_{+}, y_{aj} \epsilon \mathbb{Z}_{+} \quad \forall \quad a \epsilon A, \; j \epsilon J$$

Integer restriction

Extension to Model 1 (Model 2)

- First-come first-serve (FCFS) principle:

  If there is a car available (idle) at that node when a customer comes in, you must serve the customer

- Model 2 (M2) enforces FCFS
- Denied trip percentage serves as metric
- New binary variable introduced at each node

Extension to Model 1 (Model 2)

Add the following constraints to M1:

$$y_{(n_{it}, n_{i,t+1}),j} \leq v_j^{max} z_{it}^j \qquad \forall\ i \epsilon\ I,\ \ t = 0, 1, \ldots, T-1,\ \ j \epsilon\ J$$

$$\sum_{a \epsilon \delta^+(n_{it}) \cup (A^O \cap A^U)} (u_{aj} - y_{aj}) \leq v_j^{max}(1 - z_{it}^j) \qquad \forall\ i \epsilon\ I,\ \ t = 0, 1, \ldots, T-1,\ \ j \epsilon\ J$$

$$z_{it}^j \ \epsilon\ \{0, 1\} \qquad \forall\ i \epsilon\ I,\ \ t = 0, 1, \ldots, T-1,\ \ j \epsilon\ J$$

Extension to Model 1 (Model 2)

Add the following constraints to M1:

$$y_{(n_{it}, n_{i,t+1}),j} \leq v_j^{max} z_{it}^j \qquad \forall\, i \epsilon I,\ \ t = 0, 1, \ldots, T-1,\ \ j \epsilon J$$

$$\sum_{a \epsilon \delta^+(n_{it}) \cup (A^O \cap A^U)} (u_{aj} - y_{aj}) \leq v_j^{max}(1 - z_{it}^j) \qquad \forall\, i \epsilon I,\ \ t = 0, 1, \ldots, T-1,\ \ j \epsilon J$$

$$z_{it}^j \ \epsilon\ \{0, 1\} \qquad \forall\, i \epsilon I,\ \ t = 0, 1, \ldots, T-1,\ \ j \epsilon J$$

If z_{it}^j is 1, then idle cars can flow from that node.

Else, no idle cars can flow from that node.

Extension to Model 1 (Model 2)

Add the following constraints to M1:

$$y_{(n_{it}, n_{i,t+1}),j} \leq v_j^{max} z_{it}^j \qquad \forall\, i \epsilon I,\ \ t = 0, 1, \ldots, T-1,\ \ j \epsilon J$$

$$\sum_{a \epsilon \delta^+(n_{it}) \cup (A^O \cap A^U)} (u_{aj} - y_{aj}) \leq v_j^{max}(1 - z_{it}^j) \quad \forall\, i \epsilon I,\ \ t = 0, 1, \ldots, T-1,\ \ j \epsilon J$$

$$z_{it}^j \ \epsilon\ \{0, 1\} \qquad \forall\, i \epsilon I,\ \ t = 0, 1, \ldots, T-1,\ \ j \epsilon J$$

If z_{it}^j is 1 (idle cars can flow from that node), then all capacity must be fulfilled.

Extension to Model 1 (Model 2)

Add the following constraints to M1:

$$y_{(n_{it}, n_{i,t+1}),j} \leq v_j^{max} z_{it}^j \qquad \forall\, i \epsilon I,\;\; t = 0, 1, \ldots, T-1,\;\; j \epsilon J$$

$$\sum_{a \epsilon \delta^+(n_{it}) \cup (A^O \cap A^U)} (u_{aj} - y_{aj}) \leq v_j^{max}(1 - z_{it}^j) \qquad \forall\, i \epsilon I,\;\; t = 0, 1, \ldots, T-1,\;\; j \epsilon J$$

$$z_{it}^j \;\epsilon\; \{0, 1\} \qquad \forall\, i \epsilon I,\;\; t = 0, 1, \ldots, T-1,\;\; j \epsilon J$$

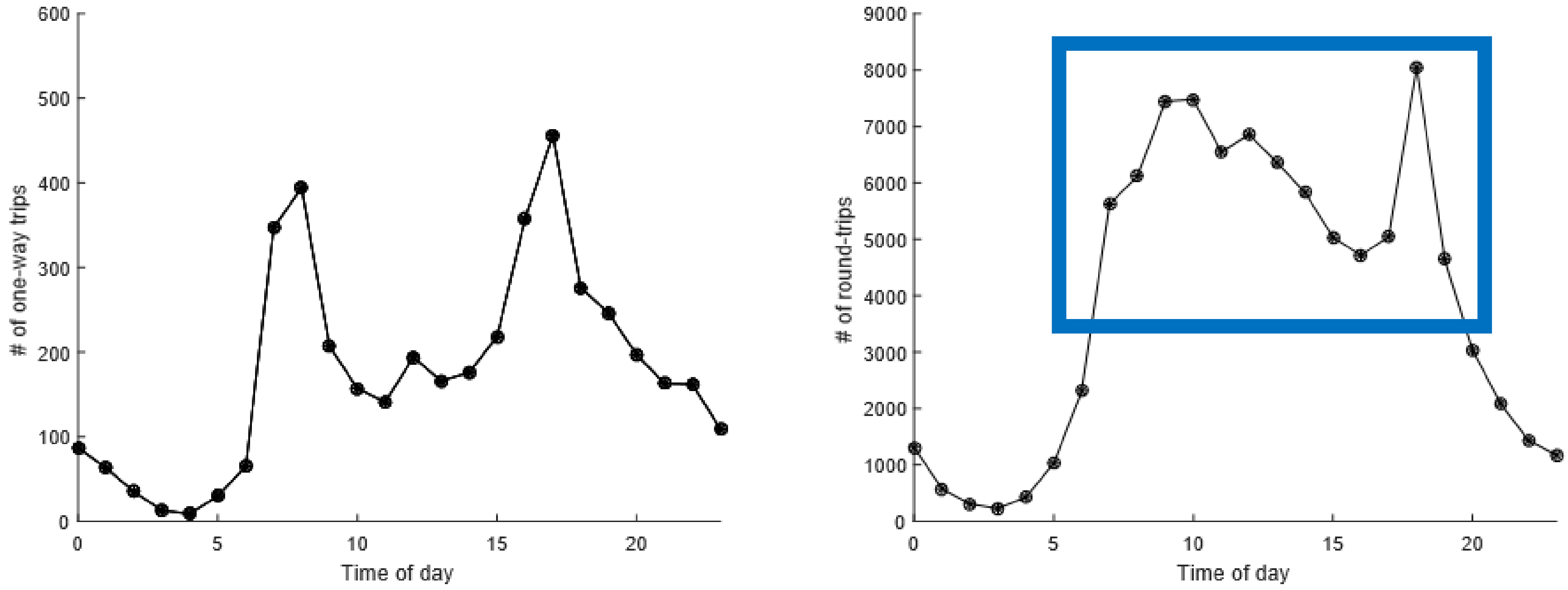
All capacity must be fulfilled to have idle cars flow from the node.

Outline

- Introduction
- Mathematical Models
- **Computational Results**
- Conclusions

Data description

- Zipcar operations for Greater Boston
- Timeframe from Oct. 1 to Nov. 30, 2014
- # of reservations made each hour for 60 zip codes



(a) One-way demand pattern

(b) Round-trip demand pattern

Car type description

- 4 sedan types
- Gasoline powered, electric, hybrid, plug-in hybrid electric

Vehicle type j	MSRP (m_j)	Revenue (r_j/r'_j)	Relocation (c^{rel})	Idle (p)	CO_2 (c_j)
Fit EV 2014	$37,445	$7.75/$12.00	$8.00	$0.4	1200 g
Fit LX 2015	$17,270	$7.75/$12.00	$8.00	$0.4	2960 g
Accord PHEV 2014	$39,780	$7.75/$12.00	$8.00	$0.4	2000 g
Accord Hybrid 2015	$29,305	$7.75/$12.00	$8.00	$0.4	2270 g

Computational efficiency

- Tests run for M1 and M2
- Vary one-way demand
- M1 significantly faster than M2

*Use Python + Gurobi 6.0.3, Intel(R) Core(TM) i5-4200U CPU with 6GM RAM

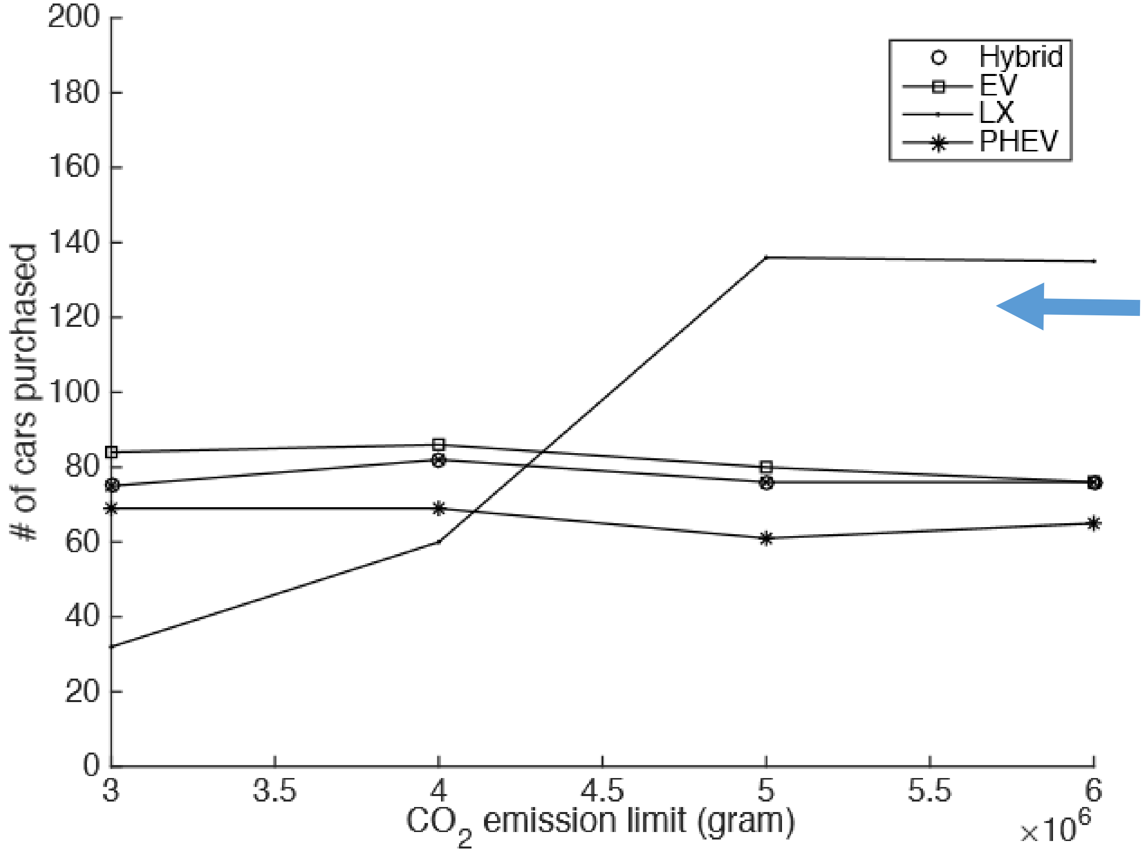
One-Way Proportion	0%	40%	80%	100%
CPU Time	61.44*	39.39	52.77	63.59
Optimal Objective Value	$16,709.95	$17,382.00	$20,779.70	$21,732.05

*: The best optimality gap = 0.031% is achieved.

One-Way Proportion	0%	40%	80%	100%
CPU Time	169.33	233.55	998.31	91.54
Optimal Objective Value	$16,701.15	$17,371.20	$20,732.25	$21,732.05

Carbon emissions constraint

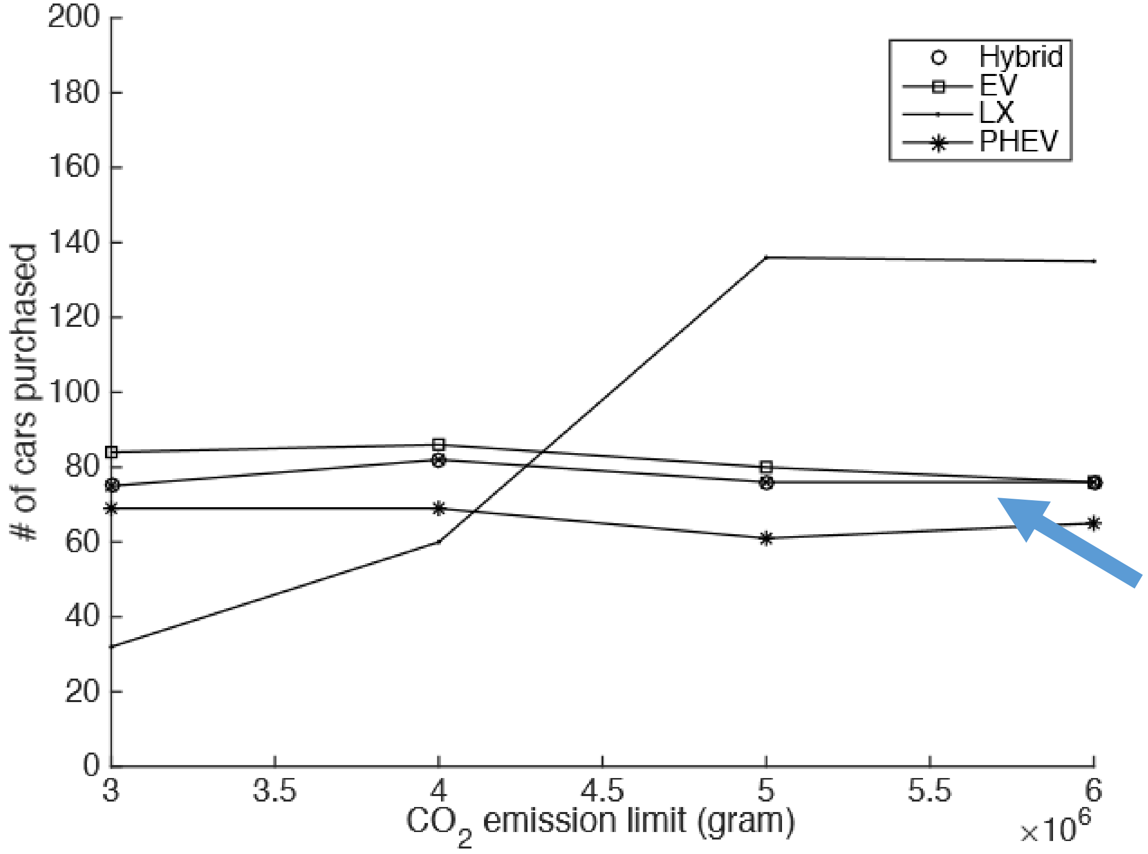
- Vary carbon emission constraint between 3×10^6 and 6×10^6 grams
- Demand: 40% LX, 20% Hybrid, 20% PHEV, 20% EV



Gasoline-powered

Carbon emissions constraint

- Vary carbon emission constraint between 3 x 10^6 and 6 x 10^6 grams
- Demand: 40% LX, 20% Hybrid, 20% PHEV, 20% EV



Non-gasoline powered

Quality of Service (QoS)

- Vary one-way proportion between 0%, 40%, 80%, 100%
- M1 enforces high QoS and FCFS principle
- Deny trip percentage between 0.1% and 1%

One-Way Proportion	Unfulfilled Rentals	Unfulfilled Rentals (%)	Denied Trip (%)	Idle Vehicle Hours	Vehicle Utilization
0%	164	15.43%	1.03%	1412	61.22%
40%	53	5.74%	0.76%	1690	56.48%
80%	44	4.84%	1.65%	1667	56.82%
100%	10	1.14%	0.11%	1653	57.43%

Quality of Service (QoS)

- Vary one-way proportion between 0%, 40%, 80%, 100%
- M1 enforces high QoS and FCFS principle
- Deny trip percentage between 0.1% and 1%

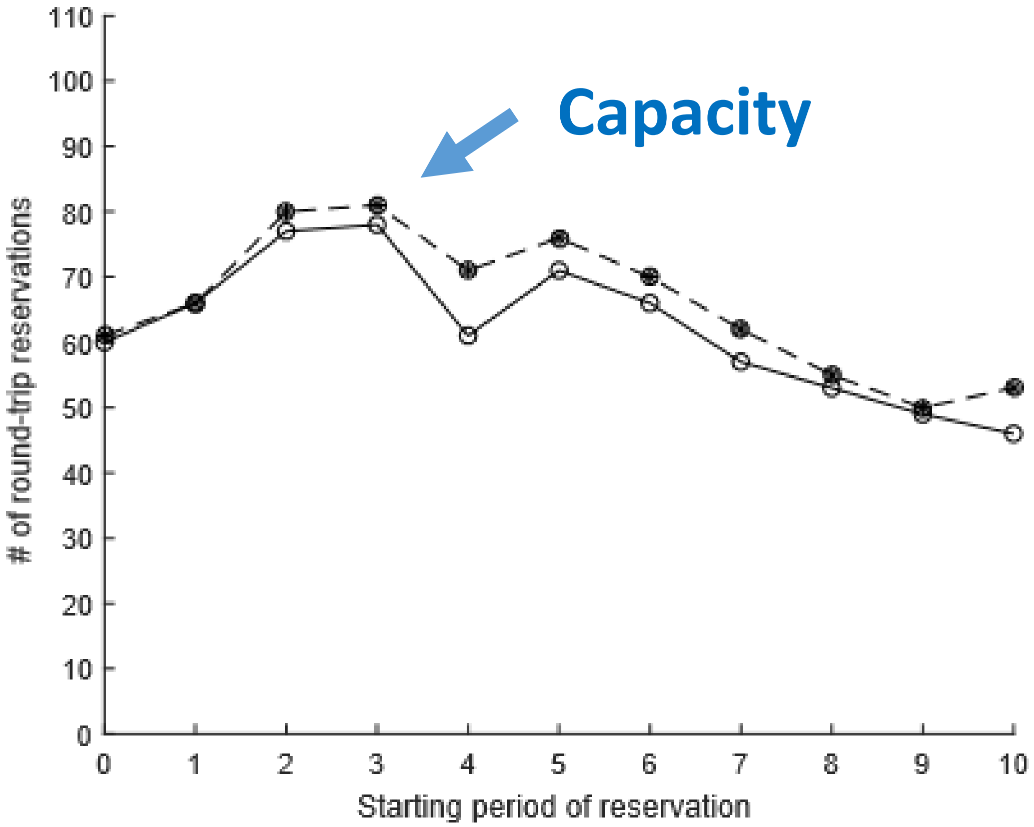
One-Way Proportion	Unfulfilled Rentals	Unfulfilled Rentals (%)	Denied Trip (%)	Idle Vehicle Hours	Vehicle Utilization
0%	164	15.43%	1.03%	1412	61.22%
40%	53	5.74%	0.76%	1690	56.48%
80%	44	4.84%	1.65%	1667	56.82%
100%	10	1.14%	0.11%	1653	57.43%

Quality of Service (QoS)

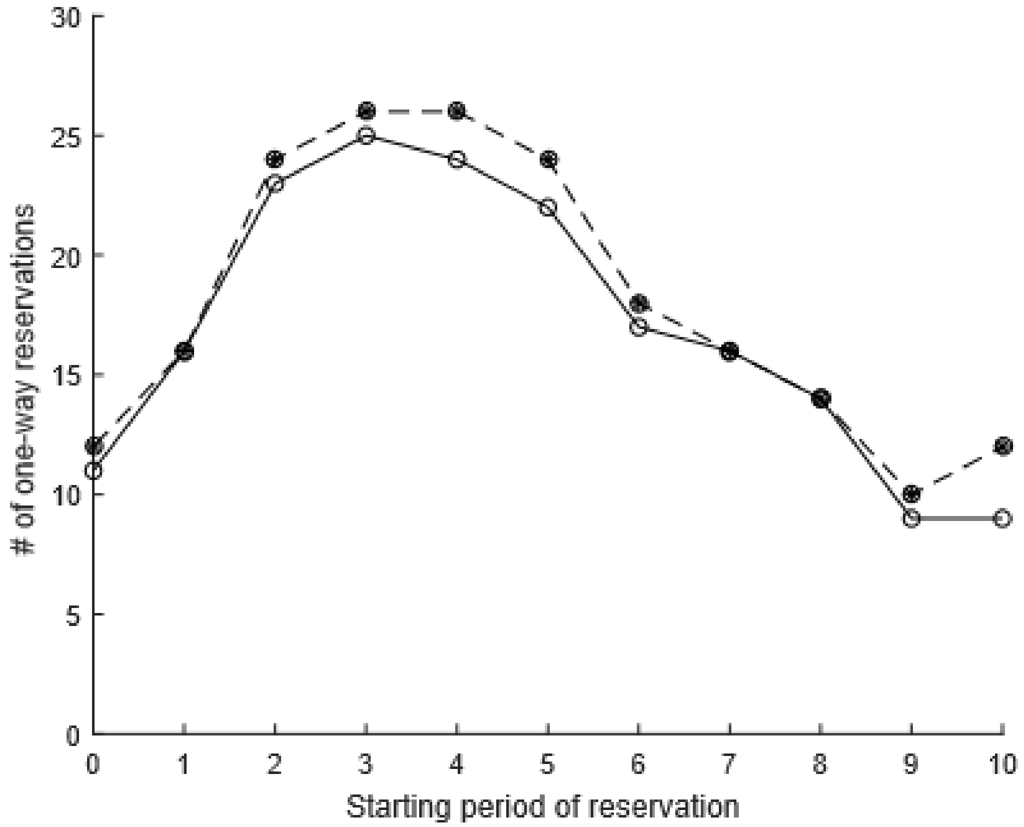
- Vary one-way proportion between 0%, 40%, 80%, 100%
- M1 enforces high QoS and FCFS principle
- Deny trip percentage between 0.1% and 1%

One-Way Proportion	Unfulfilled Rentals	Unfulfilled Rentals (%)	Denied Trip (%)	Idle Vehicle Hours	Vehicle Utilization
0%	164	15.43%	1.03%	1412	61.22%
40%	53	5.74%	0.76%	1690	56.48%
80%	44	4.84%	1.65%	1667	56.82%
100%	10	1.14%	0.11%	1653	57.43%

Trip fulfillment for 40% one-way setting

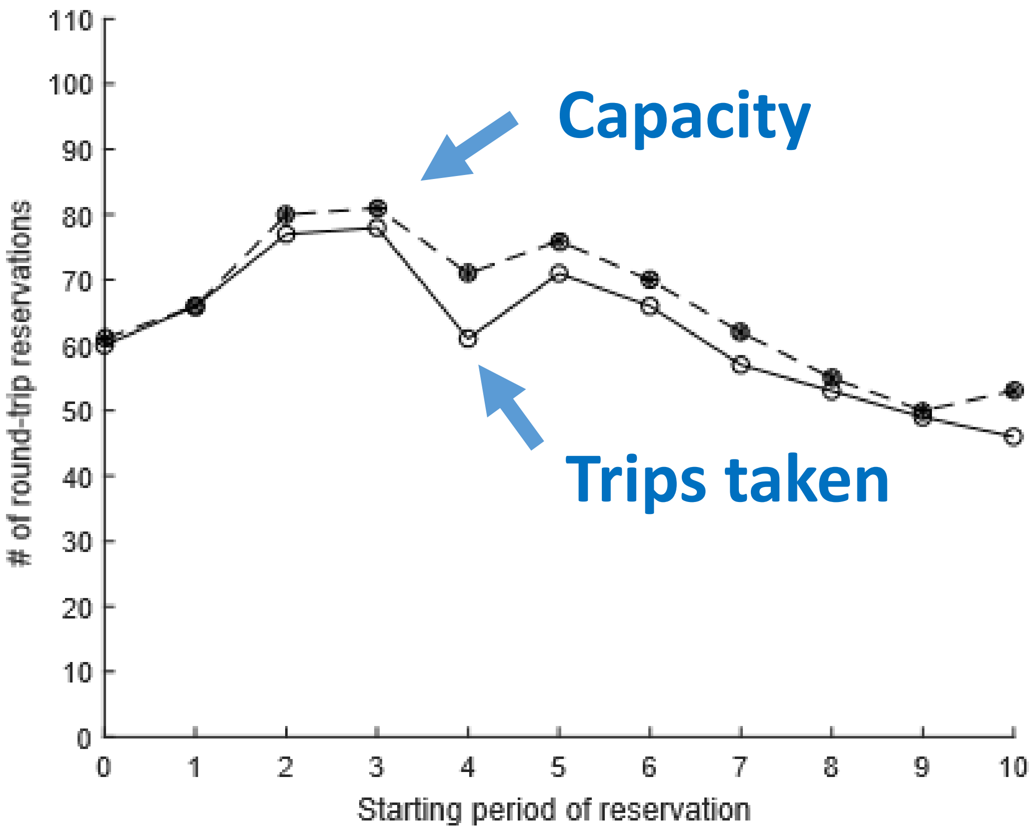


(a) Round-trip

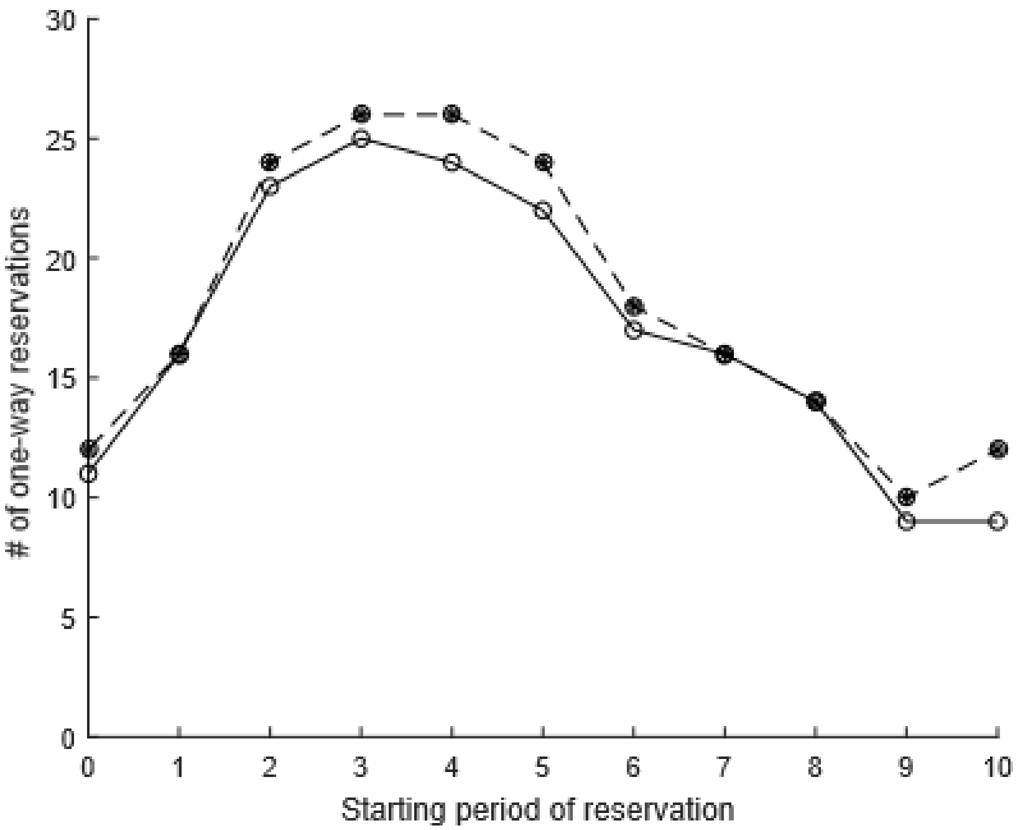


(b) One-way

Trip fulfillment for 40% one-way setting



(a) Round-trip



(b) One-way

Outline

- Introduction
- Mathematical Models
- Computational Results
- **Conclusions**

Conclusions

Carsharing companies want to

- Expand market demographic
- Provide reliable service
- Benefit environment by lowering carbon emissions

Our model

- Determines diverse vehicle portfolio
- Enforces high QoS and first-come first-serve principle
- Enforces carbon emissions constraints while still maximizing profit

The future: service-based transportation

- Ford’s expanded business plan is to be “both an auto *and* a mobility company”
- General Motors invested $500 million in Lyft, a ridesharing service

- Future work:

  Developing more strategies to expand ridesharing services

  Integrating shared autonomous vehicles into daily life

Questions?