



Understanding the Impact of Parking on Urban Mobility via Routing Games on Queue-Flow Networks

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Lillian Ratliff (Univ. of Washington)

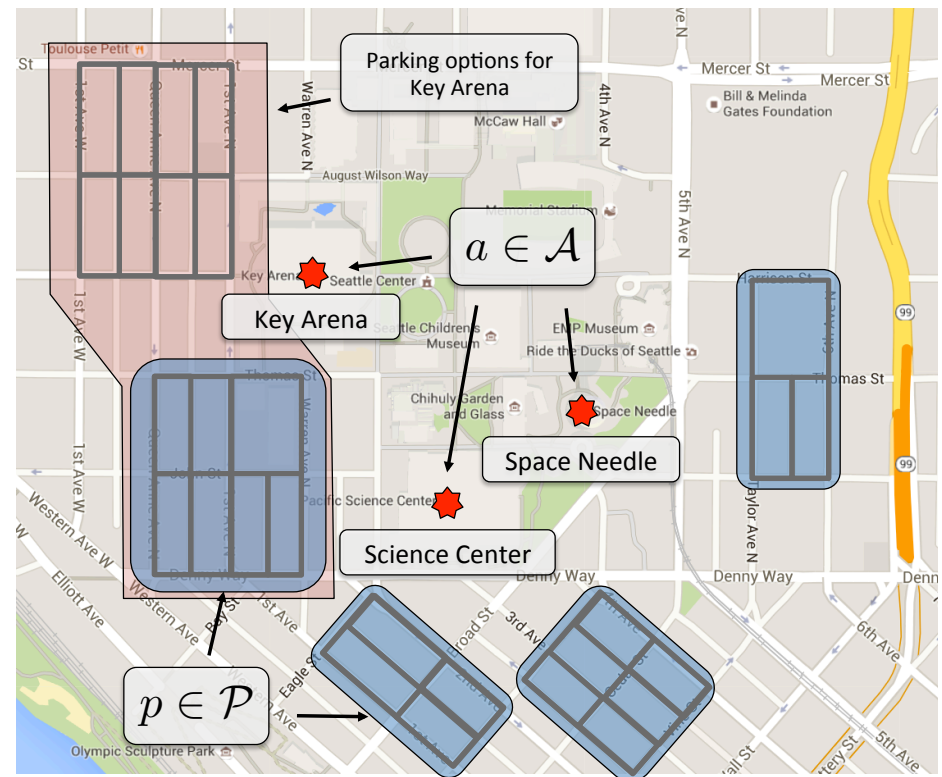
June 9, 2016



Urban Street Parking

Seattle Center in Downtown Seattle

Studies estimate on average, **30%** of congestion in urban areas is due to circling traffic.[1]

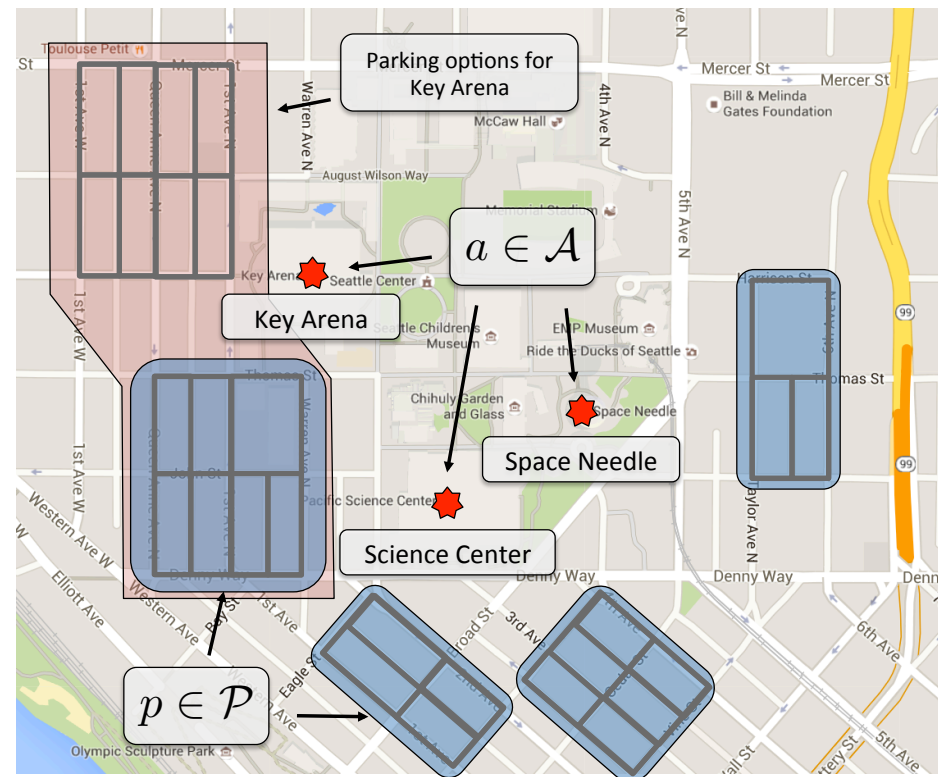


[1] Shoup, Donald C. "Cruising for parking." Transport Policy 13.6 (2006): 479-486.

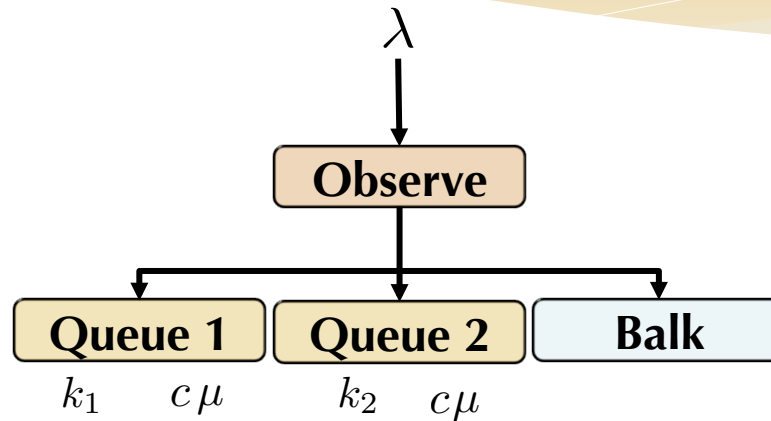
Overview

- * Observable Queuing Game
- * Queue-Routing Game
 - * Example 1: Downtown Seattle
 - * Example 2: Amazon

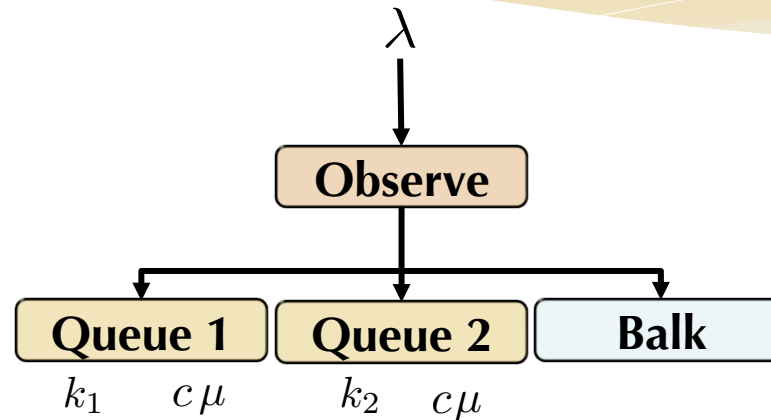
Seattle Center in Downtown Seattle



Observable Queuing Game

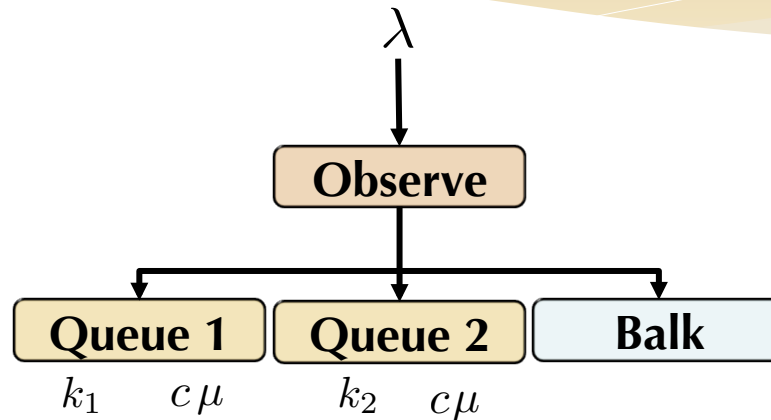


Observable Queuing Game



Expected Utility: $U(k) = R - \frac{C_w(k+1)}{\mu c} - \frac{C_T}{\mu} \quad U_B = 0$

Observable Queuing Game

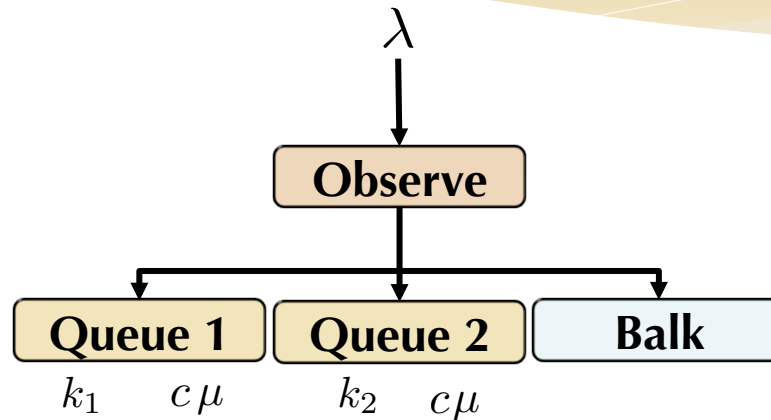


Expected Utility: $U(k) = R - \frac{C_w(k+1)}{\mu c} - \frac{C_T}{\mu}$ $U_B = 0$

Balking Level: $n_b = \left\lfloor \frac{(R\mu - C_T)c}{C_w} \right\rfloor$

If k_1 or k_2 are $\leq n_b$ the arriving customer will enter a queue otherwise they will balk.

Observable Queuing Game



Expected Utility: $U(k) = R - \frac{C_w(k+1)}{\mu c} - \frac{C_T}{\mu} \quad U_B = 0$

Balking Level: $n_b = \left\lfloor \frac{(R\mu - C_T)c}{C_w} \right\rfloor$

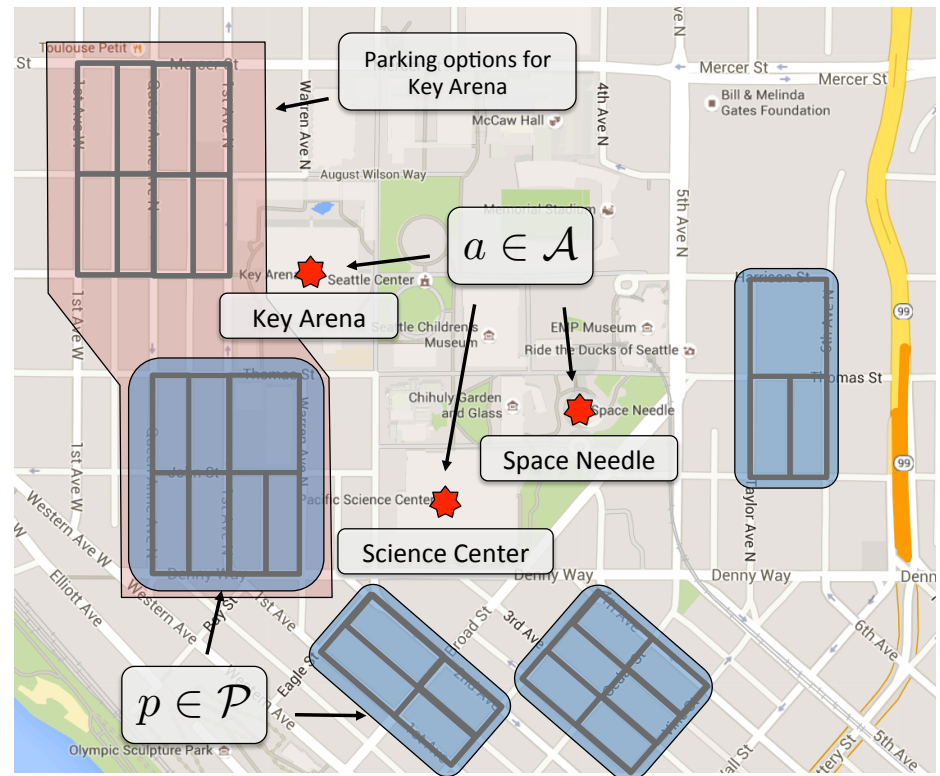
If k_1 or k_2 are $\leq n_b$ the arriving customer will enter a queue otherwise they will balk.

Continuous Version: $U(k) = R - \frac{C_w(k+1)}{\mu c} - \frac{C_T}{\mu} \quad \Rightarrow \quad C(x) = -R + \frac{C_w x}{\mu c} + \frac{C_T}{\mu}$

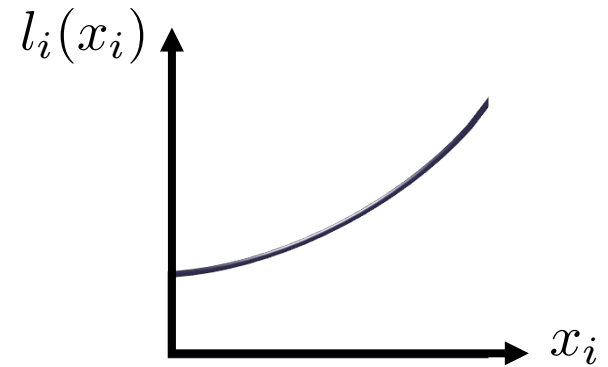
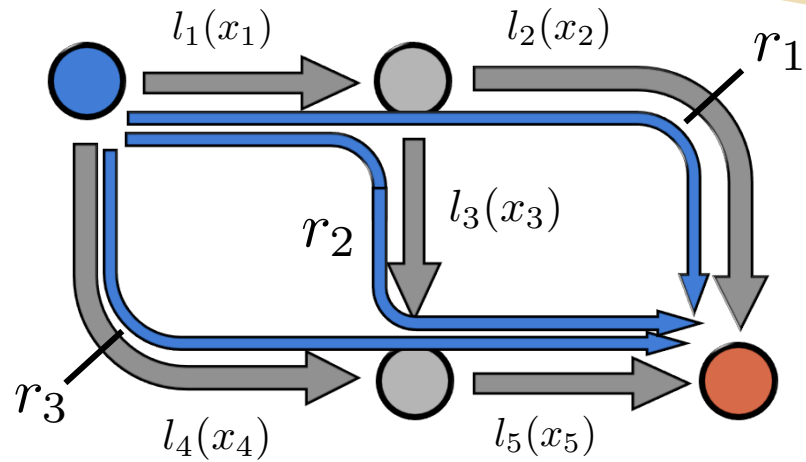
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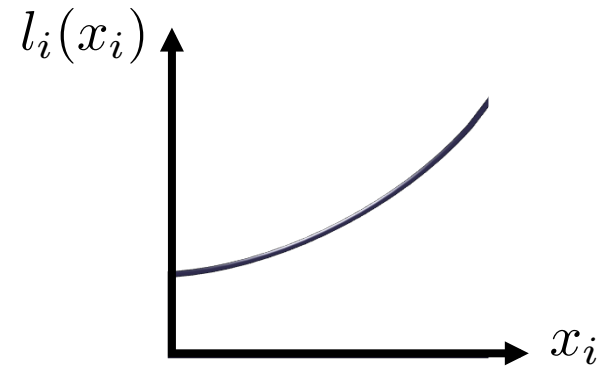
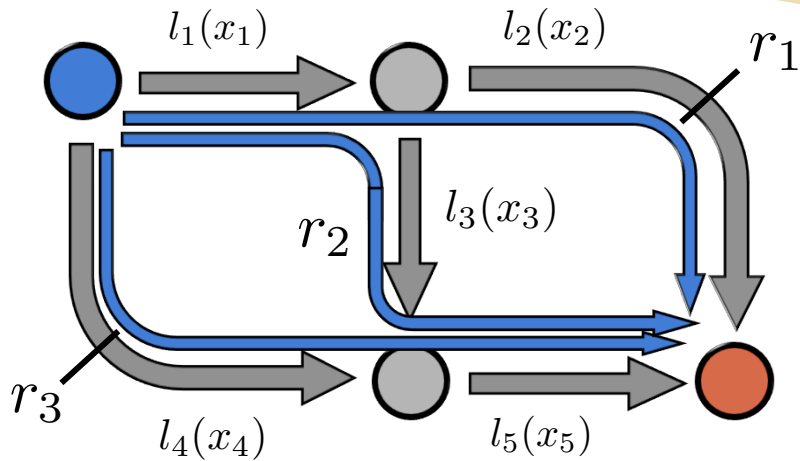
Seattle Center in Downtown Seattle



Classic Routing Game



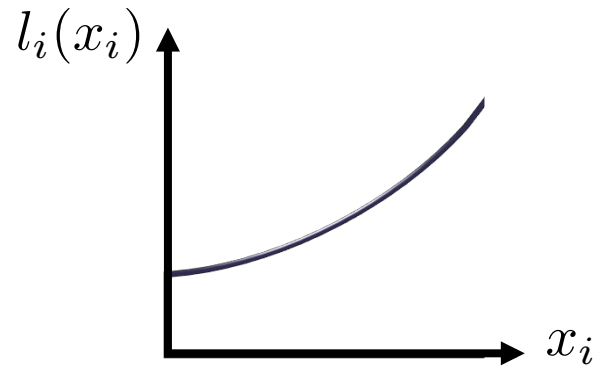
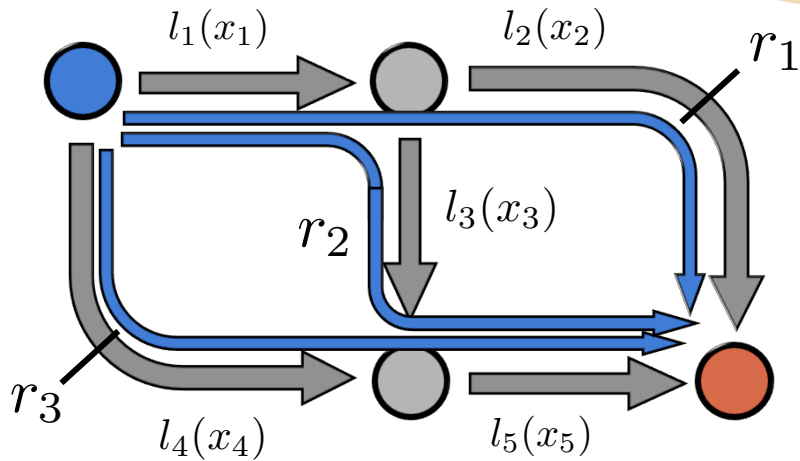
Classic Routing Game



Potential Function
$$P(x) = \sum_e \int_0^{x_e} l_e(u) du$$

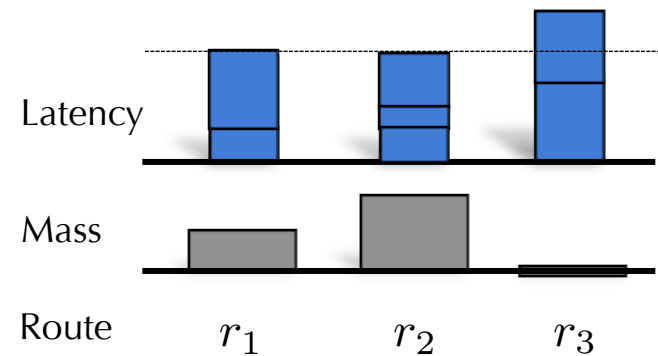
$$\nabla_x P(x) = l(x)$$

Classic Routing Game

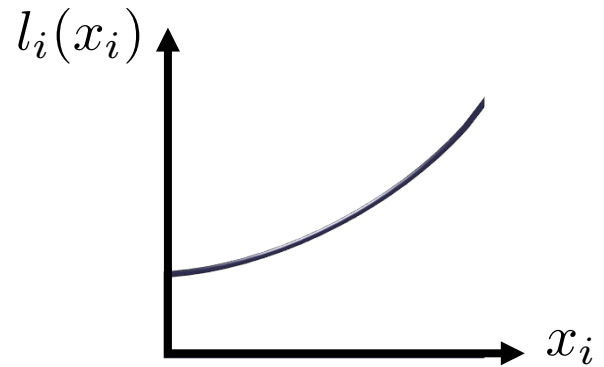
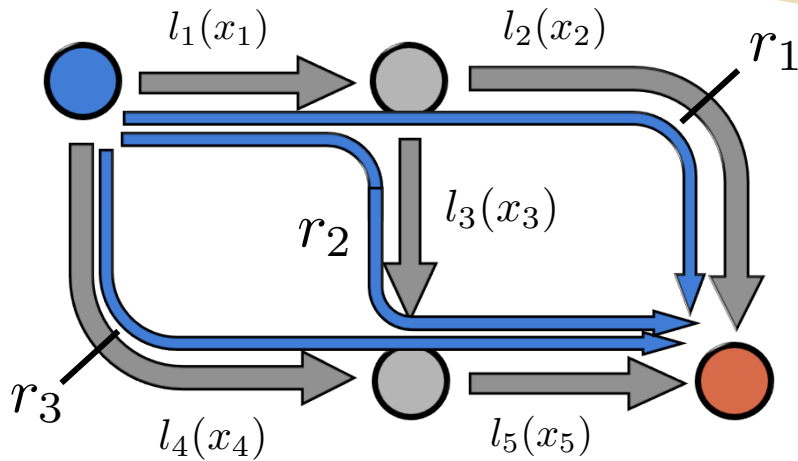


Potential Function
$$P(x) = \sum_e \int_0^{x_e} l_e(u) du$$

$$\nabla_x P(x) = l(x)$$



Classic Routing Game



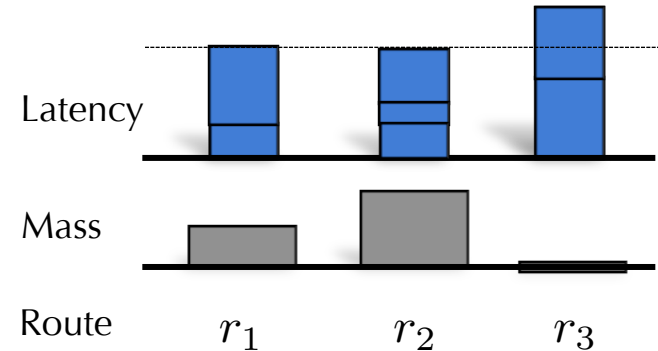
Potential Function
$$P(x) = \sum_e \int_0^{x_e} l_e(u) du$$

Equilibrium Condition

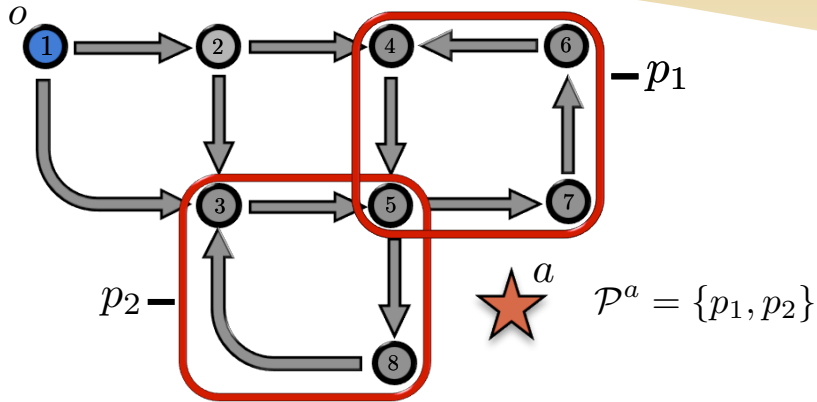


$$\nabla_x P(x) = l(x)$$

Wardrop Equilibrium



Queue-Routing Game



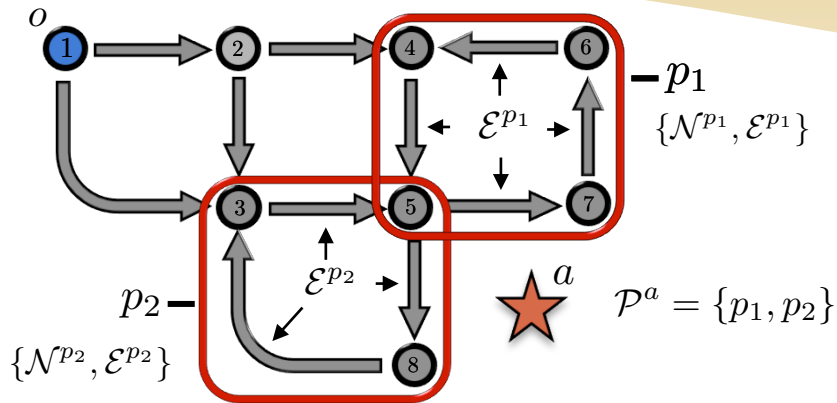
Strategy

Parking Area

Area 1

Area 2

Queue-Routing Game



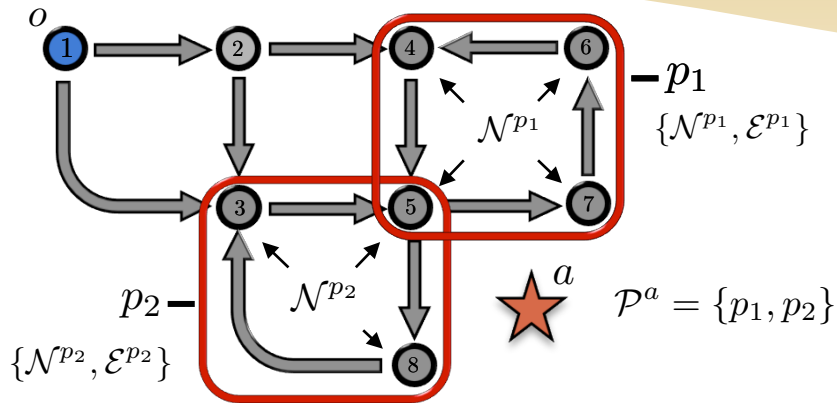
Strategy

Parking Area

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Queue-Routing Game



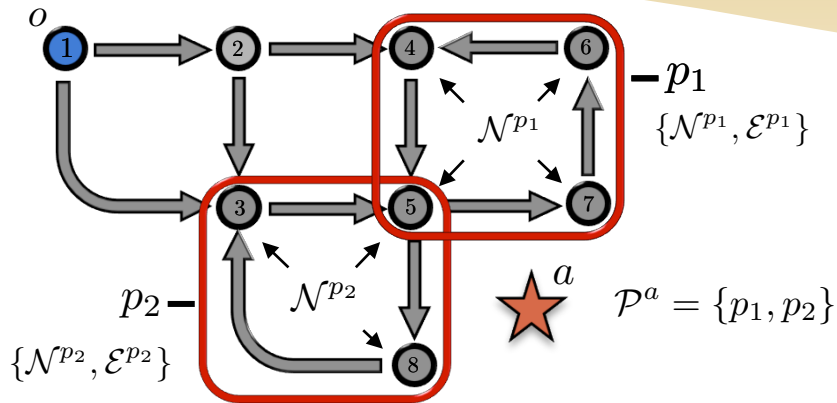
Strategy

Parking Area

Area 1

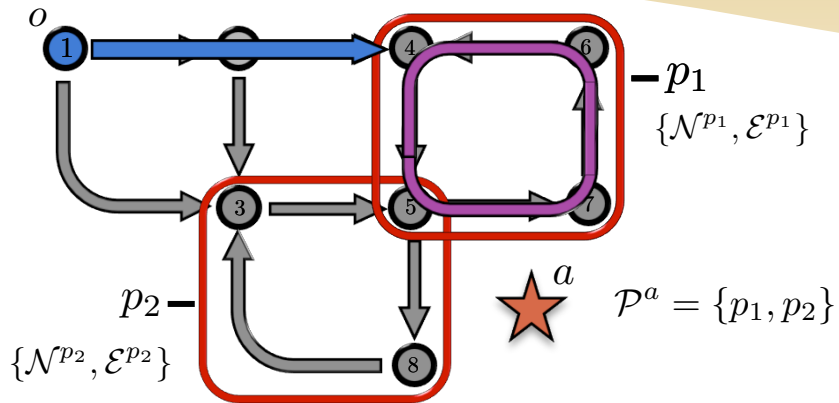
Area 2

Queue-Routing Game



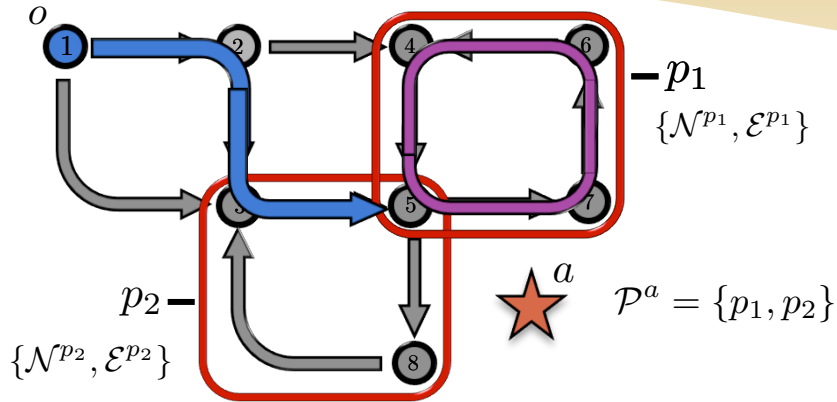
| | | | | | |
|----------|--------------|--------|---|--------|---|
| Strategy | Node | 4 | 5 | 5 | 3 |
| | Parking Area | Area 1 | | Area 2 | |

Queue-Routing Game



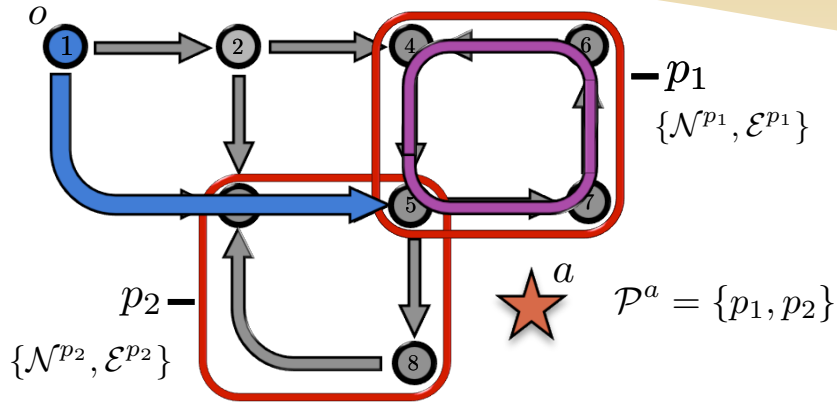
| | | | | | |
|----------|--------------|---|--------|--------|---|
| Strategy | Path to Node | ↑ | | | |
| | Node | 4 | 5 | 5 | 3 |
| | Parking Area | | Area 1 | Area 2 | |

Queue-Routing Game



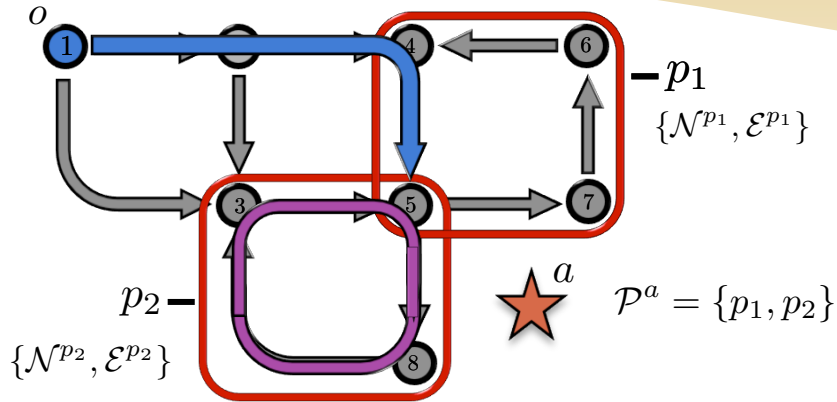
| | | | | | |
|----------|--------------|---|--------|--------|---|
| Strategy | Path to Node | ↑ | ↑ | ↑ | |
| | Node | 4 | 5 | 5 | 3 |
| | Parking Area | | Area 1 | Area 2 | |

Queue-Routing Game



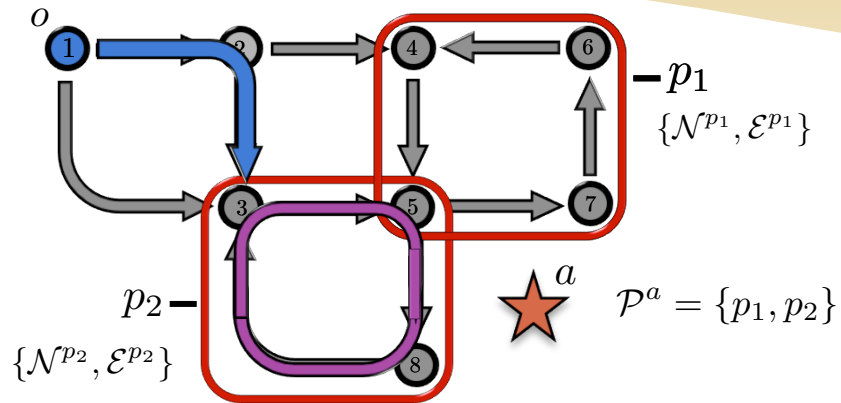
| | | | | | | |
|----------|--------------|--------|---|--------|---|--|
| Strategy | Path to Node | ↑ | ↑ | ↑ | | |
| | Node | 4 | 5 | 5 | 3 | |
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Queue-Routing Game



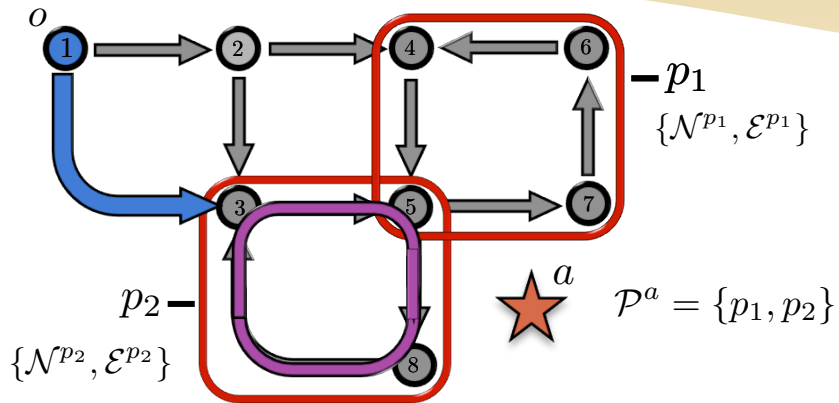
| | | | | | | |
|----------|--------------|--------|---|--------|---|--|
| Strategy | Path to Node | ↑ | ↑ | ↑ | ↑ | |
| | Node | 4 | 5 | 5 | 3 | |
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Queue-Routing Game



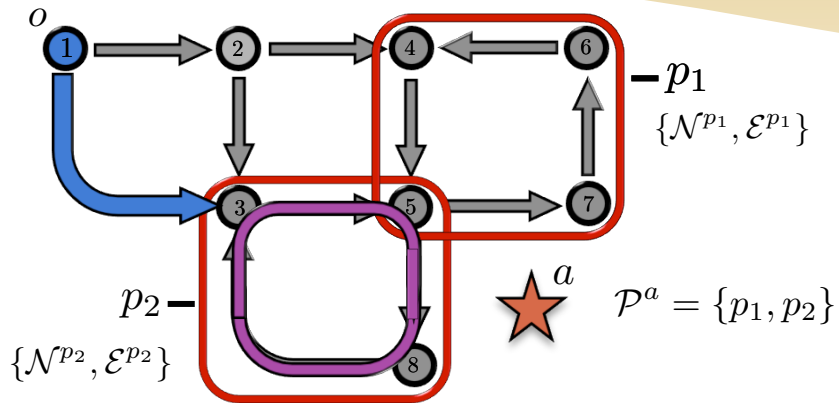
| | | | | | | | |
|----------|--------------|--------|---|---|--------|---|---|
| Strategy | Path to Node | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ |
| | Node | 4 | 5 | 5 | 5 | 3 | 3 |
| | Parking Area | Area 1 | | | Area 2 | | |

Queue-Routing Game



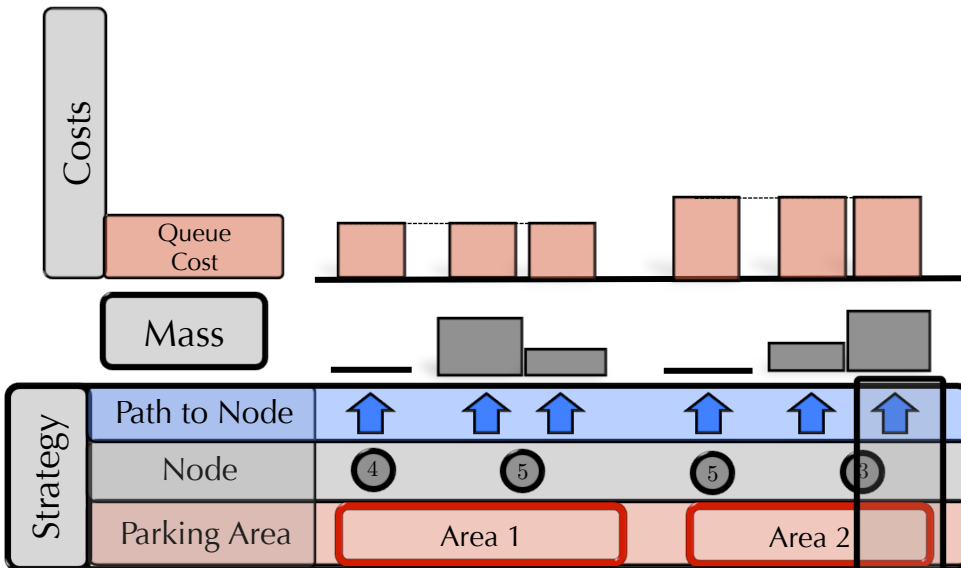
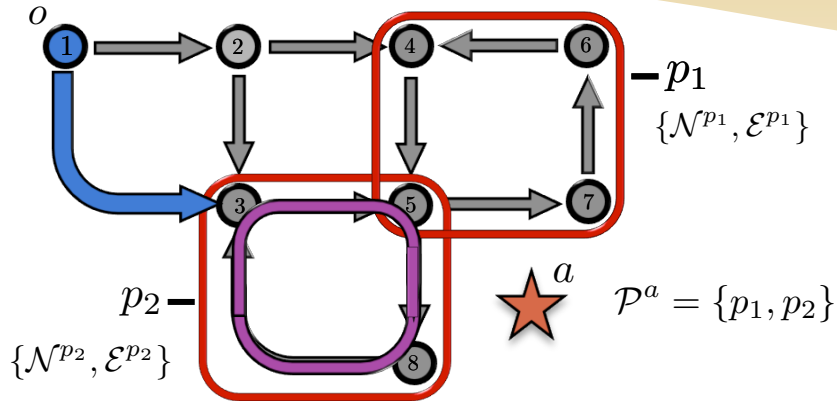
| | | | | | | | |
|----------|--------------|--------|---|--------|---|---|---|
| Strategy | Path to Node | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ |
| | Node | 4 | 5 | 5 | 3 | | |
| | Parking Area | Area 1 | | Area 2 | | | |

Queue-Routing Game

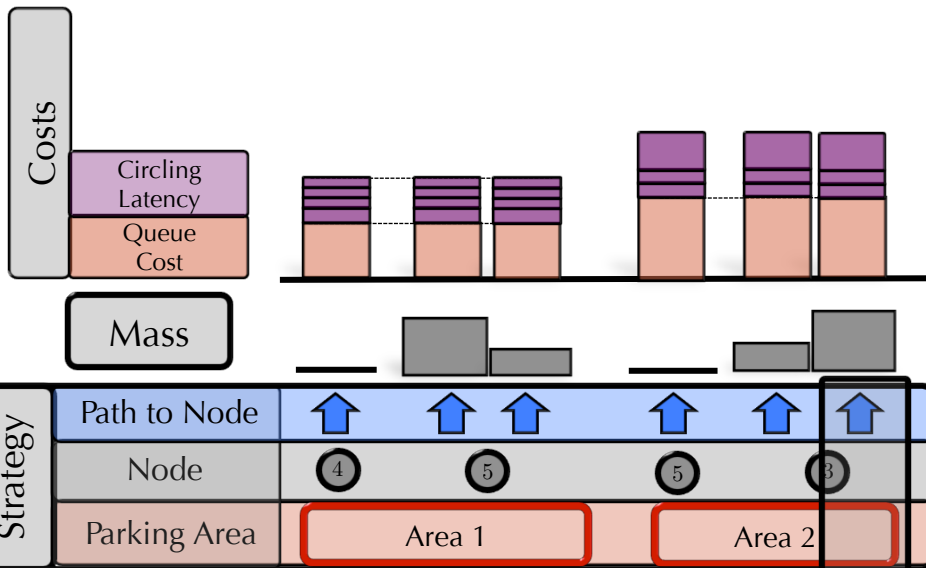
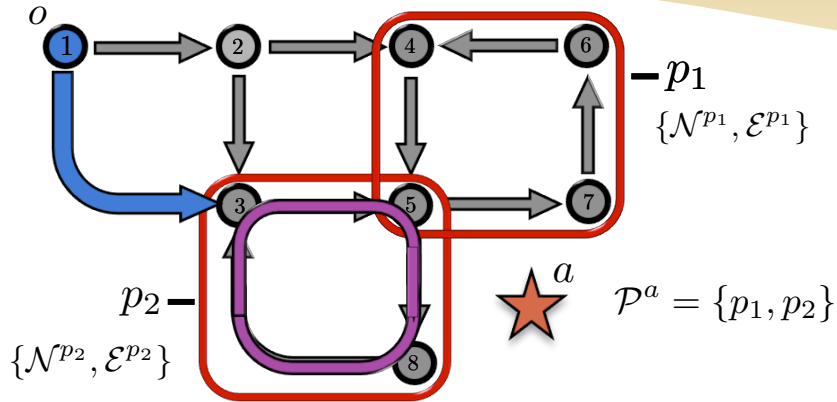


| | | | | | | |
|----------|--------------|--------|---|--------|---|---|
| | Mass | | | | | |
| Strategy | Path to Node | ↑ | ↑ | ↑ | ↑ | ↑ |
| | Node | 4 | 5 | 5 | 3 | |
| | Parking Area | Area 1 | | Area 2 | | |

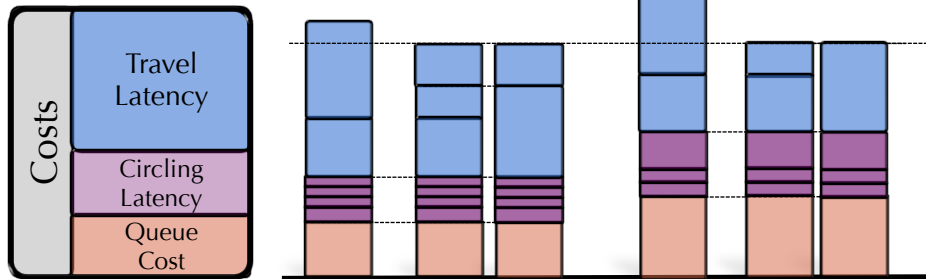
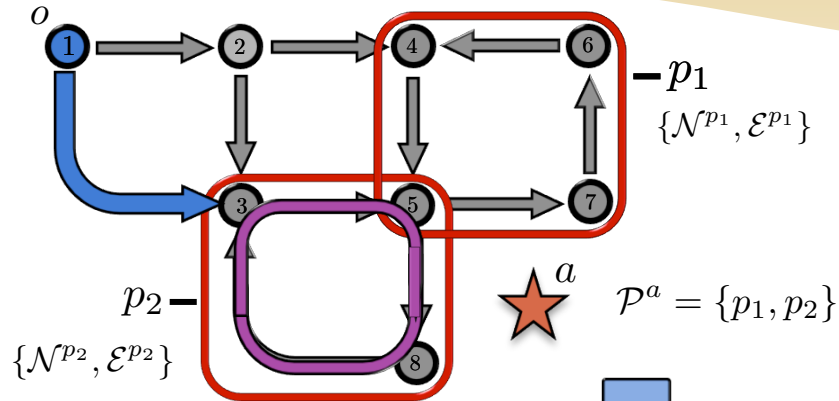
Queue-Routing Game



Queue-Routing Game

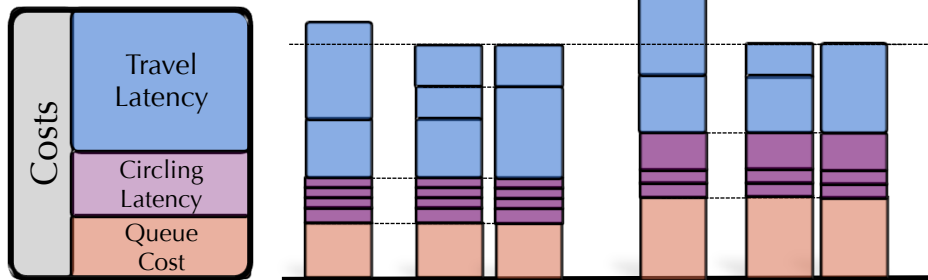
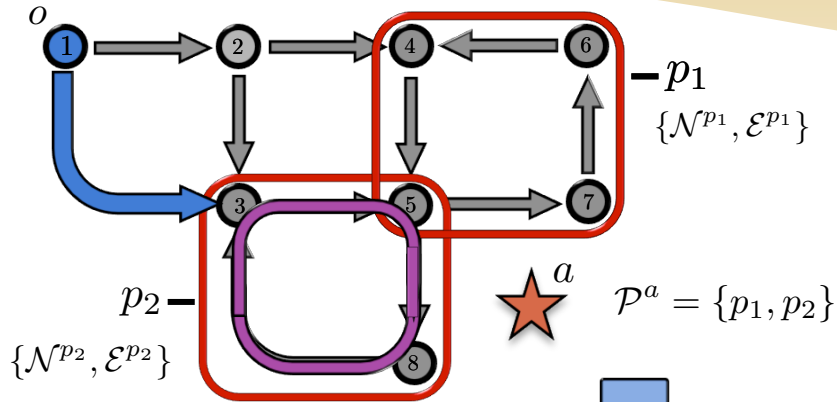


Queue-Routing Game



| Mass | | Mass Distribution | | | | | |
|----------|--------------|-------------------|---|---|--------|---|---|
| Strategy | Path to Node | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ |
| | Node | 4 | 5 | 5 | 5 | 3 | 3 |
| | Parking Area | Area 1 | | | Area 2 | | |

Queue-Routing Game



Equilibrium Condition



Mass

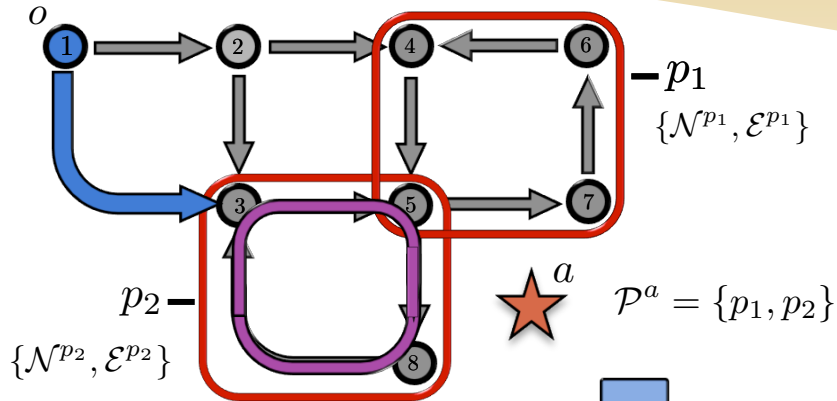


Queue-Routing Wardrop Equilibrium



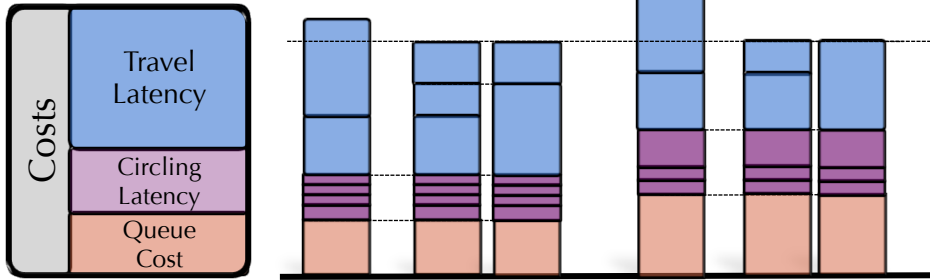
| Strategy | Path to Node | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ |
|----------|--------------|--------|---|--------|---|---|---|
| | Node | 4 | 5 | 5 | 5 | 3 | 3 |
| | Parking Area | Area 1 | | Area 2 | | | |

Queue-Routing Game



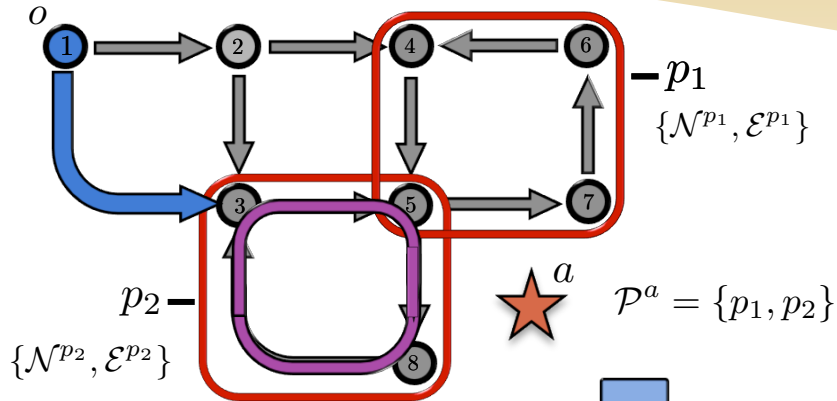
Potential Function

$$P(x) = \sum_e \int_0^{x_e} l_e(u) du + \sum_p \int_0^{s^p} C^p(u) du$$



| | | | | | | | |
|----------|--------------|--------|---|--------|---|---|---|
| Strategy | Path to Node | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ |
| | Node | 4 | 5 | 5 | 5 | 3 | 3 |
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Queue-Routing Game



Potential Function

$$P(x) = \sum_e \int_0^{x_e} l_e(u) du + \sum_p \int_0^{s^p} C^p(u) du$$

Gradient...

$$\nabla_x P = l(x)$$

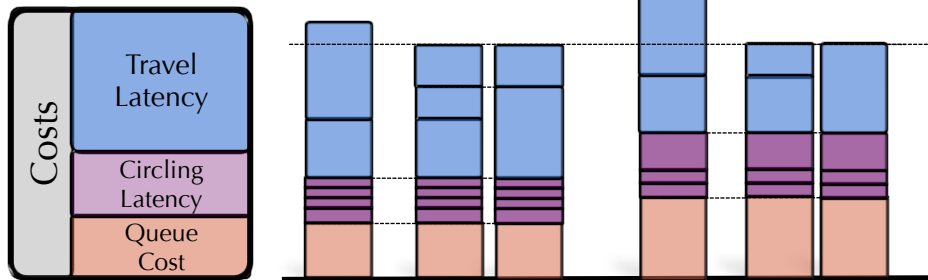
$$\nabla_{s^p} P = \frac{1}{|\mathcal{E}^p|} l(x) \mathbf{E}^p$$

$$+ C^p(s^p)$$

Travel Latency

Circling Latency

Queue Cost

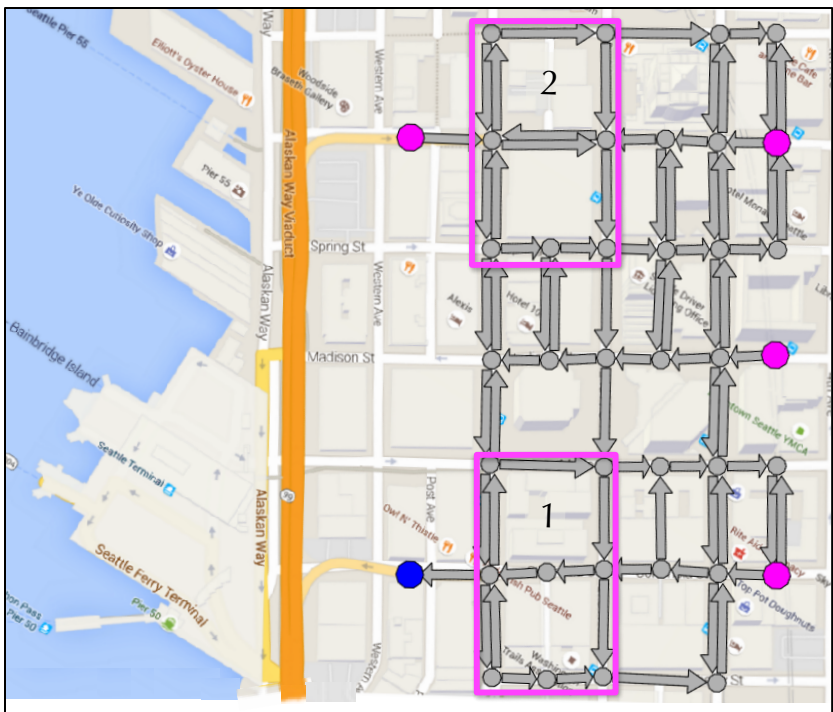


Mass

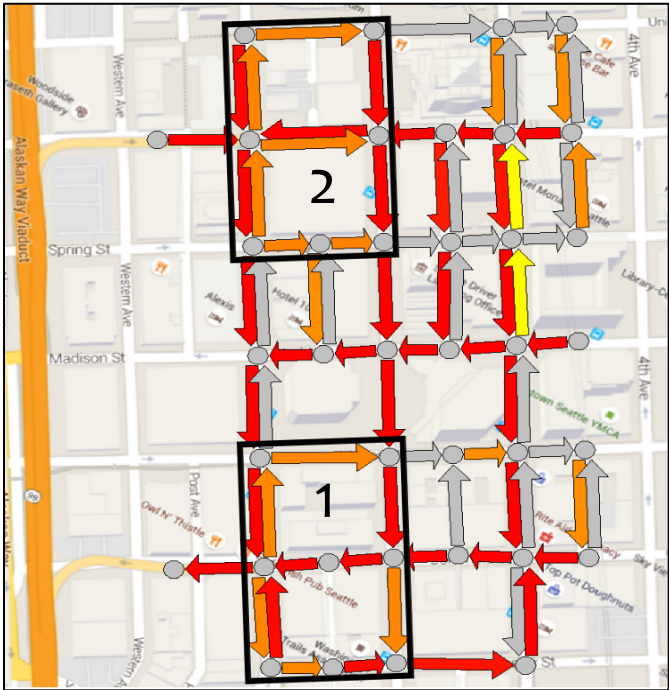


| | | | | | | | |
|----------|--------------|--------|---|--------|---|---|---|
| Strategy | Path to Node | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ |
| | Node | 4 | 5 | 5 | 5 | 3 | 3 |
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Example 1: Rush-Hour in Downtown Seattle

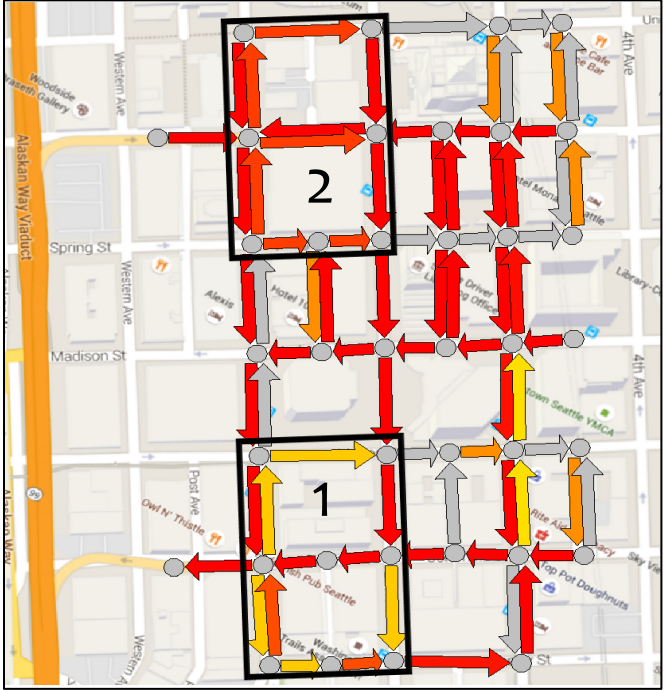


Example 1: Rush-Hour in Downtown Seattle



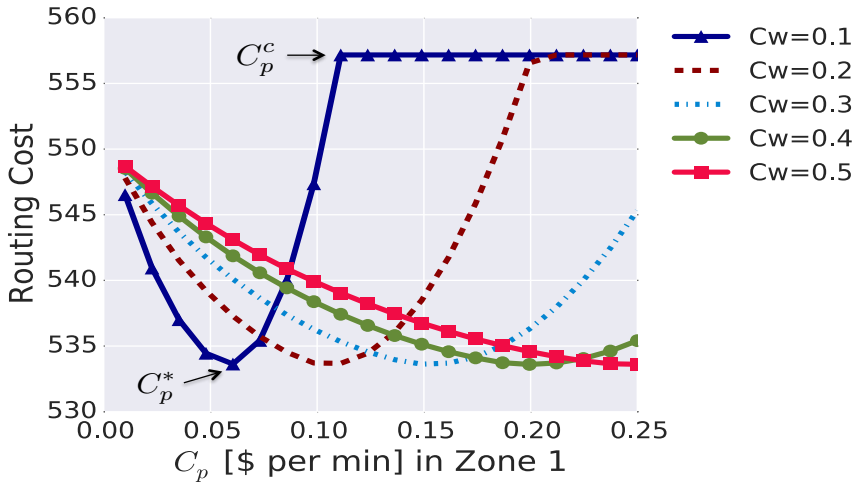
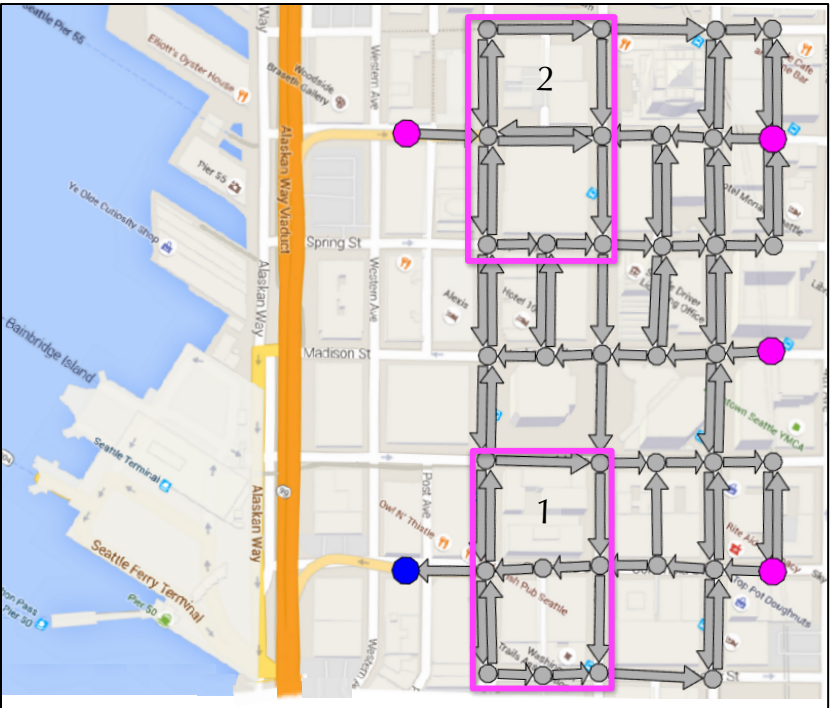
Area 1:
Area 2:

$\$0.01/min$
 $\$0.01/min$

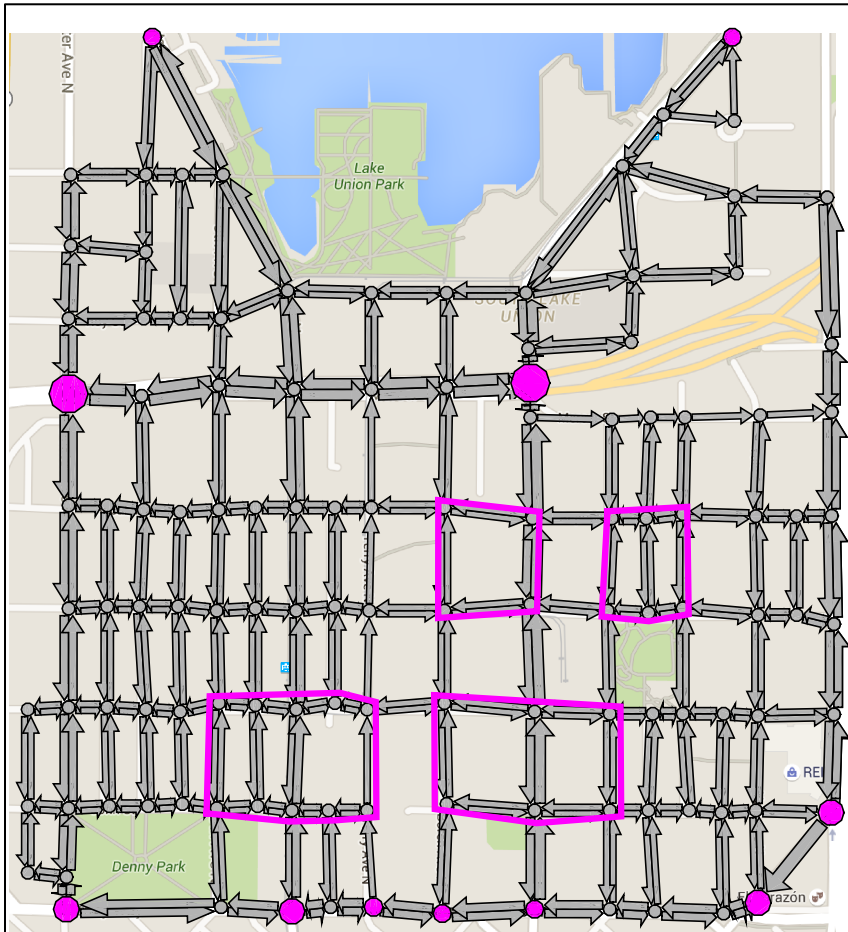


$\$0.2/min$
 $\$0.01/min$

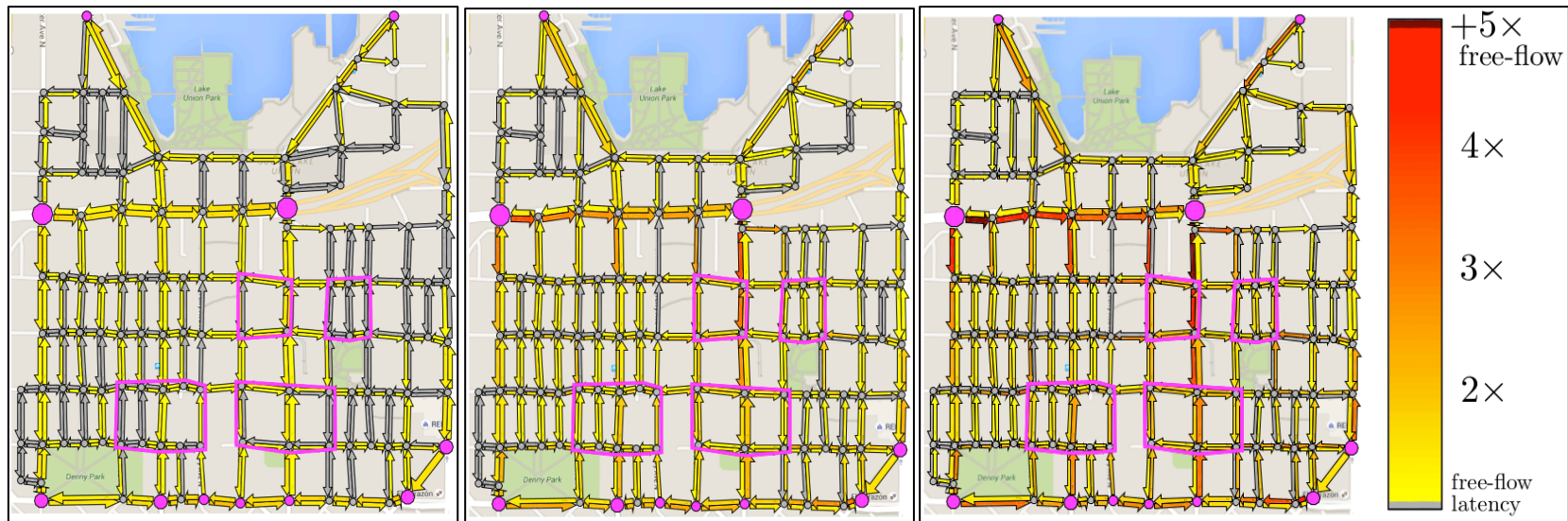
Example 1: Rush-Hour in Downtown Seattle



Example 2: Parking around Amazon campus



Example 2: Parking around Amazon campus



Population Sizes (cars/min):

Parking: 0

150

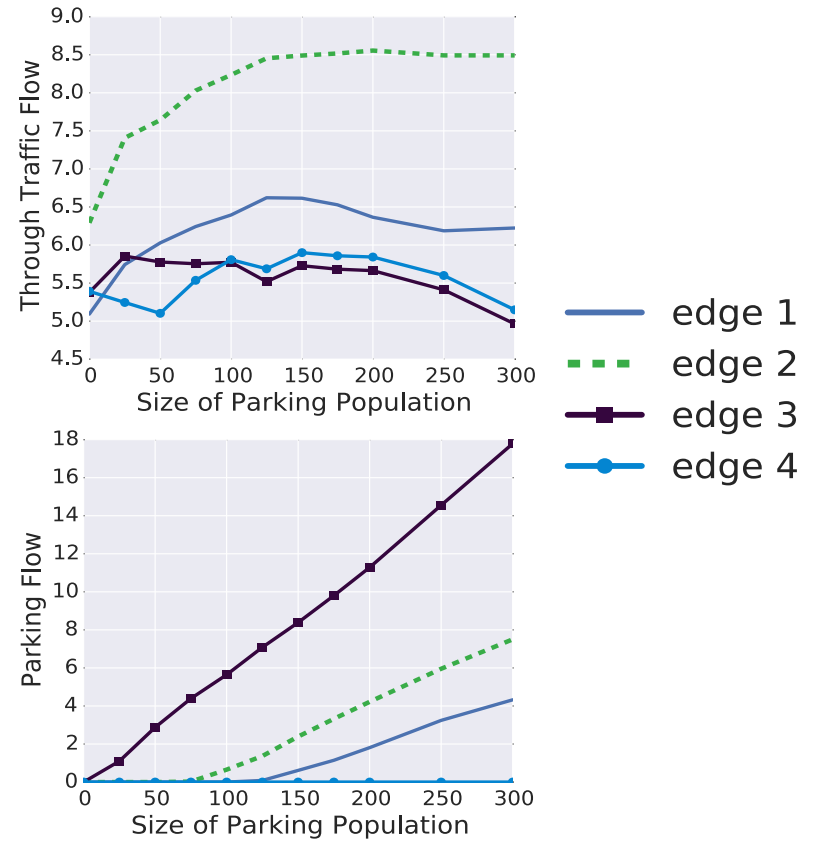
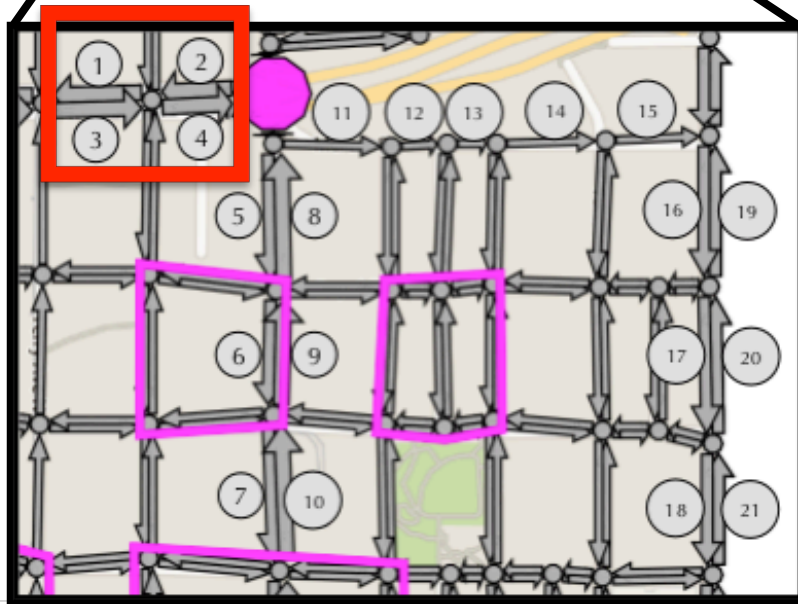
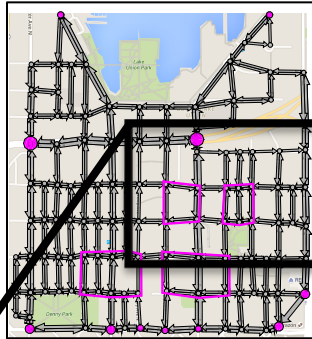
300

Thru Traffic: 75

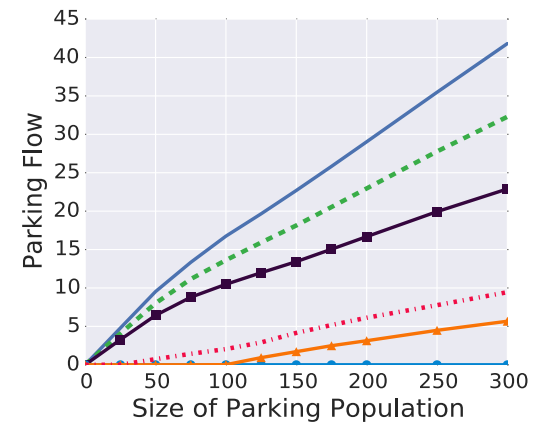
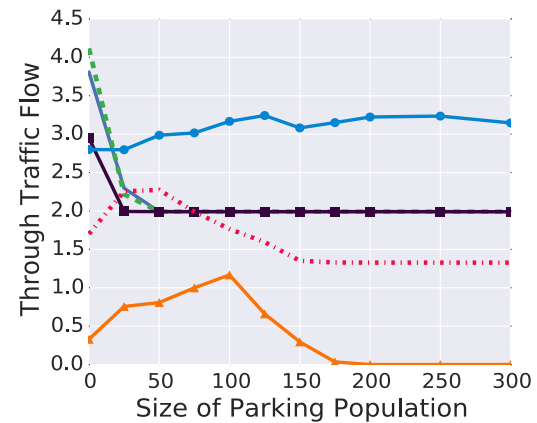
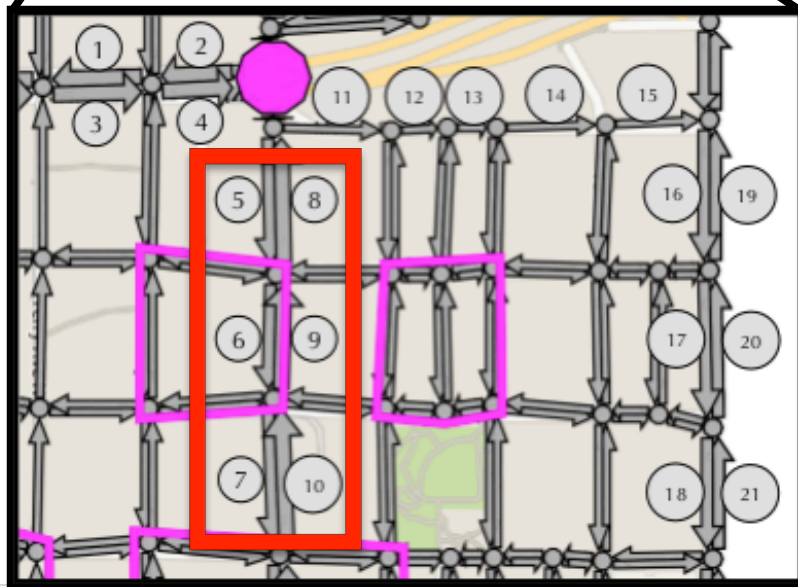
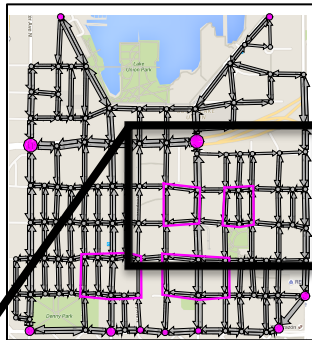
75

75

Example 2: Parking around Amazon campus

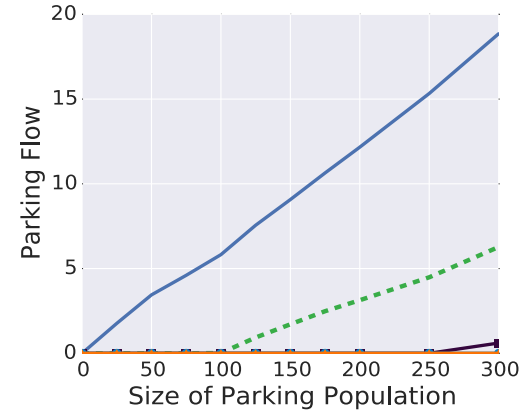
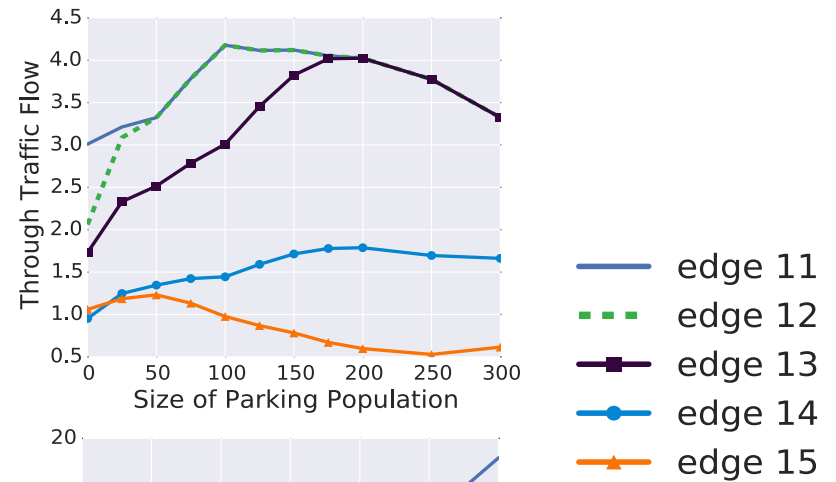
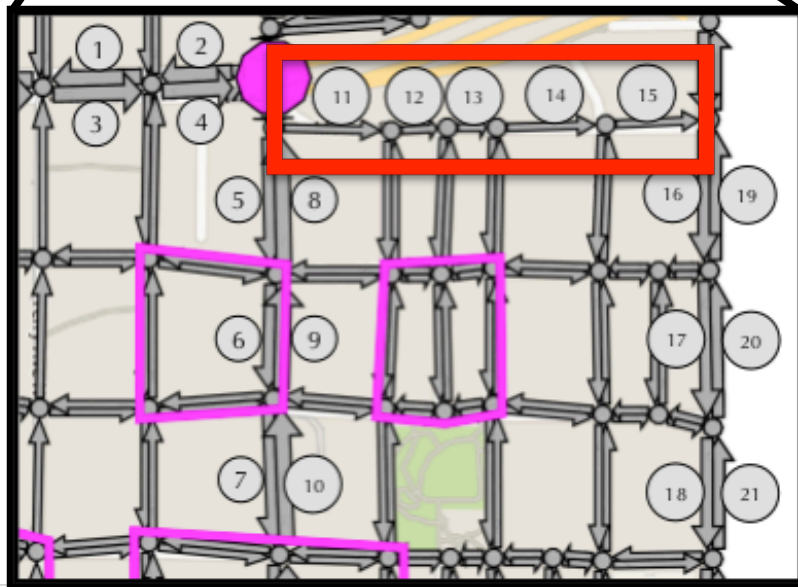
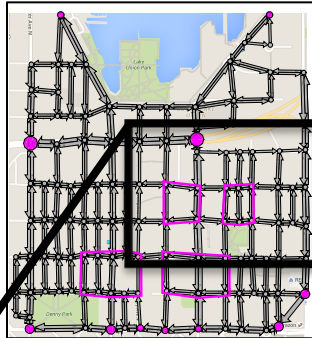


Example 2: Parking around Amazon campus



- edge 5
- - - edge 6
- edge 7
- edge 8
- ▲- edge 9
- ...- edge 10

Example 2: Parking around Amazon campus



Conclusion

- * Future Work
 - * Incorporate balking – variable demand routing games
 - * Parking toll design – bilevel optimization
- * Thanks!