Improvements To Worker Assignment Problem

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Overview

- What is Bike Sharing System?
- Rebalancing
- Worker Assignment Problem
- Graph Matching
- Algorithms
  - TRM, LR, HS, GHS, IRS
- Conclusions

What is Bike Sharing System?

- Bike Sharing Systems (BSS)
- Docked vs Dock-less
- Benefits
  - Exercise
  - Eco-Friendly
  - Reduce Traffic
  - Cheap
  - Low Infrastructure

Alta Planning + Design. *LimeBike in Seattle, Washington*. Seattle

K, P. (n.d.). *Melbourne City Bikes*. photograph, Melbourne.

What is Rebalancing?

- Variable demand at stations
  - Time
  - Location
- Overflow/Underflow stations
  - Stations with too many bikes
  - Stations with not enough bikes

Gwenneth Leech. *Empty bike docking station at Spring and Lafayette*. New York City

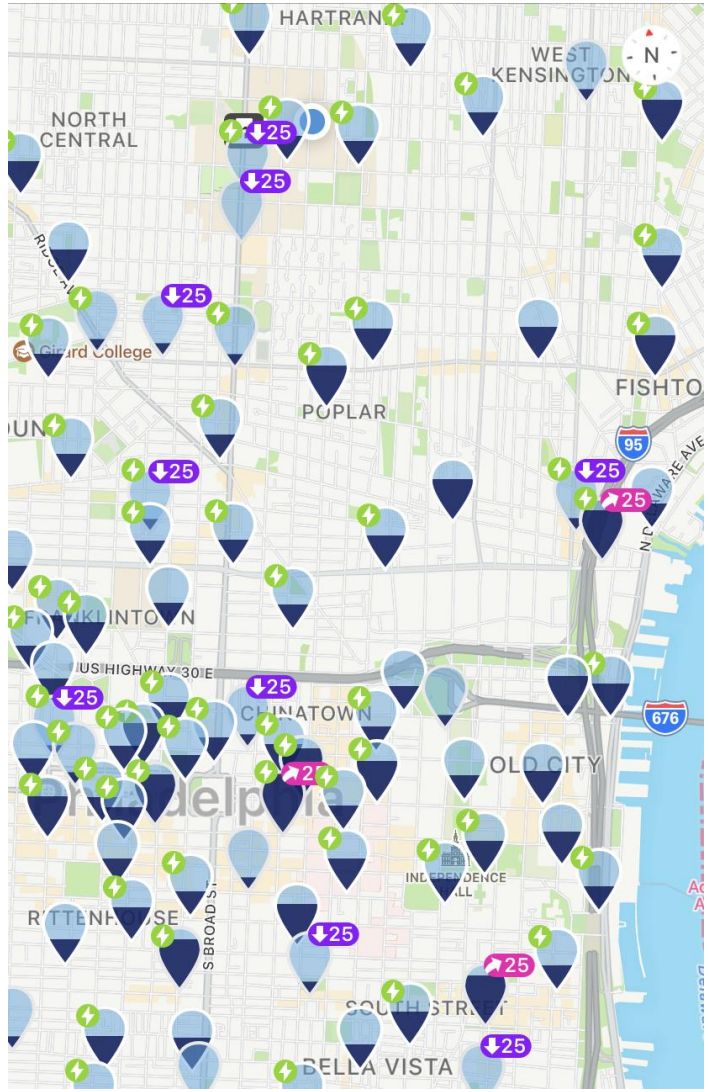
Trucks for Rebalancing

- Optimal Hamiltonian Path
- Traveling Salesman
- Advantages
  - Centralized
- Disadvantages
  - Expensive
  - Cause Traffic
  - Pollution

Ted Timmons. *BiciQuito bikeshare rebalancing truck*. Quito

Crowdsourcing with Users

- Use existing users for rebalancing
- Incentive model
  - Rewards for stations
  - Free rides, prizes, etc.
  - Any user can rebalance
- Assignment model
  - Hire workers
  - Assign stations

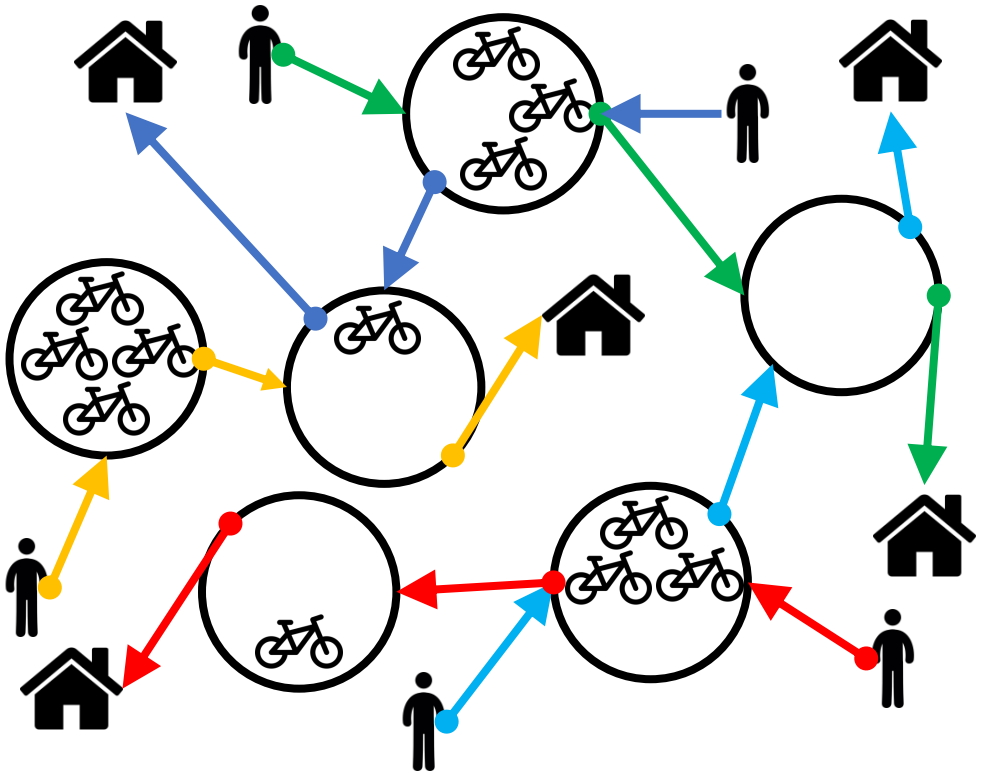


Temporal vs Spatial

- Rebalancing
  - Divide into spatial and temporal domains
- Temporal
  - Predict station usage and workers
  - Divide into time slices
- Spatial
  - Create incentives/assignments
  - Use temporal predictions
  - Static problem in each time slice

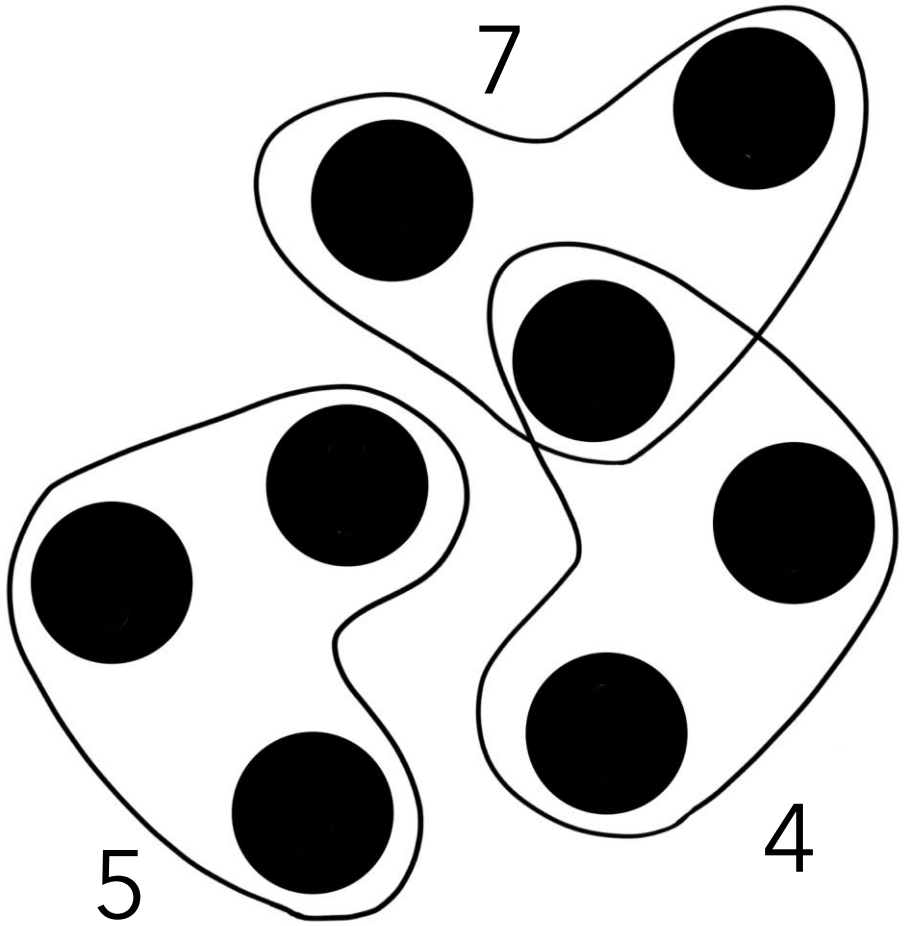
Worker Assignment Problem

- Optimal assignment of worker and stations
- Partial Assignments
- NP-Hard
- Same number overflow and underflow targets
- Any number of workers



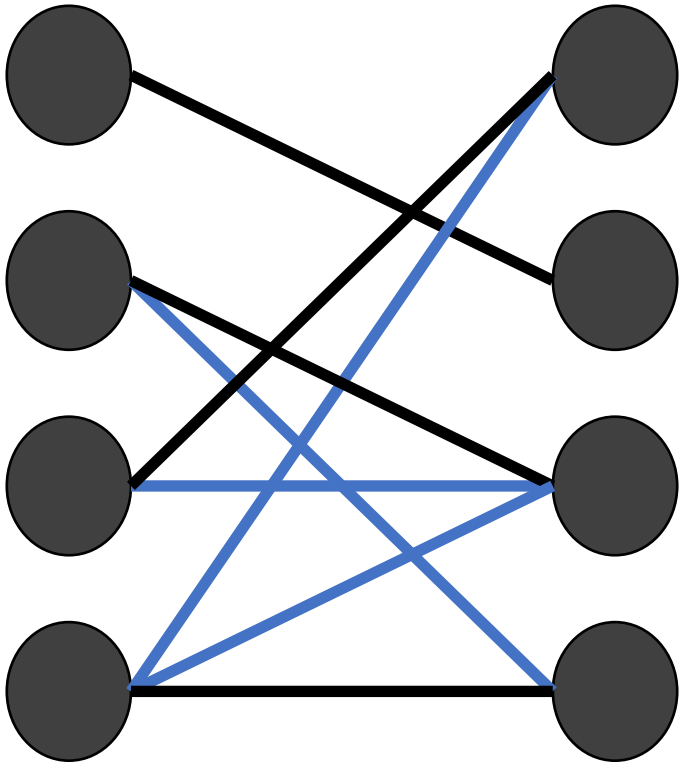
3-Dimensional Matching

- 3D hypergraph
  - 3 vertices per edge
- Weighted 3-dimensional matching
  - Find set of disjoint edges
  - Maximal sum of weights
- NP-complete



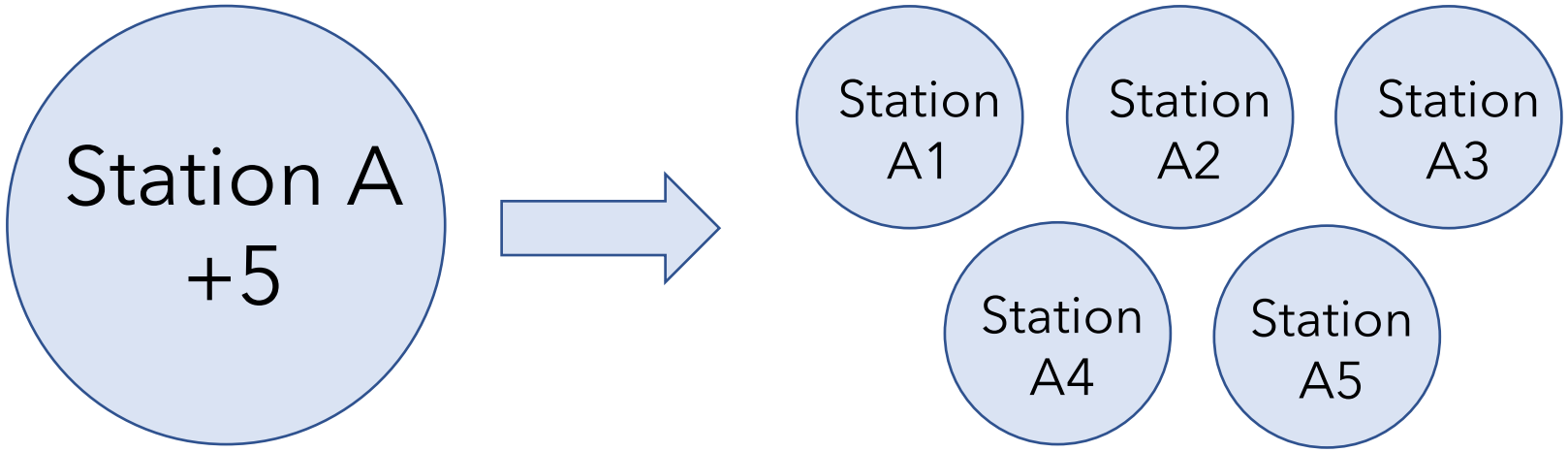
Graph Matching

- Matching problem
  - Pair every vertex with a neighbor
  - Set of disjoint edges with all vertices
- Maximal matching
  - Set of disjoint edges with maximal weight
- Many real-world applications
- Hungarian algorithm
  - O(V log(V))



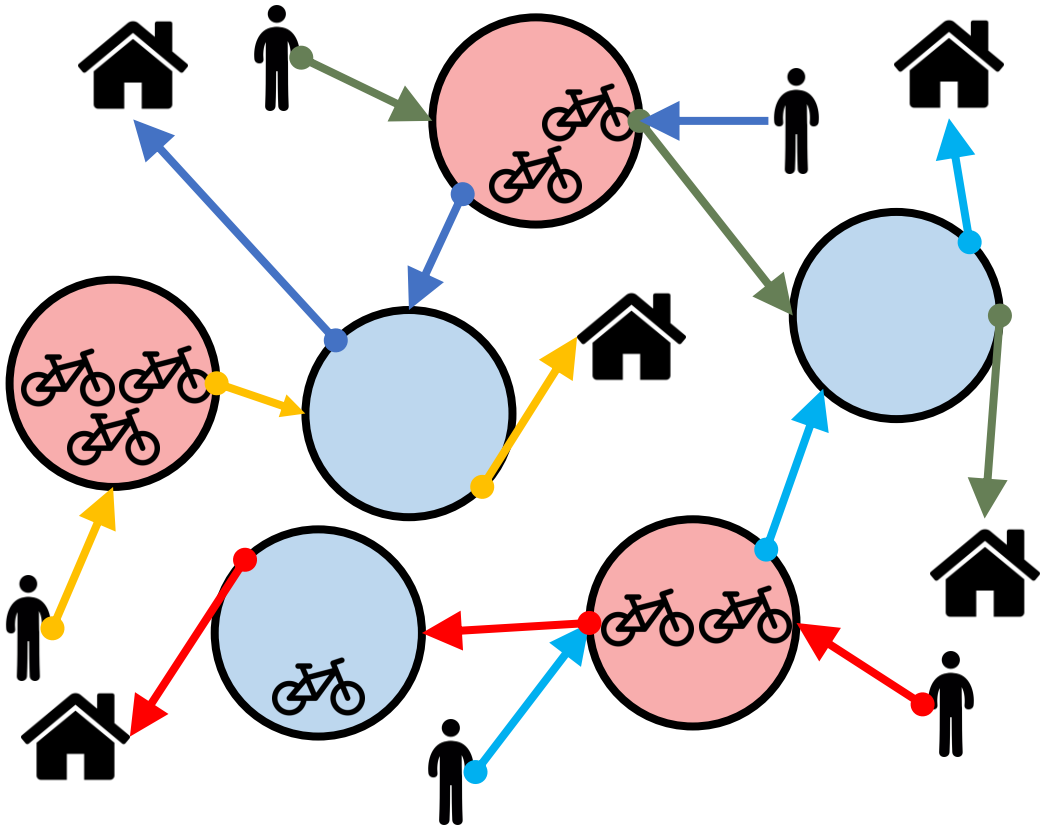
WAP and 3D Matching

- Give each station a rebalancing target
- Clone stations by target
- Edges
  - (Worker, Overflow Target, Underflow Target)
- Matching to find the best edges/assignments



Two Round Matching (TRM)

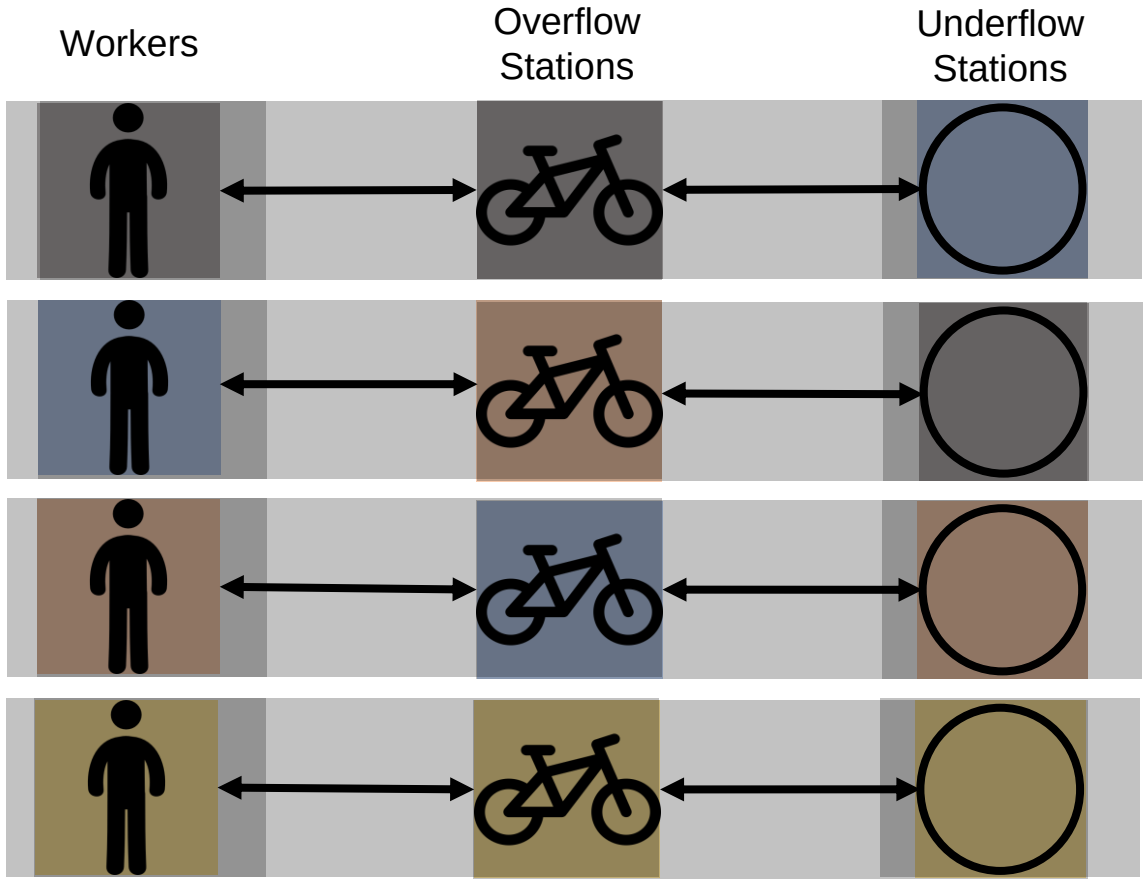
- Round 1: Create overflow underflow matching
- Round 2: Create worker station pair matching
- 3-approximate



Y. Duan and J. Wu, "Spatial-temporal inventory rebalancing for bike sharing systems with worker recruitment, "IEEE Transactions on Mobile Computing, 2020.

Hungarian Search (HS)

- Hungarian Search
  - Improves a weighted matching
  - Iteratively optimizes
- Iteration of HS
  - Fix parts of the graph
  - Perform a weighted matching
- Random Hungarian Search
  - Random graph optimized by HS



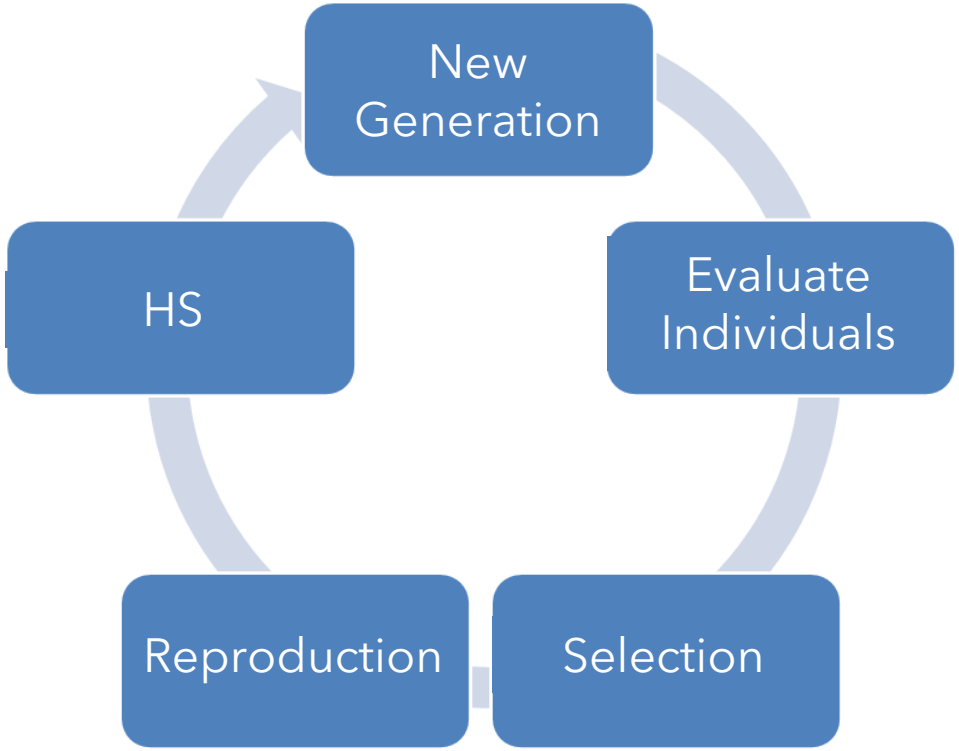
G. Huang and A. Lim, “A hybrid genetic algorithm for three-index assignment problem,” in IEEE CEC, vol. 4, 2003, pp.2762–2768.

Genetic Hungarian Search

- Genetic Algorithm
  - Iteratively search for better graphs
  - Optimize with HS
- Partially Mapped Crossover

$$P_1 = (3\ 4\ 8 \mid 2\ 7\ 1 \mid 6\ 5)$$

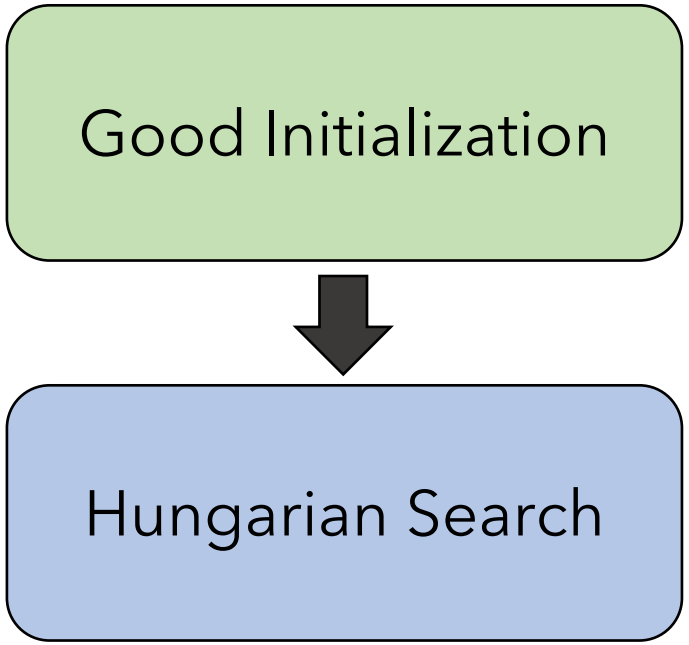
$$P_2 = (4\ 2\ 5 \mid 1\ 6\ 8 \mid 3\ 7)$$



G. Huang and A. Lim, "A hybrid genetic algorithm for three-index assignment problem," inIEEE CEC, vol. 4, 2003, pp.2762–2768.

Initialized Round Search (IRS) [Proposed]

- Algorithm
  - Run TRM
  - Run HS on the results
- Speed of TRM
- Performance of HS
- Still 3-approximate



Local Ratio (LR)

- Creates an order of edges
  - Linear programming
- Local Ratio Subroutine
  - Recursive
  - Prunes bad edges
  - Adds first edge in ordering to matching

$$\max \quad \sum_{e \in E} x_e w_e$$

$$\text{s.t.} \quad \sum_{e \in A(v))} x_e w_e \leq 1 \quad \forall x_e$$

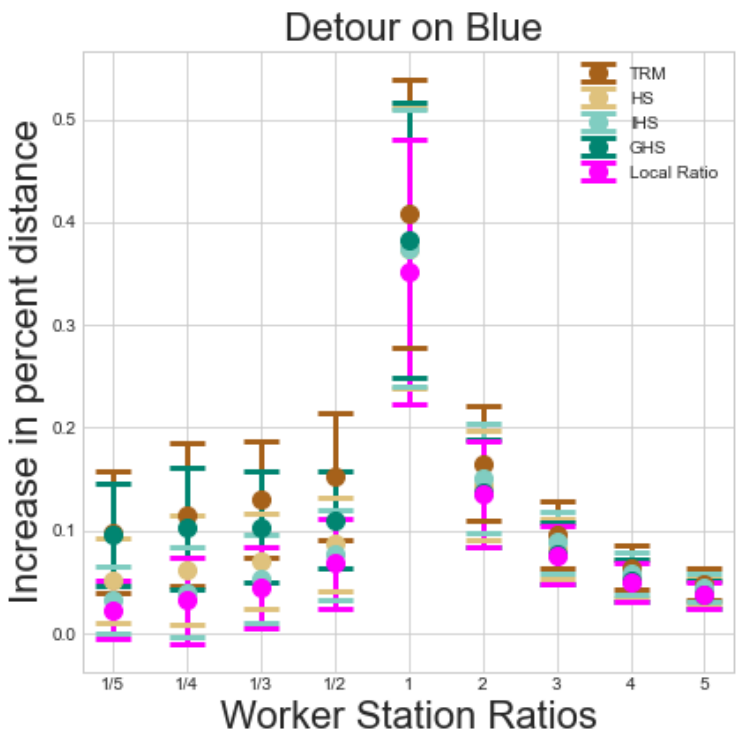
$$x_e \geq 0 \quad \forall x_e$$

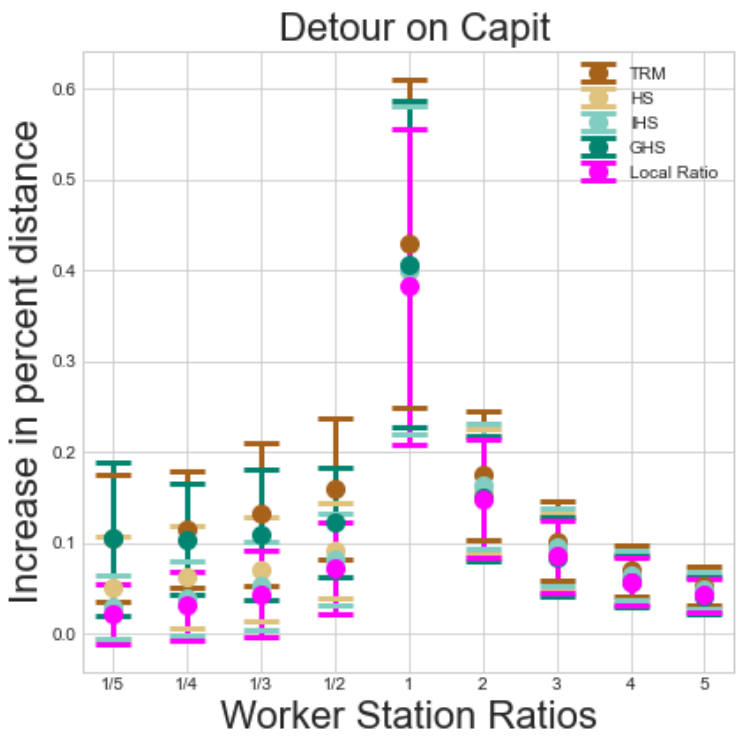
Y. H. Chan and L. C. Lau, "On linear and semidefinite programming relaxations for hypergraph matching," Math. Program, vol. 135, no. 1, pp. 123–148, 2012.

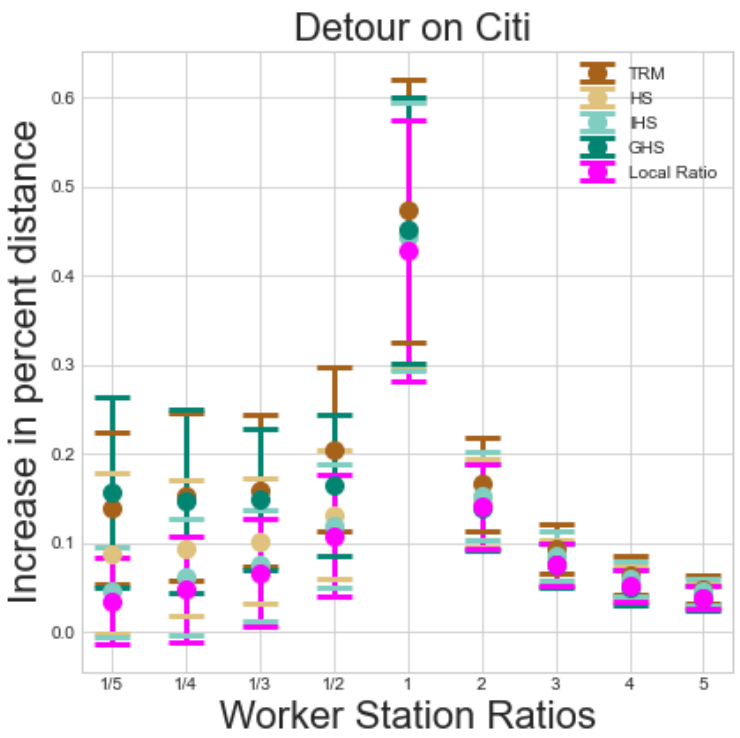
Simulation Set Up

- NYC, Boston, and Washington DC data sets
  - May 2021
- Random workers
  - Within 500m of stations
- Time slices
  - 100-400 nodes
- Workers per overflow/underflow target
  - 1/5-5x
- Trials per data set
  - 62

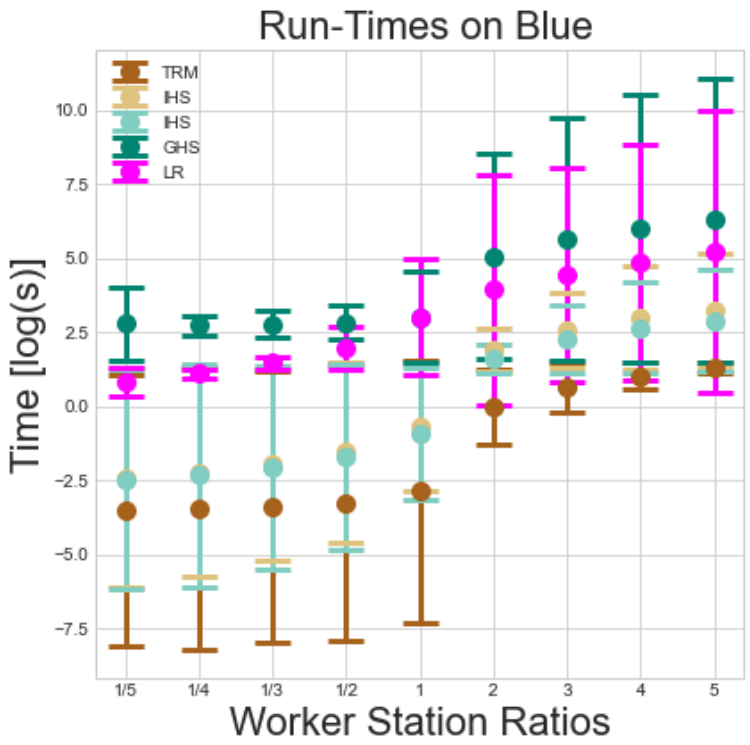
Detour Distance

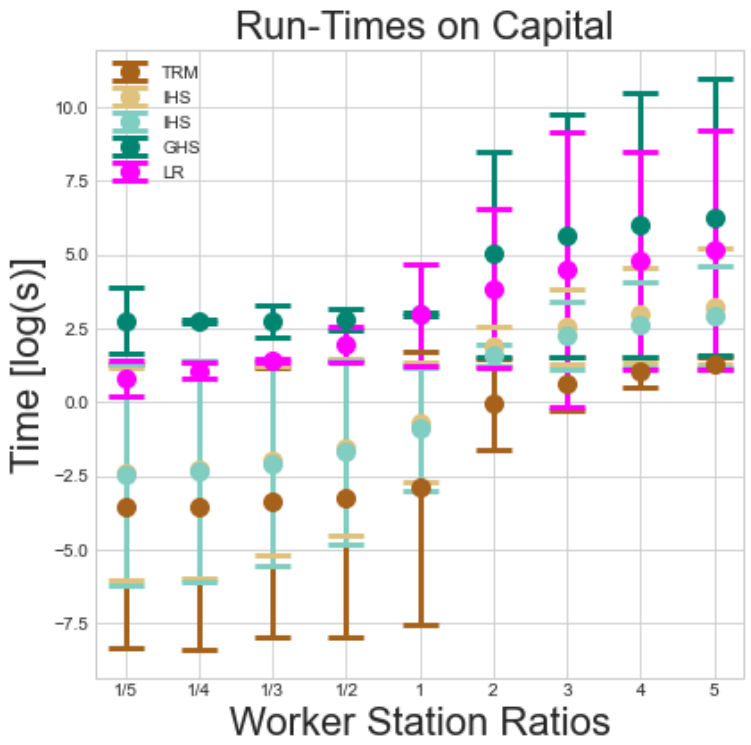


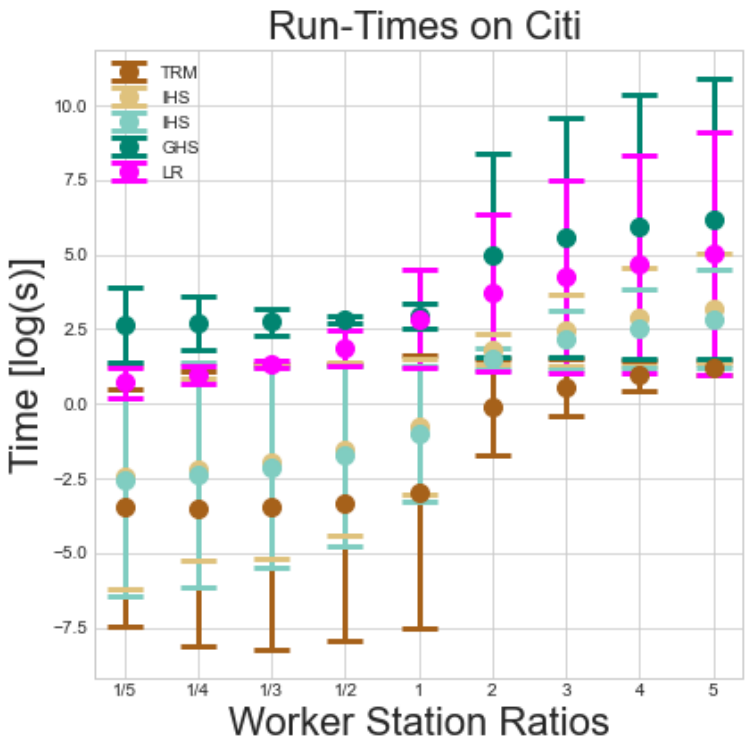




Run-Times


Run-Times on Blue
TRM
IHS
IHS
GHS
LR
Time [log(s)]
10.0
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
1/5
1/4
1/3
1/2
1
2
3
4
5
Worker Station Ratios


Run-Times on Capital
TRM
IHS
IHS
GHS
LR
Time [log(s)]
10.0
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
1/5
1/4
1/3
1/2
1
2
3
4
5
Worker Station Ratios


Run-Times on Citi
TRM
IHS
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GHS
LR
Time [log(s)]
10.0
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
1/5
1/4
1/3
1/2
1
2
3
4
5
Worker Station Ratios

Algorithm Performance

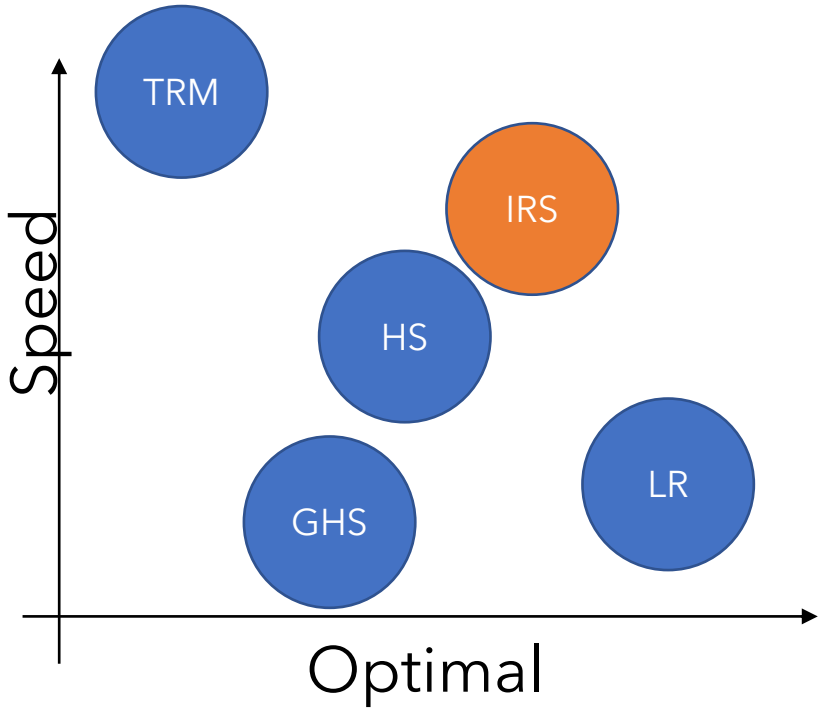


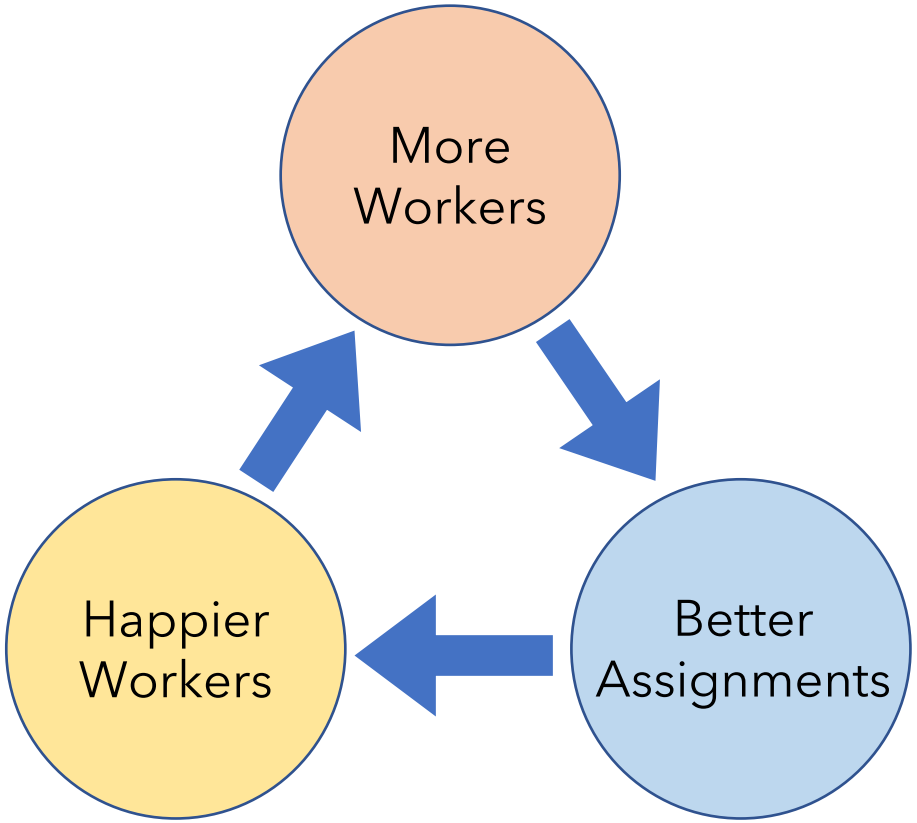
TABLE II: Increase in Travel Distance (%)

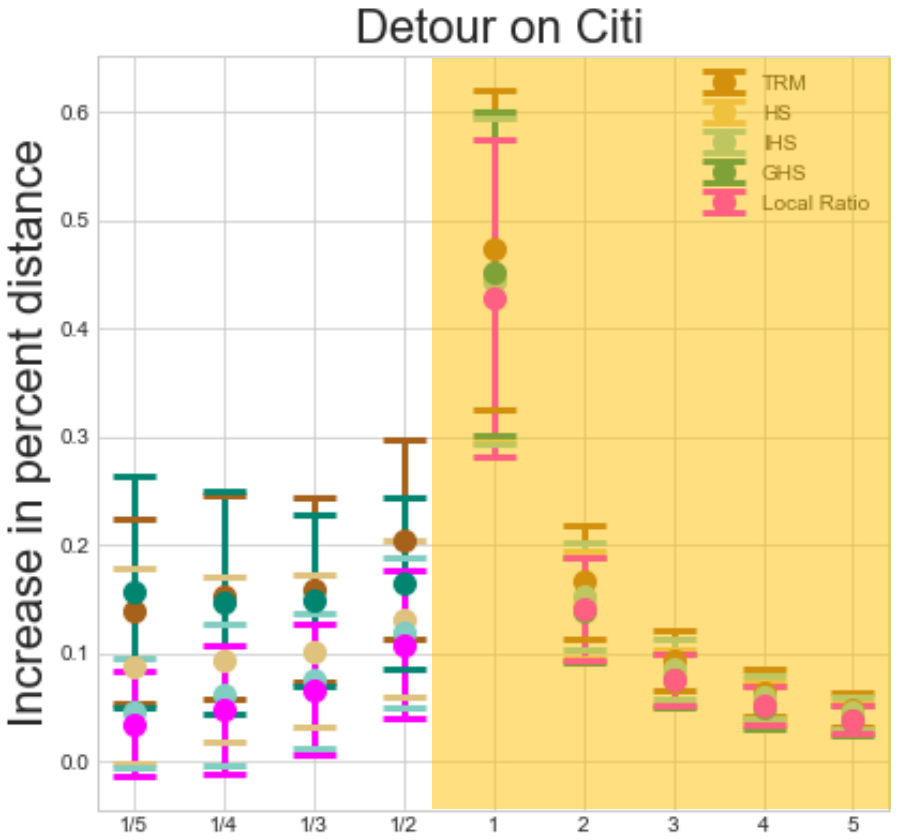
	TRM*	RHS	IRS	GHS	LR
1/5	0.14	0.09	0.05	0.16	**0.03**
1/4	0.15	0.09	**0.06**	0.15	**0.05**
1/3	0.16	0.1	**0.08**	0.15	**0.07**
1/2	0.21	0.13	**0.12**	0.16	**0.11**
1	0.47	**0.45**	**0.44**	**0.45**	**0.43**
2	0.17	**0.15**	**0.15**	**0.14**	**0.14**
3	**0.09**	**0.08**	**0.09**	**0.08**	**0.08**
4	**0.06**	**0.05**	**0.06**	**0.05**	**0.05**
5	**0.05**	**0.04**	**0.05**	**0.04**	**0.04**

TABLE III: Run-Times (s)

	TRM	RHS	IRS	GHS	LR
1/5	**0.03**	0.09	0.08	14.31	2.02
1/4	**0.03**	0.11	0.09	15.07	2.64
1/3	**0.03**	0.14	0.12	15.74	3.77
1/2	**0.04**	0.21	0.17	16.75	6.30
1	**0.05**	0.47	0.36	19.40	16.75
2	**0.86**	6.14	4.45	140.76	40.29
3	**1.7**	11.71	8.47	255.82	69.38
4	**2.52**	17.60	12.50	372.20	105.25
5	**3.34**	23.50	16.81	487.48	148.07

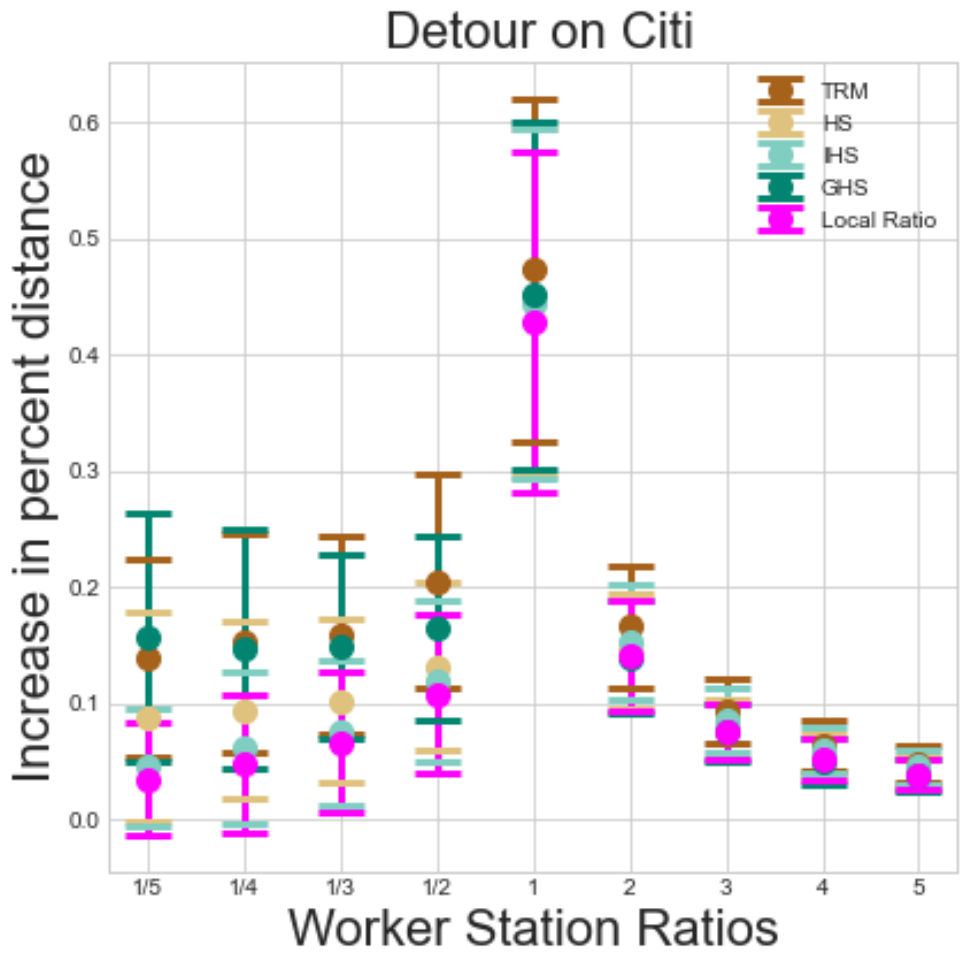
Worker Feedback Loop





How Many Targets?

- Too Few Workers = Poor Rebalancing
- Less Detour = More Satisfaction
- More workers = Better Assignments
- Balance worker/target ratio

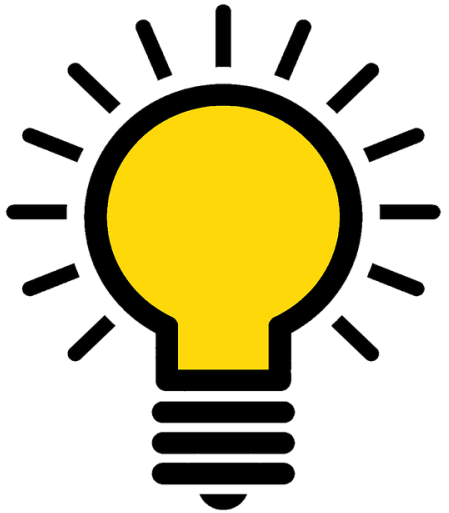


Simulation Conclusion

- TRM provides speed
- Local Ratio provides accuracy
- IRS provides a good balance
- Worker Feedback Loop
  - Manage station targets

Conclusions

- Bike sharing systems
  - Rebalancing is a major issue
- Graph theory solutions
- Introduced algorithms to BSS
- IRS: a good speed-performance trade-off



Questions?

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This research was supported in part by NSF REU site grant CNS 1757533.