Plowing the Streets of Pittsburgh

A Dynamic Route Planning System

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Motivation & Goals

"Drivers have printed routing directions laying on the passenger seat. Most of them know the route (or an interpretation thereof) by heart."

"A lot of time is lost due to emergency plow requests."

"People complain that primary roads in their district are full of snow, while in other districts tertiary roads have already been serviced."

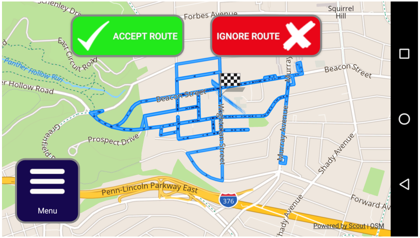
Motivation (2)

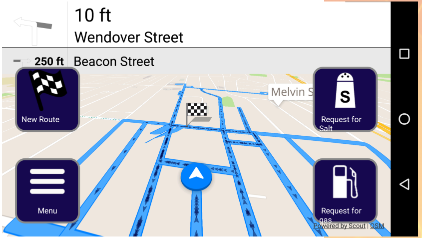
1. Consumable resource costs: 4,3M$ (2014/2015), 3.3M$ (2013/2014)
2. Labor costs: 3.3M$ (2014/2015)
3. Equipment costs: 800K$ (2014/2015)
4. Snow and ice control staff: 275

- safety
- economy
- environment
- Generalizes to street sweeping, street maintenance, garbage collection, etc.

Goal

Design a route planning system that issues optimized turn-by-turn instructions to the vehicles as they execute routes, and dynamically revises these plans as unexpected events force changes.





Problem Description - Routes

Road segments:

- start/end
- # lanes
- priority class
- shape
- driving speed
- directionality

Problem Description - Vehicles

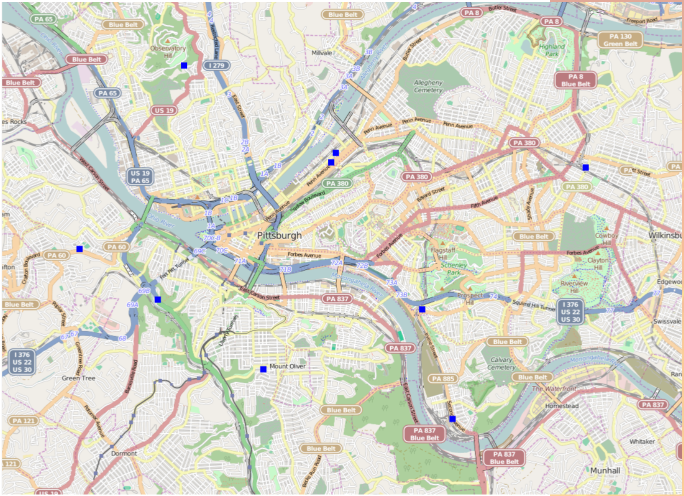
Vehicles:

- Location
- Salt Capacity
- Fuel Capacity
- Salt economy
- Fuel economy

Problem Description - Depots

Depots:

- Location
- Salt (y/n)
- Fuel (y/n)



Related models

- Chinese postman problem
- Vehicle routing with resource constraints
- Resource-constrained project scheduling with renewable and non-renewable resources

For overview of Snow plowing literature, see N. Perrier, A. Langevin, et. al: [1, 2, 3, 4]

Synchronized arc routing for snow plowing operations [5]

- City of Dieppe: 24,000 inhabitants, 462 intersections, 1,234 road segments ($\leq$ 20% Downtown Pittsburgh)

Model - Objective

Objectives:

1. Makespan
2. Minimize deadheading
3. Weighted objective of Completion times per priority class

Model - Constraints

Constraints:

1. Vehicles start/end at depot
2. Every lane on a street segment must be covered, subject to traffic direction.
3. Renewable resource constraints: fuel, salt
4. Time constraints

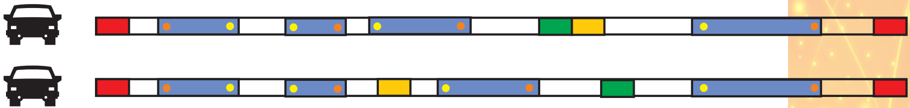
Model

Job:

1. ID
2. start location
3. end location
4. duration
5. fuel & salt requirement

Job types:

1. source depot job
2. target depot job
3. plow job
4. refuel job
5. resupply salt job



Mathematical models

- Mixed Integer Programming
- Constraint Programming

Mixed Integer Programming Model - Outline

- Variables:
  - Three-index formulation: Vehicle k performs job j after job i.
  - Variables recording resource utilization: time, salt, fuel
- Constraints:
  - All plow jobs have to be performed, refuel/resupply jobs are optional
  - Decide on direction for bidirectional jobs
  - Resource constraints for fuel/salt/time

Constraint Programming Model - Outline

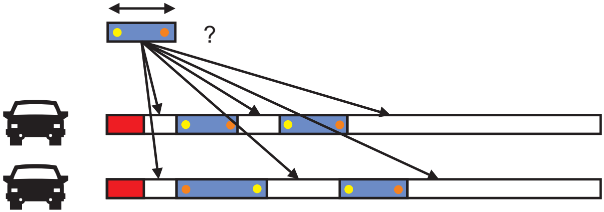
- Variables:
  - Job (interval) variables.
  - Job to vehicle assignment variables
- Constraints (outline):
  - Job sequencing constraints for each vehicle
  - Alternative constraint for job to vehicle assignment
  - Cumulative functions to manage resources

Heuristic

- Constructive Heuristic
- Late Acceptance improvement heuristic

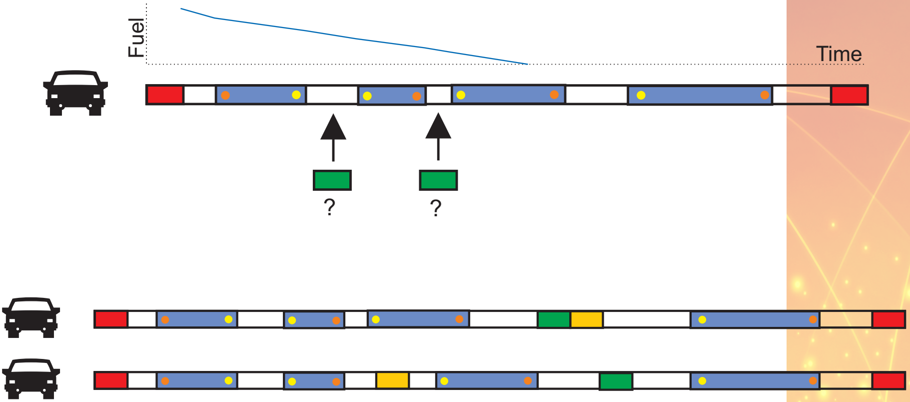
Constructive Heuristic - Phase 1

1. Order jobs based on their priority
2. Constructively build schedules - Insert jobs 1 by 1

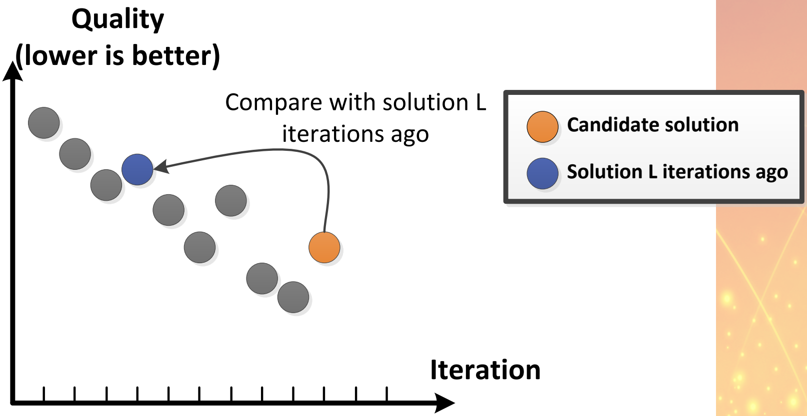


Constructive Heuristic - Phase 2

1. Insert Refuel and Resupply salt jobs



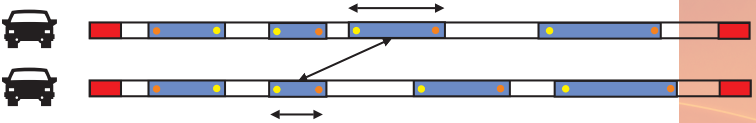
Late acceptance improvement heuristic



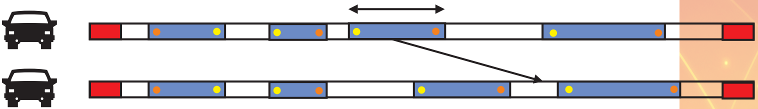
Late acceptance heuristic

Moves:

1. Swap



2. Remove/insert



Termination:

1. Time limit
2. Max number of non-improvements

Experiments - Setup

1. Take 2 snapshots from OSM
2. Extract graph, pre-process and ensure Strong Connectivity
3. Execute routing algorithm

Routing and Plowing Graph

Experiments (4/22 instances)

Kamin St:

1. 28 intersections
2. 45 plow jobs
3. plowing: 4mi
4. bidirectional: 38%

mt Washington:

1. 406 intersections
2. 577 plow jobs
3. plowing: 52mi
4. bidirectional: 81%

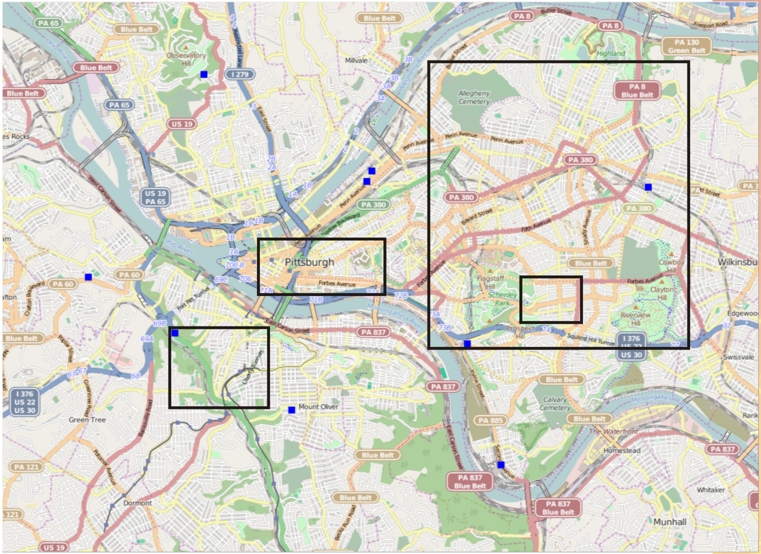
Residential:

1. 2441 intersections
2. 4073 plow jobs
3. plowing: 316mi
4. bidirectional: 64%

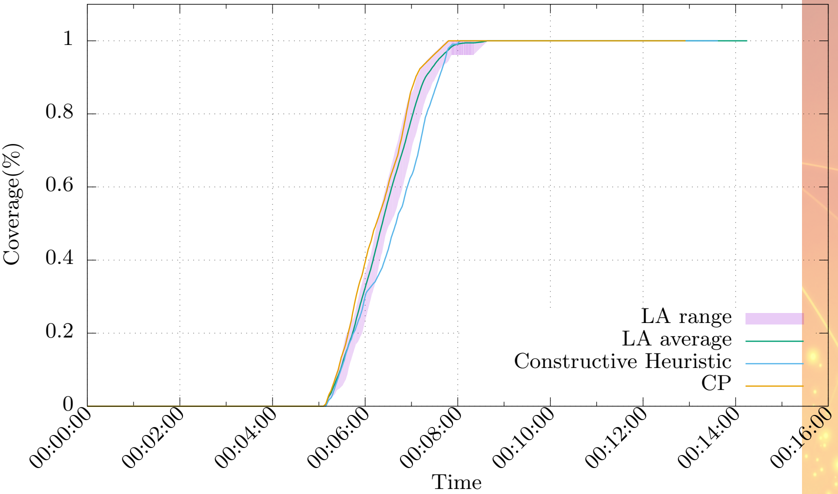
Downtown:

1. 345 intersections
2. 724 plow jobs
3. plowing: 38mi
4. bidirectional: 38%

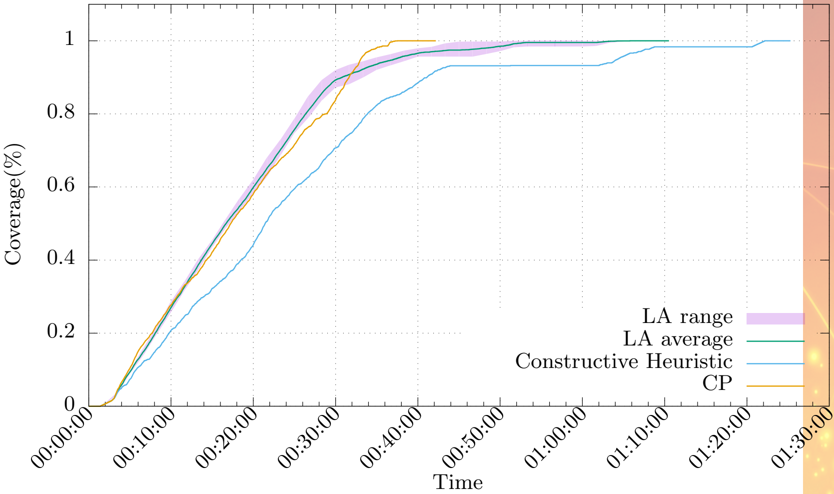
Experiments



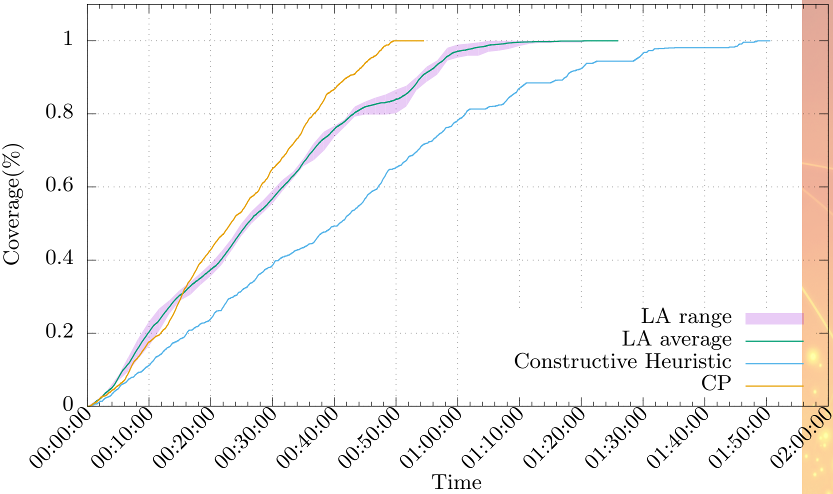
Experiments - Kamin



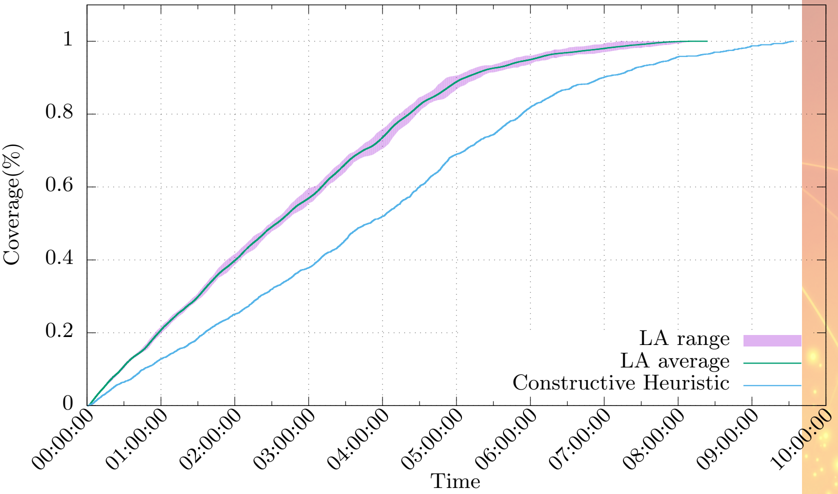
Experiments - Downtown



Experiments - Mnt Washington

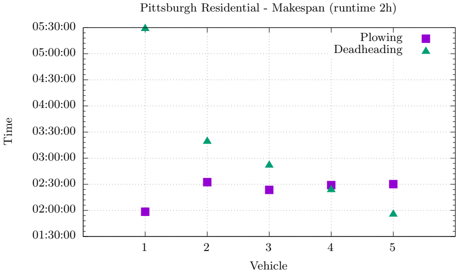


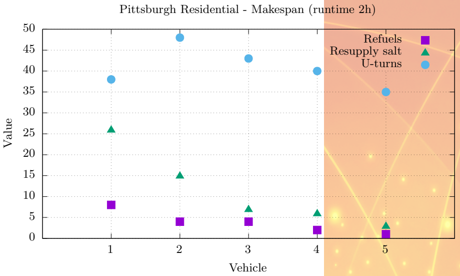
Experiments - Residential



Experiments - Residential Pittsburgh solution

- Schedule completion time: 07:38:33





Summary of preliminary results

- MIP not suitable: bounds are too weak
- CP works well for small instances
- Constructive heuristic finds reasonable solutions in ms.
- LA heuristic produces solutions of consistent quality

- Idea: Improve LA solutions with a CP-Large Neighborhood Search

Future requirements

1. Road priorities
2. U-turns
3. Vehicle weight/width restrictions on roads
4. Efficient construction/updating of distance matrix
5. Adaptive system

Bibliography I

[1] N. Perrier, A. Langevin, and J. F. Campbell, “A survey of models and algorithms for winter road maintenance. part i: system design for spreading and plowing.” *Computers & Operations Research*, vol. 33, pp. 209–238, 2006.

[2] ——, “A survey of models and algorithms for winter road maintenance. part ii: system design for snow disposal,” *Computers & Operations Research*, vol. 33, no. 1, pp. 239 – 262, 2006.

[3] ——, “A survey of models and algorithms for winter road maintenance. part iii: Vehicle routing and depot location for spreading,” *Computers & Operations Research*, vol. 34, no. 1, pp. 211 – 257, 2007.

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[4] ——, "A survey of models and algorithms for winter road maintenance. part iv: Vehicle routing and fleet sizing for plowing and snow disposal," *Computers & Operations Research*, vol. 34, no. 1, pp. 258 – 294, 2007.

[5] M. A. Salazar-Aguilar, A. Langevin, and G. Laporte, "Synchronized arc routing for snow plowing operations." *Computers & Operations Research*, vol. 39, no. 7, pp. 1432–1440, 2012.