Dynamic Multiple Vehicle Routing under Energy Capacity Constraints

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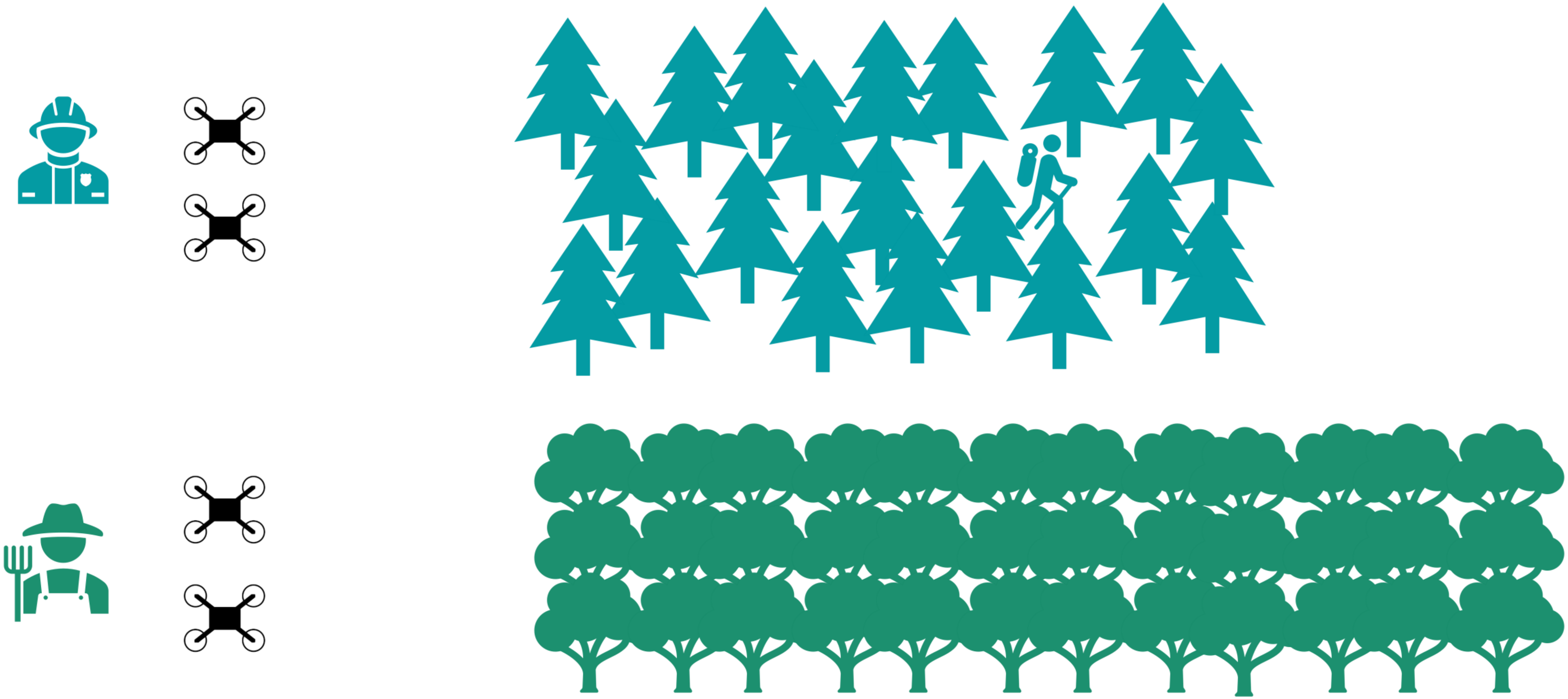
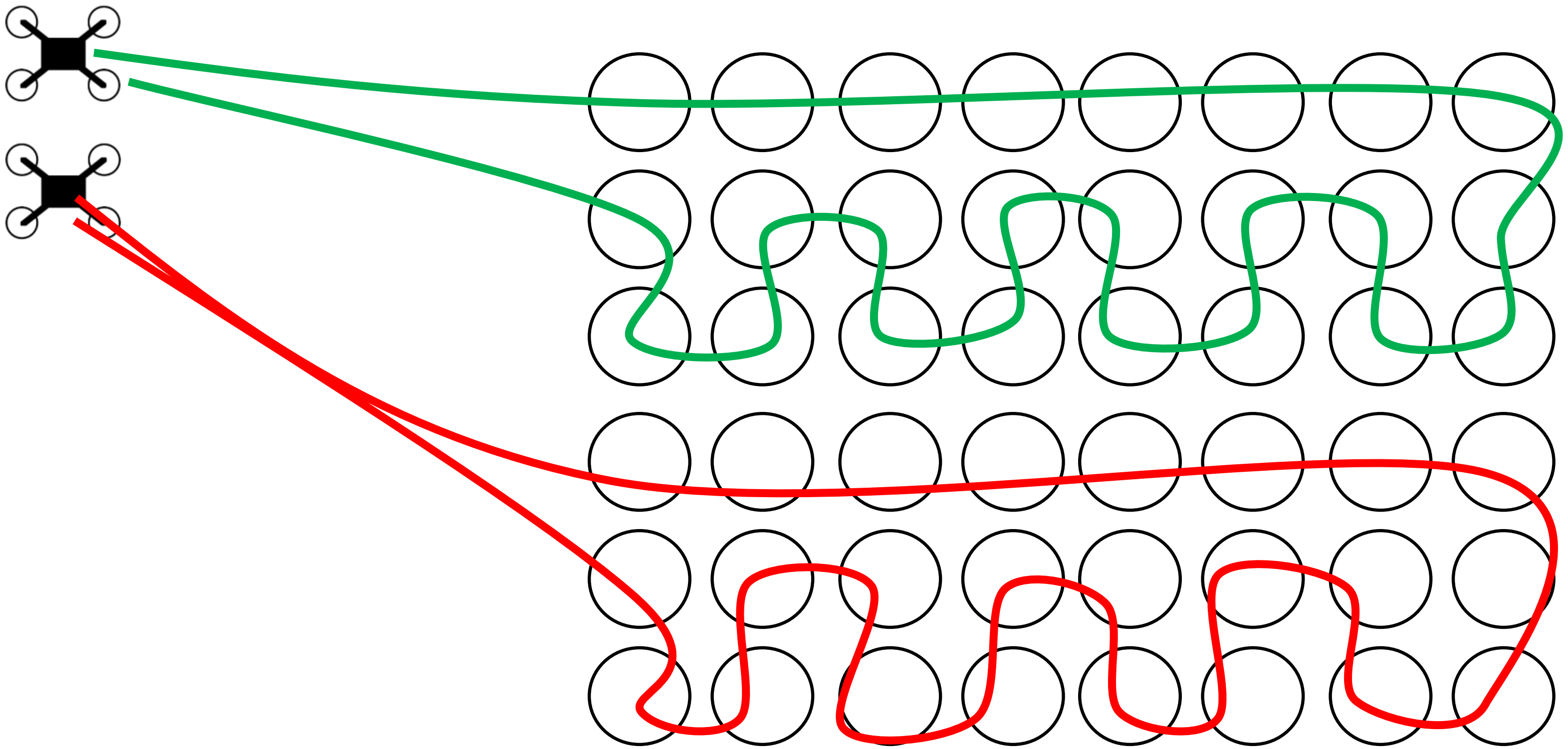
- Motivation
- Problem formulation
- Approach
- Experiments and results
- Conclusion

Application Scenarios



The problem



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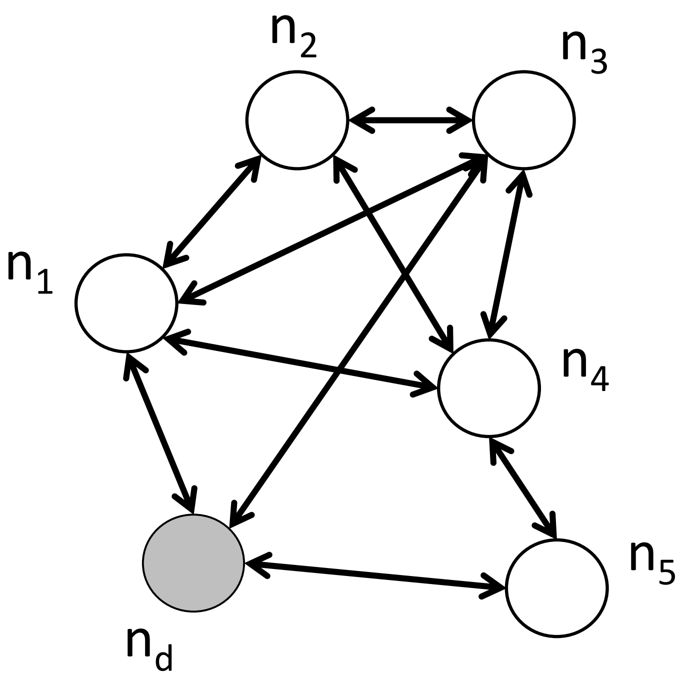
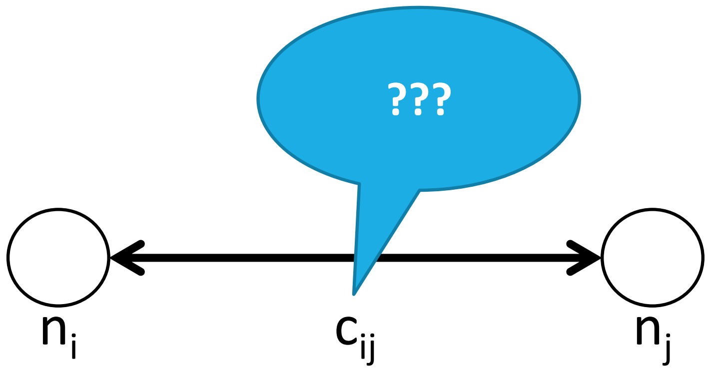
Terrain

- $G = (N,E)$
- N is the set of nodes
- n_d is a depot node
- E is the set of edges



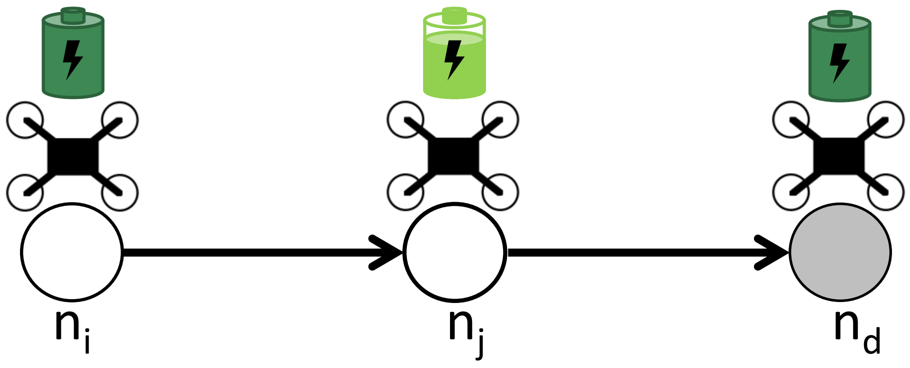
Edge cost

- Let $c_{ij} > 0$ be the cost of edge e_{ij}, corresponding to the energy/fuel that is required to cross e_{ij}
- The exact edge costs are unknown a priori (before crossing an edge)
- During planning, c_{ij} is estimated based on its random distribution



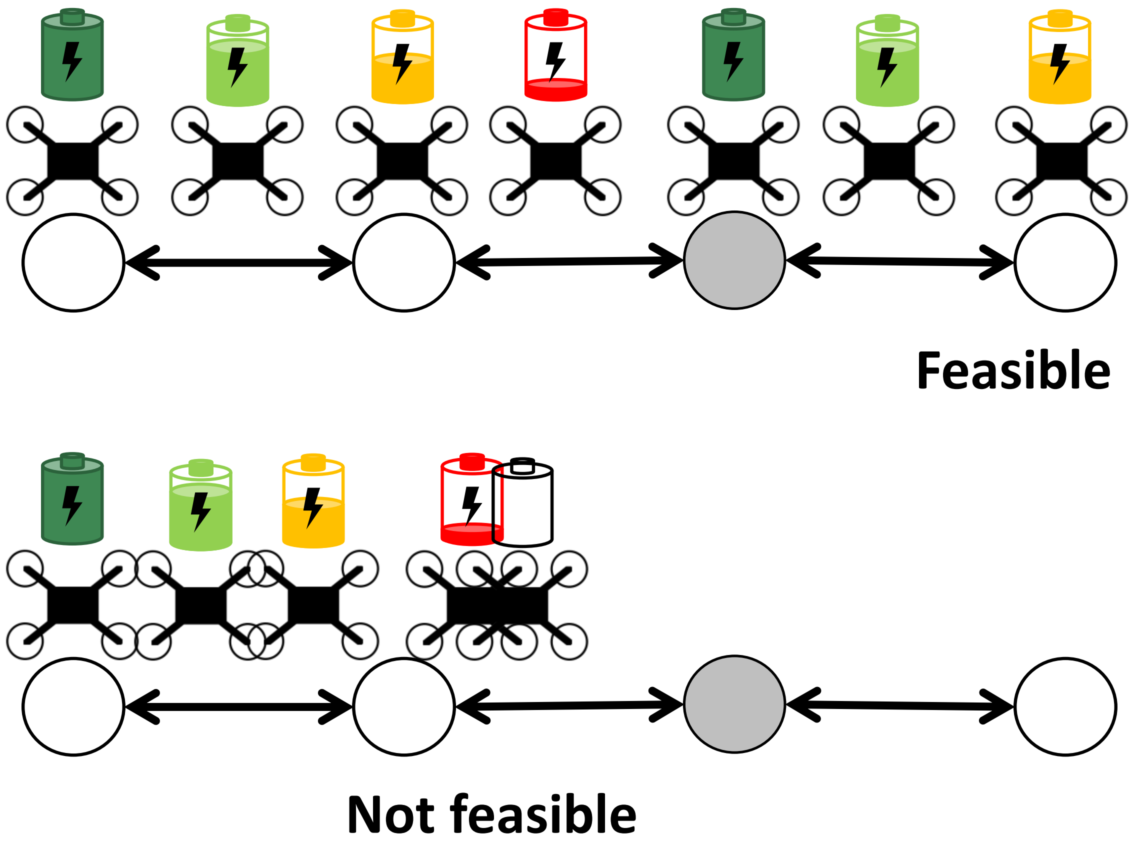
Energy: capacity - consumption - gain

- Each vehicle has maximum energy/fuel capacity B_{MAX}
- The energy decreases relevantly to the edge cost
- Vehicles can refuel/change batteries in the depot nodes



Path feasibility

- A path is a sequence of nodes
- A path is feasible if the energy of the vehicle is not exhausted in any point of the path

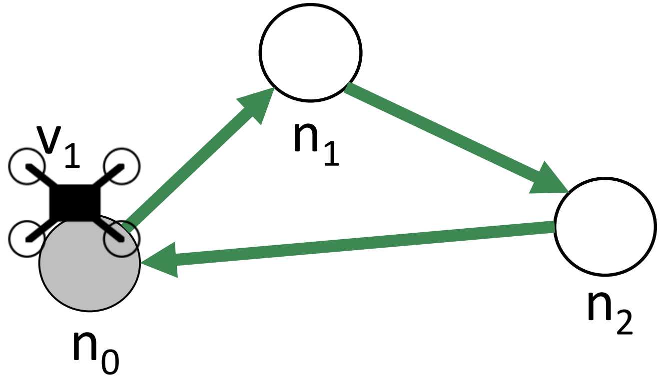


Vehicle makespan

- Let travel(c_{ij}) = t_{ij} be the time needed to cross the edge e_{ij}

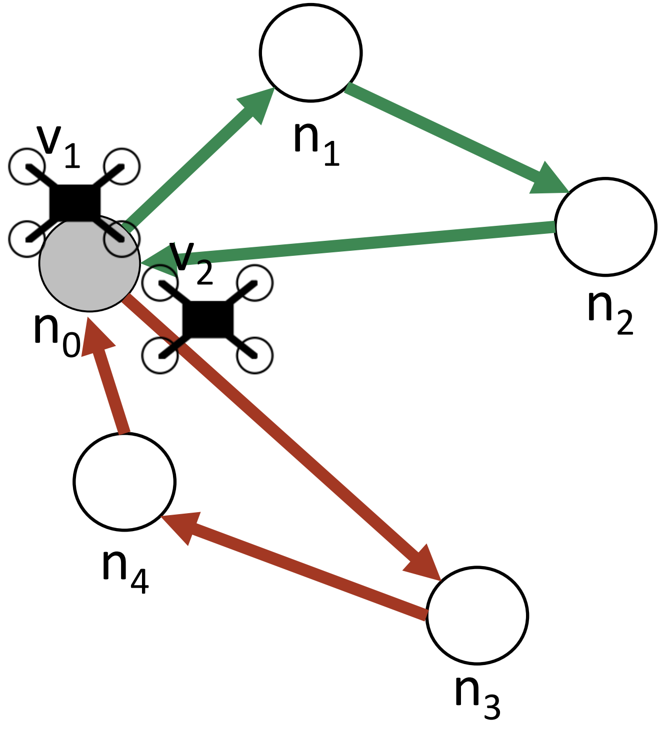
- Let the makespan of one vehicle be the sum of the travel times of the edges in its path

- $makespan_{v1} = t_{0,1} + t_{1,2} + t_{2,0}$



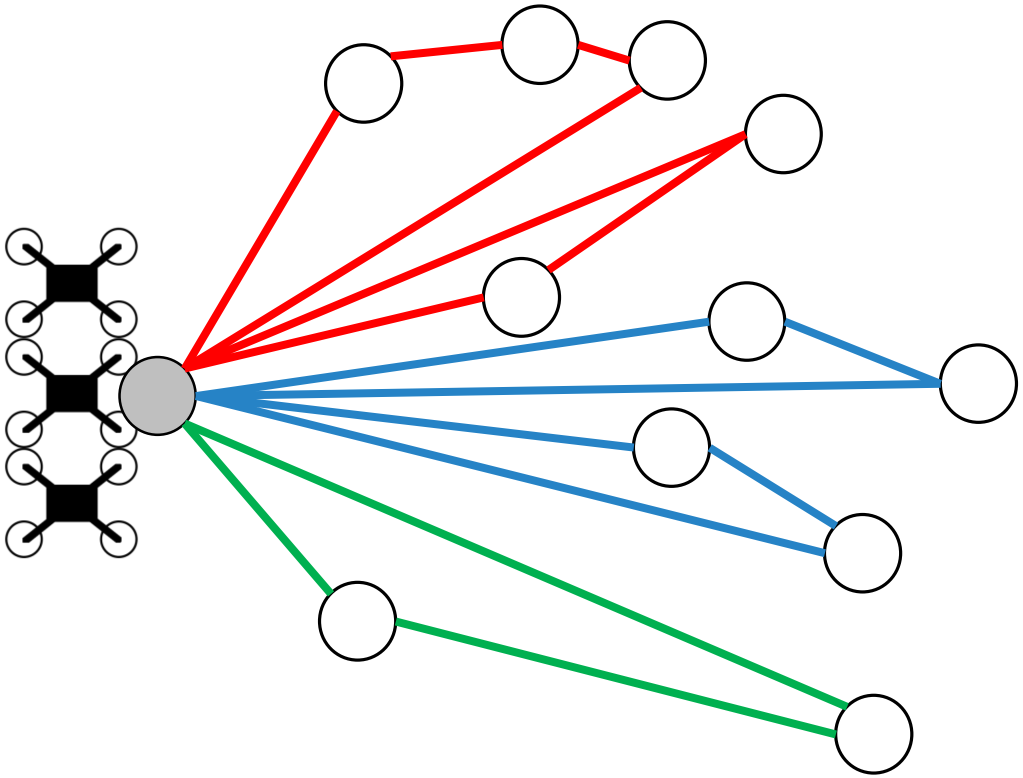
Mission makespan

- Let the mission's makespan be the maximum makespan of all vehicles
- makespan = $\max(\text{makespan}_{v1}, \text{makespan}_{v2}) = \max(t_{0,1}+t_{1,2}+t_{2,0}, t_{0,3}+t_{3,4}+t_{4,0})$



Objective

- Given M vehicles, find a schedule (paths) so that:
- All nodes are visited
- No vehicle exhausts its energy (all vehicles return safely to the starting depot node)
- The mission's makespan is minimized



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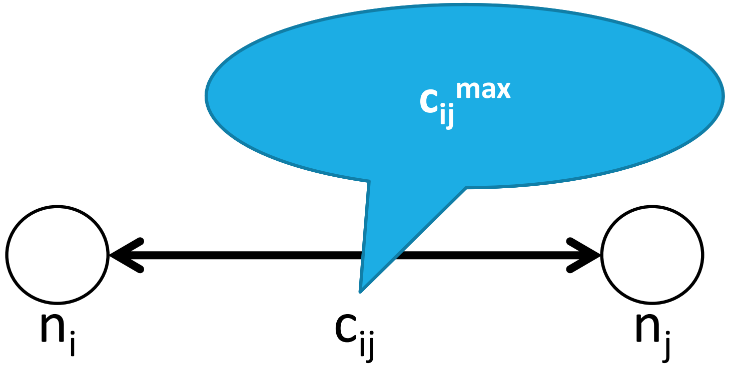
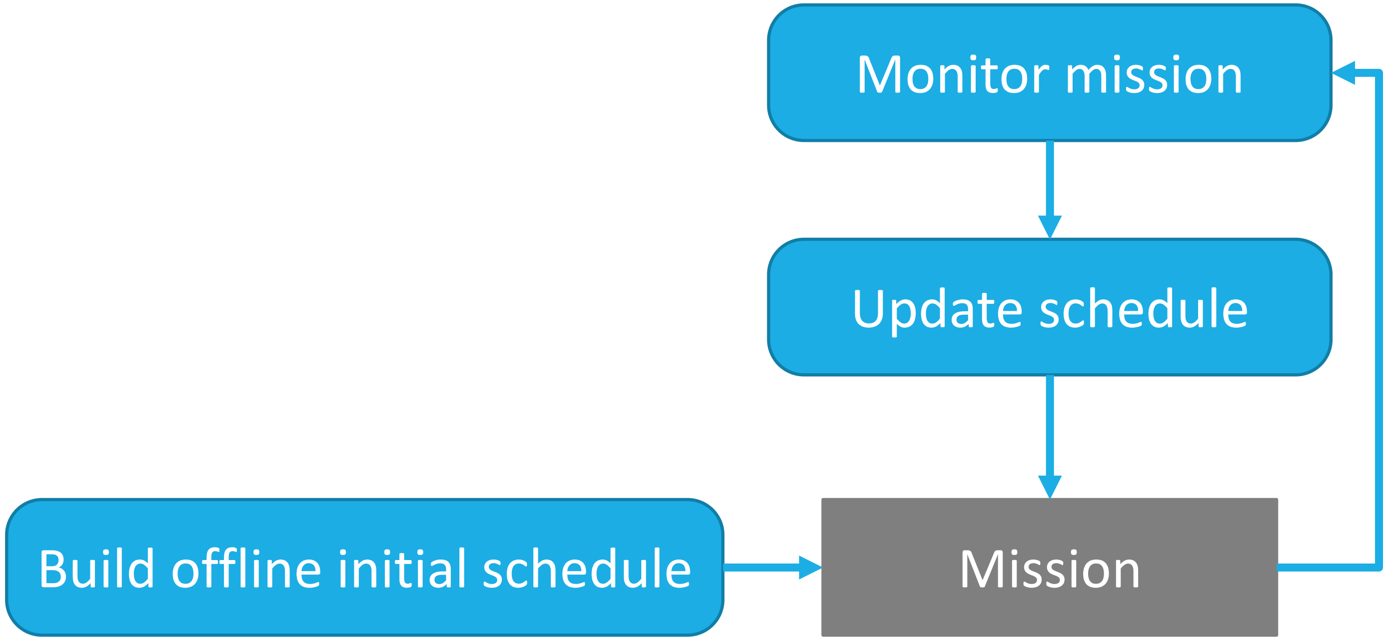
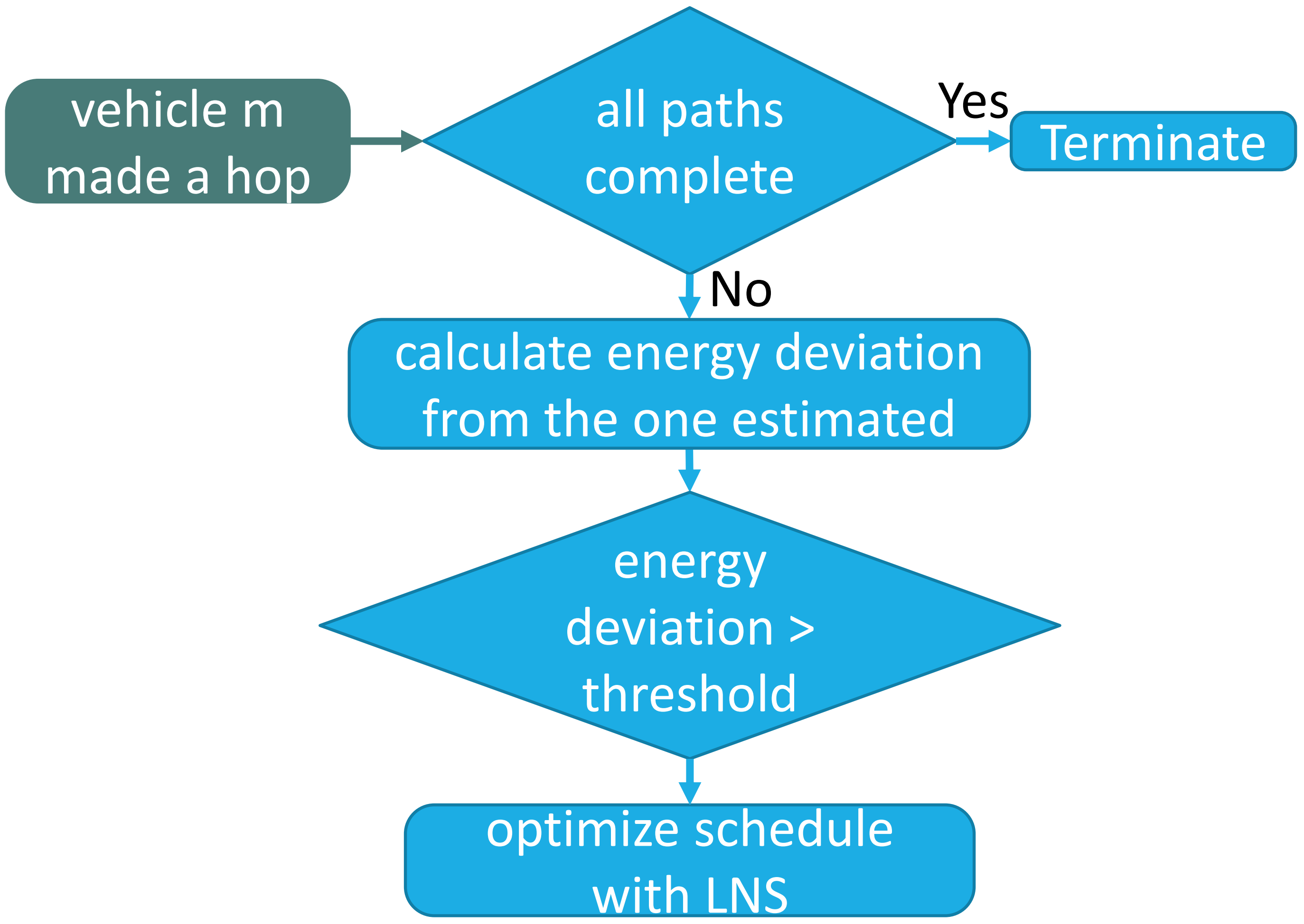
Edge cost estimation



High level concept



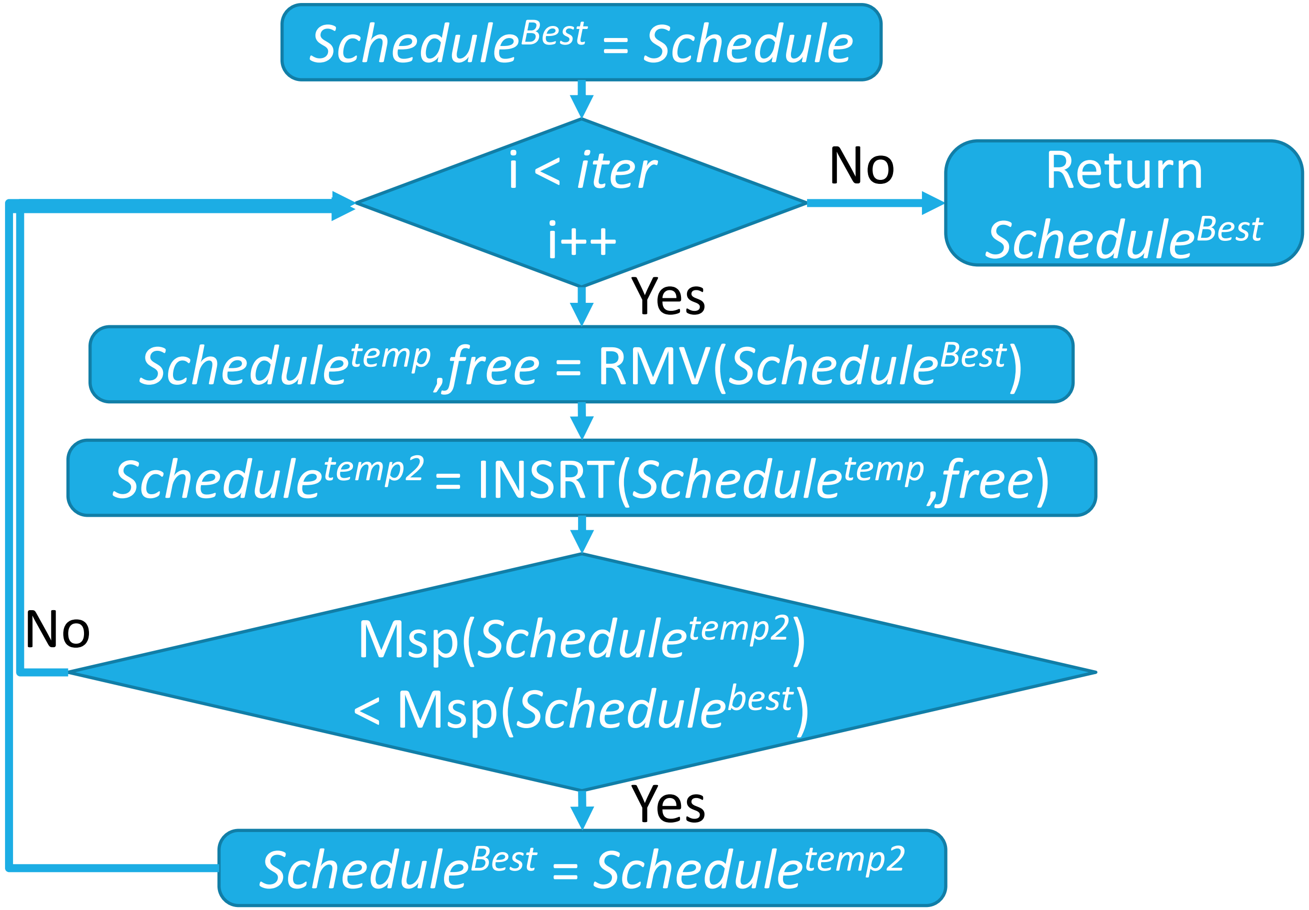
Main control loop



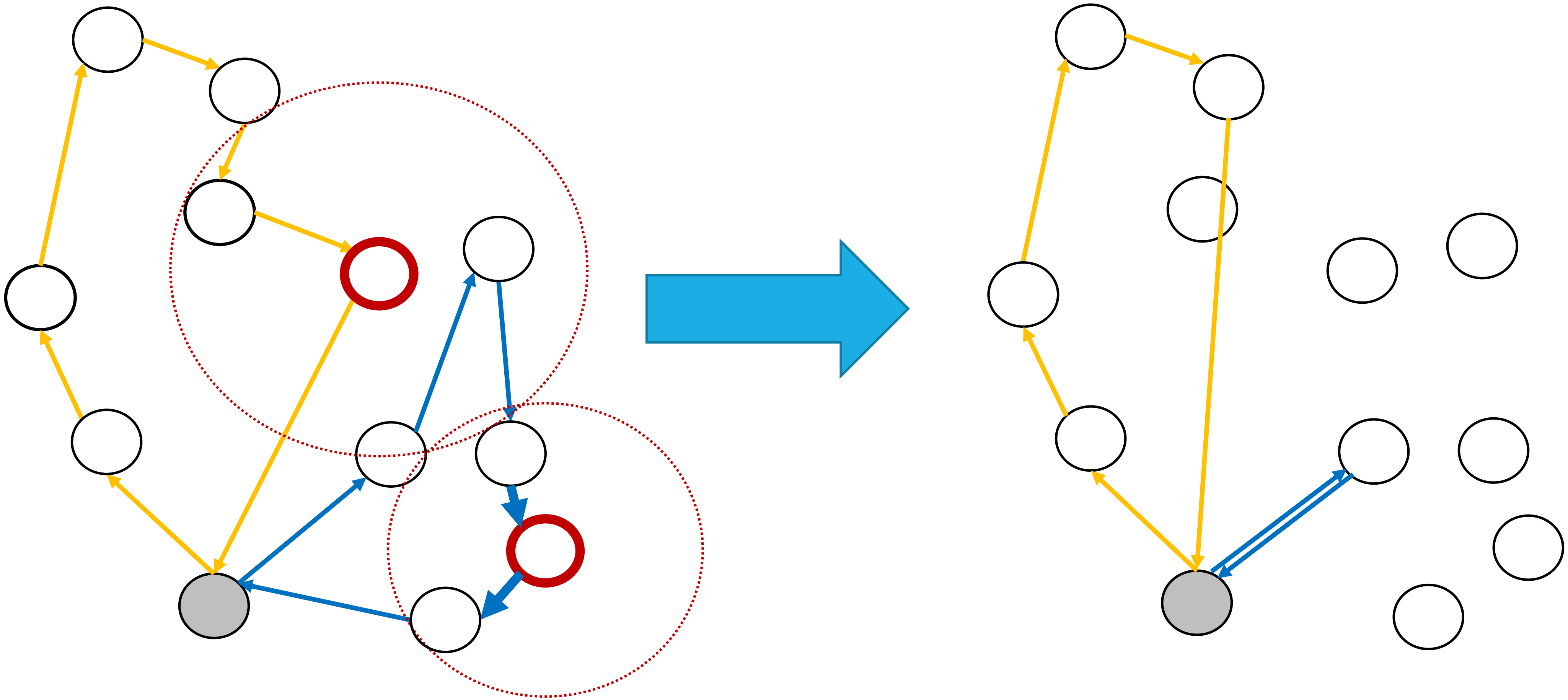
Large Neighborhood Search (LNS)

- Step 1: randomly remove some nodes from the best schedule found so far

- Step 2: reinsert the removed nodes back to the schedule

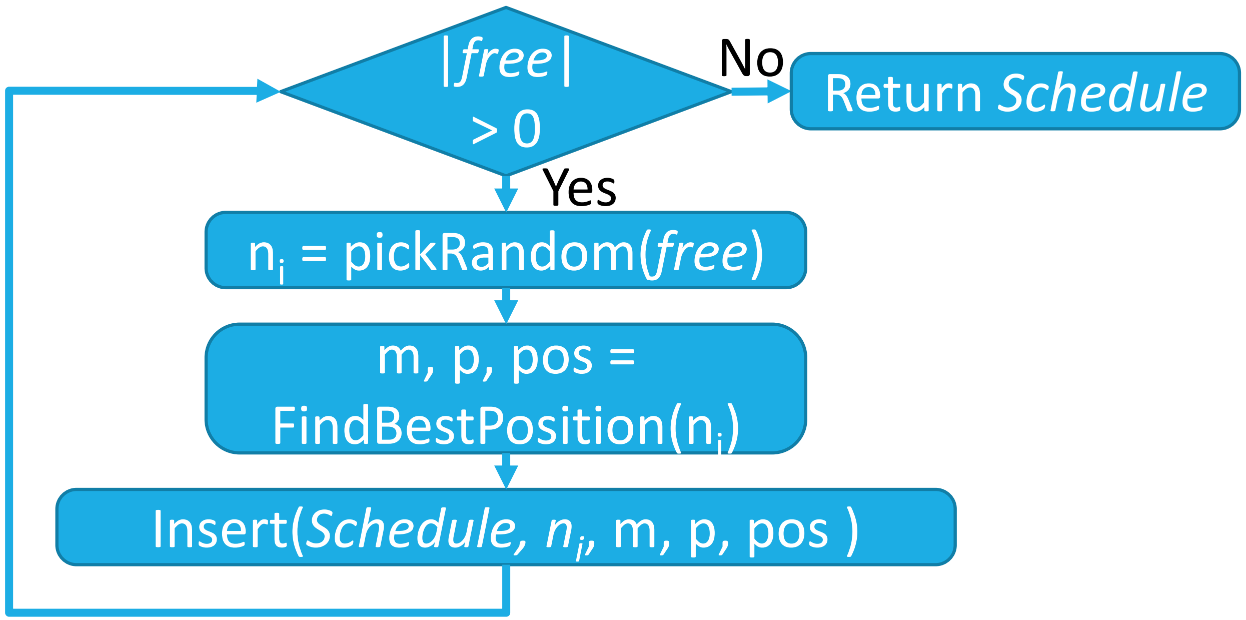


Node removal method



Node insertion method

- Pick a random node from the list of nodes that were removed
- Insert the node in the best position in the schedule



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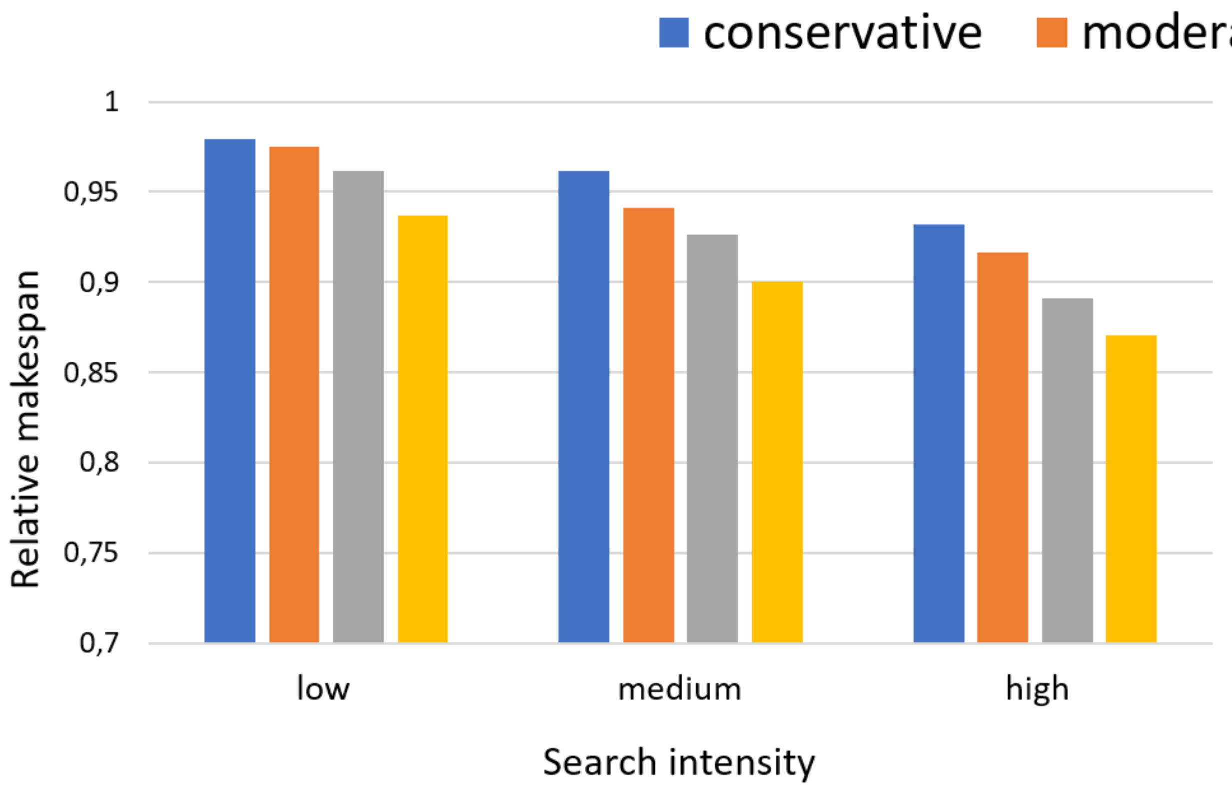
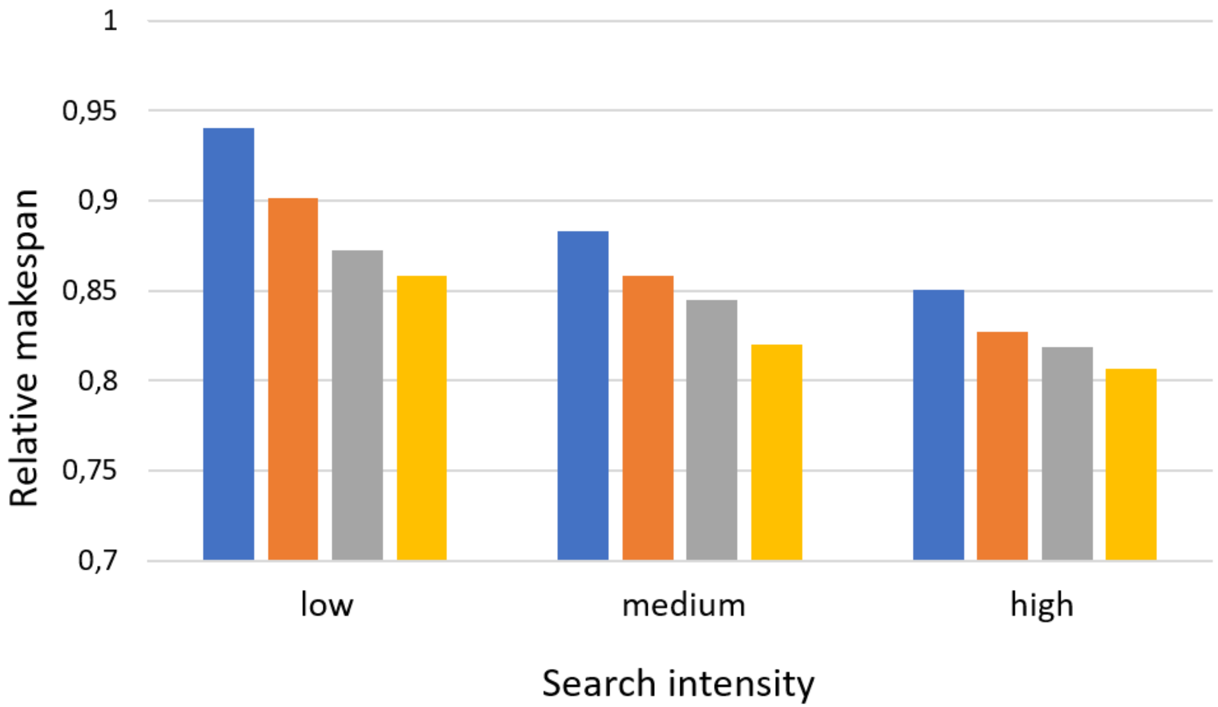
Experiments & results

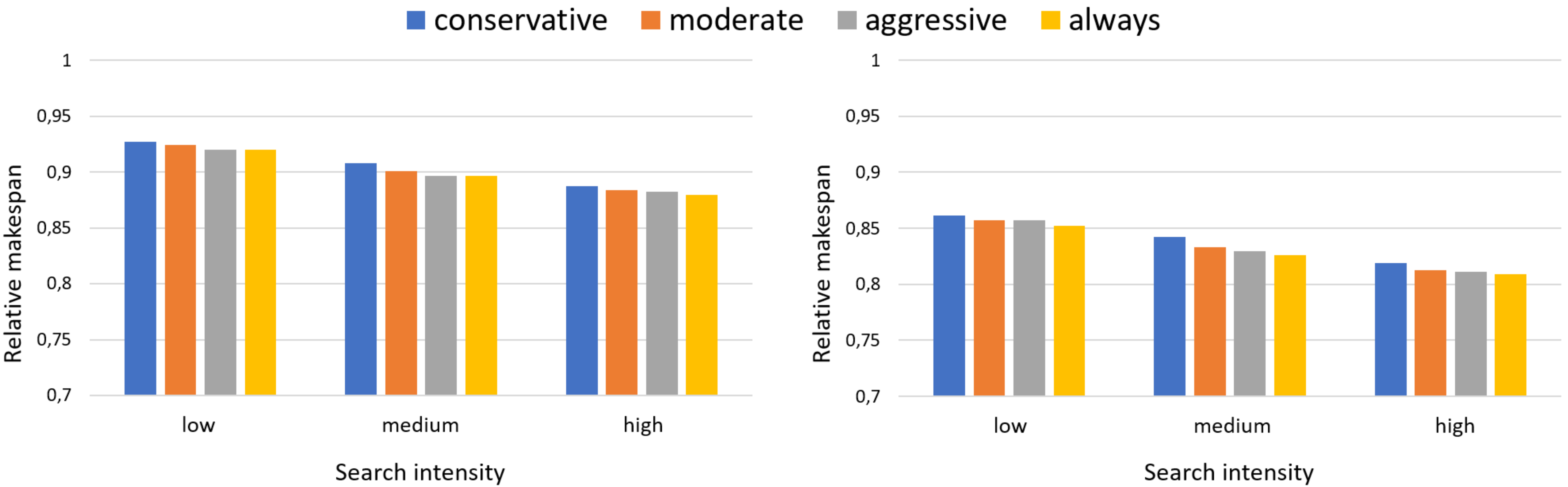
- Tested on a grid 11x11 (121 nodes)
  - Depot node on one corner node (peripheral depot scenario)
  - Depot node on the center node (central depot scenario)
- c_{ij} follows uniform distribution $[c_{ij}^{min} \dots c_{ij}^{max}]$
  - $c_{ij}^{max} = eucDist(n_i,n_j)$
  - Low uncertainty: $c_{ij}^{min} = 0.5*eucDist(n_i,n_j)$
  - High uncertainty: $c_{ij}^{min} = 0.25*eucDist(n_i,n_j)$
- Fleet of 3 vehicles
- Energy capacity = worst-case round-trip cost from depot to the farthest node
- Variables: Threshold, LNS Iteration
  - Threshold: 0.0 (always reschedule), 0.05 (aggressive), 0.1 (moderate), 0.2 (conservative)
  - LNS Iterations: 25 (low search intensity), 50 (medium), 100 (high)

Makespan (peripheral depot scenario)

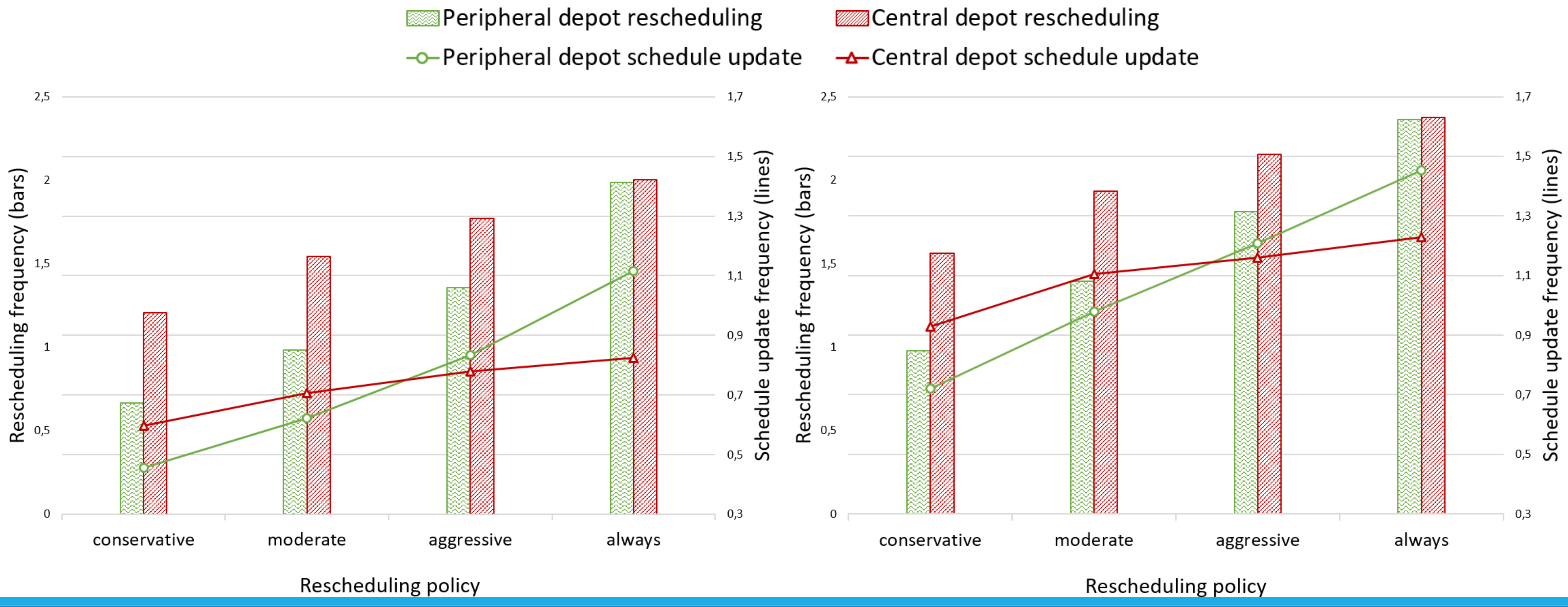




Makespan (central depot scenario)



Rescheduling/ Schedule update frequency



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Conclusion

- Online algorithm
  - Conservative planning (worst-case cost estimates)
  - Significant improvement in the makespan

- Future work
  - Test more sophisticated removal/insertion functions
  - Extend to tackle problems with multiple depots
  - Experiment with more optimistic heuristics
  - Experiment with real mission scenarios and cost estimates

Acknowledgements

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Auto-Scout

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