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Emerging paradigms and new models in urban air mobility, last-mile delivery, and fleet sizing

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Outline

Urban Air Mobility

Exact methods

Last-mile Delivery

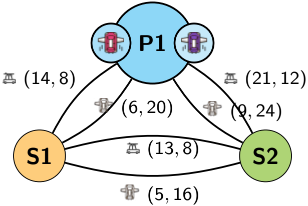
Mixed Integer Linear Programming

Fleet Sizing

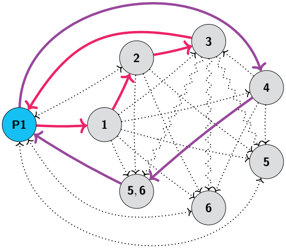
Approximate Dynamic Programming & Robust Optimization

The Multimodal Urban Air Mobility Problem with Synchronization Constraints – Problem Definition

Joint work with Feilong Wang (Beihang University) and Roberto Roberti (University of Padova)



- Requests, eVTOLs, vertiplaces
- Payload-dependent energy consumption and battery swap
- Temporal constraints: ready and due times, separation time, safety time, **synchronization**
- **Goal**: maximize the number of passengers served



The New York Times

Two Planes Collide on LaGuardia Airport Taxiway

A plane that was preparing to take off struck a plane that had landed, the authorities said. One passenger was injured.

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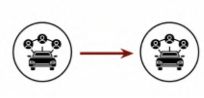
By Francesca Regalado and Mark Walker

Oct. 2, 2025 Updated 3:35 a.m. ET

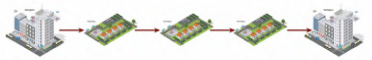
The Multimodal Urban Air Mobility Problem with Synchronization Constraints – Methodology and Results

1. (Not-so) Compact model using **arcs**



→ **MILP**

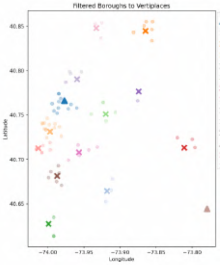
2. Integer relaxation using **trips**



+ Synchronization with **Flexible Job Shop Scheduling** → **Branch-and-Cut**

3. Integer relaxation using **journeys**

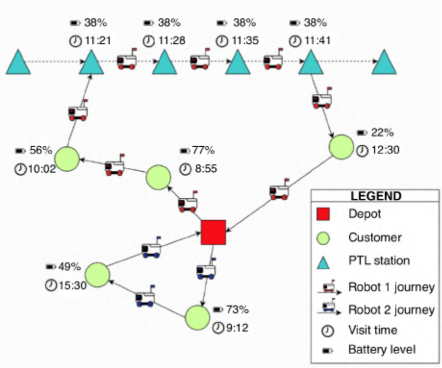
+ Synchronization with **Flexible Job Shop Scheduling** → **Branch-and-Price-and-Cut**



- Realistic instances from NYC taxi data
- BC solves instances up to 30 requests (1h), 10 (1.5h), and 10 (2h)
- BPC closes all 40 (1h), 40 (1.5h), and 30 (2h); largest: 60 requests

Last-mile Delivery with Autonomous Robots and Public Transport Lines – Problem Definition

Joint work with Antonino A. Carè (Politecnico di Milano), Roberto Roberti (University of Padova), Sara Stoia (University of Calabria), and Yanlu Zhao (Durham University)



- Single depot, homogeneous robots, customers, and **metro stations**
- Payload-dependent energy consumption and battery swap
- **Goal**: minimize total cost to serve customers

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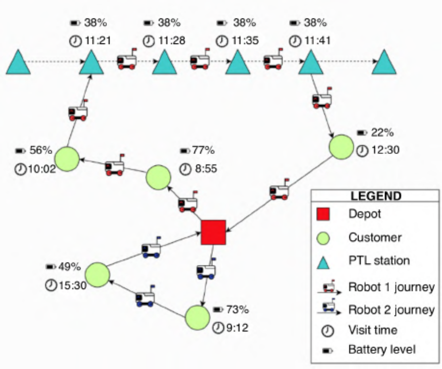

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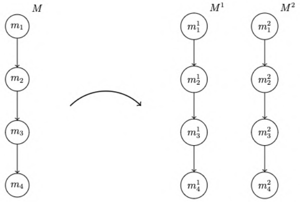
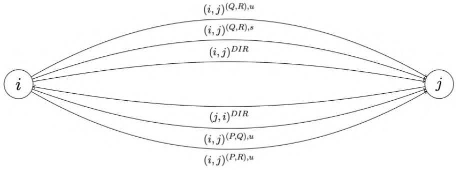
Last-mile Delivery with Autonomous Robots and Public Transport Lines – Methodology and Results

1 **Shift network**:

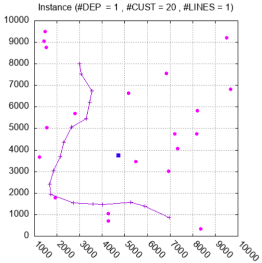


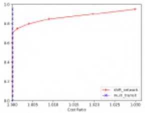
$\rightarrow$ Traditional x_{ij}

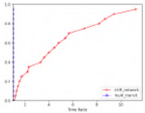
2 **Multi-transit network**:



$\rightarrow$ x_{ij}^{DIR} and $x_{ij}^{\text{PR},s}$ + dominance rule





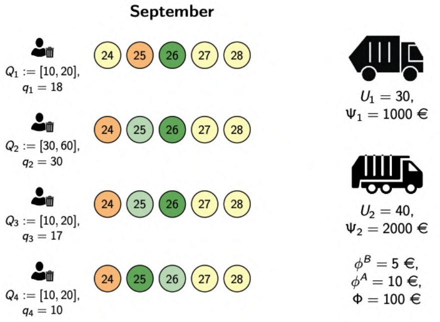


- Realistic instances with 20, 40, or 60 customers and 2, 4, or 8 robots
- Sensitivity analyses

Robust Policies for a Multi-Period Fleet Sizing Problem under Demand Uncertainty – Problem Definition

Joint work with Demetrio Laganà (University of Calabria) and Roberto Roberti (University of Padova)

- Stochastic-dynamic setting over multiple days
- Customers with **uncertain demand in known intervals**, day windows, and penalties
- Vehicles with $\neq$ capacities and fixed costs
- **Goal**: minimize total costs due to fleet sizing, staffing, and customer inconvenience



Optimal solution (value = 2205 €) – Employ vehicle 2 to serve:

- Customers 1 and 3 on 09/26
- Customers 2 and 4 on 09/25

Robust Policies for a Multi-Period Fleet Sizing Problem under Demand Uncertainty – Methodology

Lower bounds:

1. EP – Deterministic ex-post:
   - Variables for service, usage, and number of vehicles of each type each day
   - Constraints on service, capacity, vehicle availability
2. QMIN – Pending orders in the objective function and uncertain orders with minimum demand in constraints

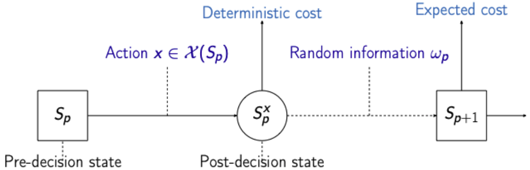
Upper bounds:

1. WC – Worst case (maximum demand)
2. RO – Robust counterpart: **budget of uncertainty** and cardinality-constrained uncertainty set

$$\sum_{i \in N_0} q'_i a_{ikp} + \sum_{i \in \tilde{N}} \underline{q}_i a_{ikp} + \max_{\substack{I \subseteq \tilde{N} \\ |I| \leq \Gamma}} \sum_{i \in S} (\overline{q}_i - \underline{q}_i) a_{ikp} \leq R_k u_{kp} \quad k \in K, p \in P \setminus \{0\}$$

Linearization through dualization or recursive equations

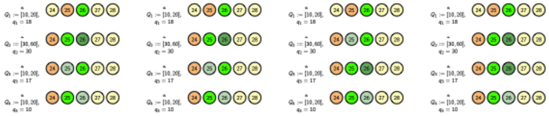
Robust Policies for a Multi-Period Fleet Sizing Problem under Demand Uncertainty – Methodology



Definition of **Approximate Dynamic Programming** policies applied in a folding-horizon fashion to provide **upper bounds**

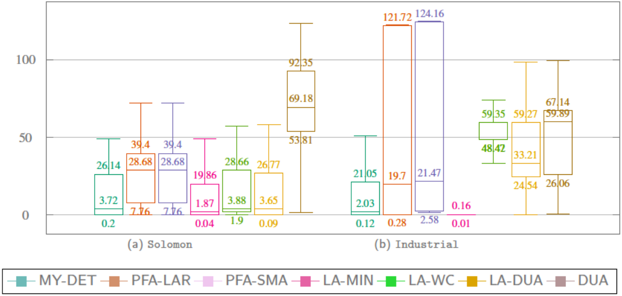
$$\text{QMIN} \leq \text{EP} \leq \text{RO}, \textbf{UB} \leq \text{WC}$$

EP	UB^{RO}	UB^{QMIN}	UB^{MY}
2205 €	**2205 €**	3305 €	3310 €



Robust Policies for a Multi-Period Fleet Sizing Problem under Demand Uncertainty – Results

- Tests on Solomon instances (25 or 50 customers, homogeneous vehicles) and others derived from an industrial case study (≈ 200 customers, small and large vehicles)
- Policy performance and price of robustness



- Sensitivity analyses increasing the degree of uncertainty, on extreme realizations, and varying maximum demand

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Thank you for your attention!
Any question or feedback is welcome.

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