DYNAMIC ANT COLONY OPTIMIZATION FOR EV ROUTING & CHARGING:

AN ADAPTIVE ACS FRAMEWORK FOR TRANSITIONING THERMAL DELIVERY ROUTES TO ELECTRICAL VEHICLES.

MOTIVATION: Urban logistics is undergoing rapid transformation due to the rise of last-mile delivery services and the shift toward low-emission transportation. Despite the growing interest in electric vehicles (EVs), internal combustion engine (ICE) tours still dominate operations. Existing delivery routes, pre-optimized for ICEs, often fail to account for EV constraints such as limited range and the need for charging stops. Fully redesigning routing plans is costly and time-consuming. The key question becomes: Which ICE routes can be feasibly operated by EVs without sacrificing delivery constraints?

METHODOLOGY

This project introduces EVROPT, a pragmatic optimization approach based on an enhanced **Ant Colony System** (ACS). Rather than redesigning tours, EVROPT adapts existing ICE-based delivery sequences to EV constraints by dynamically inserting charging stops based on energy, spatial, and temporal factors.

Key innovations

- **Dynamic Pheromone Deposition:** The ACS modifies edge desirability based on:
  - SOC (battery State of Charge)
  - Distance to nearest charging station
  - Remaining time until the next delivery window

- **Energy-Aware Transition Rule:** $P_{ij}^k = \dfrac{\tau_{ij}^{\alpha} \cdot \eta_{ij}^{\beta} \cdot E_{ij}^{\gamma}}{\sum_{k \in \mathcal{N}_i} \tau_{ik}^{\alpha} \cdot \eta_{ik}^{\beta} \cdot E_{ik}^{\gamma}}$

  Where τ_{ij}: pheromone trail, η_{ij}: visibility (inverse distance), E_{ij}: energy-based factor, α, β, γ: weighting coefficients.

- **Physics-Based Energy Model:** Energy consumption is calculated using vehicle dynamics (mass, slope, air drag, rolling resistance) instead of simple linear distance estimates.

- **Charging Network Integration:** Public and open-source station datasets are merged, deduplicated, and grouped within 1.5 km. Partial charging is supported up to 80% SOC.

- **Hard & Soft Constraints: Hard**: Time window violations lead to solution rejection ; **Soft**: SOC falling below 20% incurs penalization.

EXPERIMENTS

- **Data**: 7 delivery tours (10 clients each) from an industrial partner in Paris. All tours pre-optimized for ICE.
- **Implementation**:
  - Number of ants: equal to the number of graph nodes
  - Evaporation rate ρ: set to 0.5; Coefficients: $\alpha = \beta = \gamma = 1$;
  - Sigmoid function: applied during node selection (client vs. charging station), with steepness parameter k= 1.

Performance Metrics

- **Conversion Success Rate:** EVROPT identifies whether a tour can be executed by EV without changing delivery order.
- **Energy Feasibility**: SOC evolution monitored at each step.
- **Time Window Respect**: Evaluates on-time arrival at each delivery.

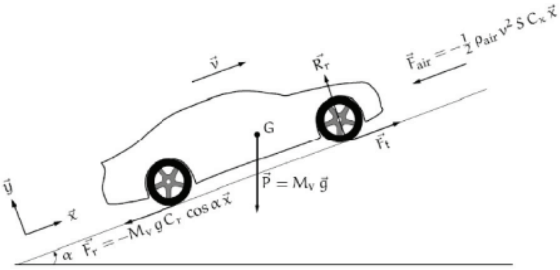

Fig. 1: Balance of forces acting on the vehicle

Results

- **< 90 km tours:** Fully converted to EV-compatible without time window violations.
- **> 90 km tours**: Charging detours introduced. Some intermediate TW violations occurred.
- **SOC Constraint**: Maintained >20% for all converted solutions.
- **Travel Time**: +39% to +65%; Distance: +11% to +112%.

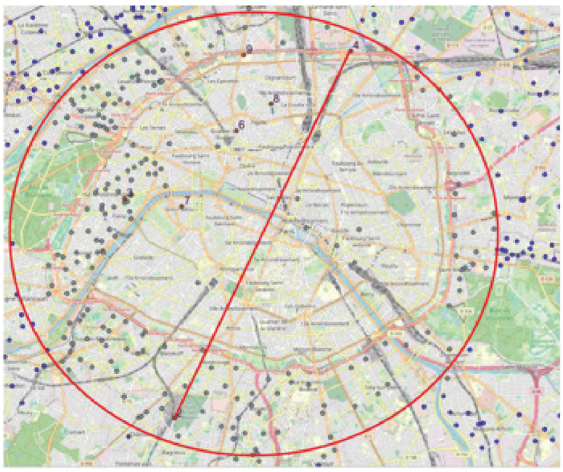

Fig. 2: Charging stations selected for the study and clients locations (Paris)

IMPACT

EVROPT bridges operational efficiency with sustainability by enabling:

- Rapid feasibility assessment of EV conversion
- Minimal disruption to logistics operations
- Better fleet segmentation between ICE and EV assets

FUTURE WORK

Our solution integrates real-time updates on traffic and charger availability, spatiotemporal clustering with time window reordering, and multi-objective optimization balancing energy, punctuality, and cost.

Reference

(PDF) Dynamic Ant Colony Optimization for EV Routing & Charging