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Fuel-based Trip-level Behavior Optimization Employing Metaheuristics

Dimitrios Nikolaou
Transportation Engineer - Research Associate
National Technical University of Athens

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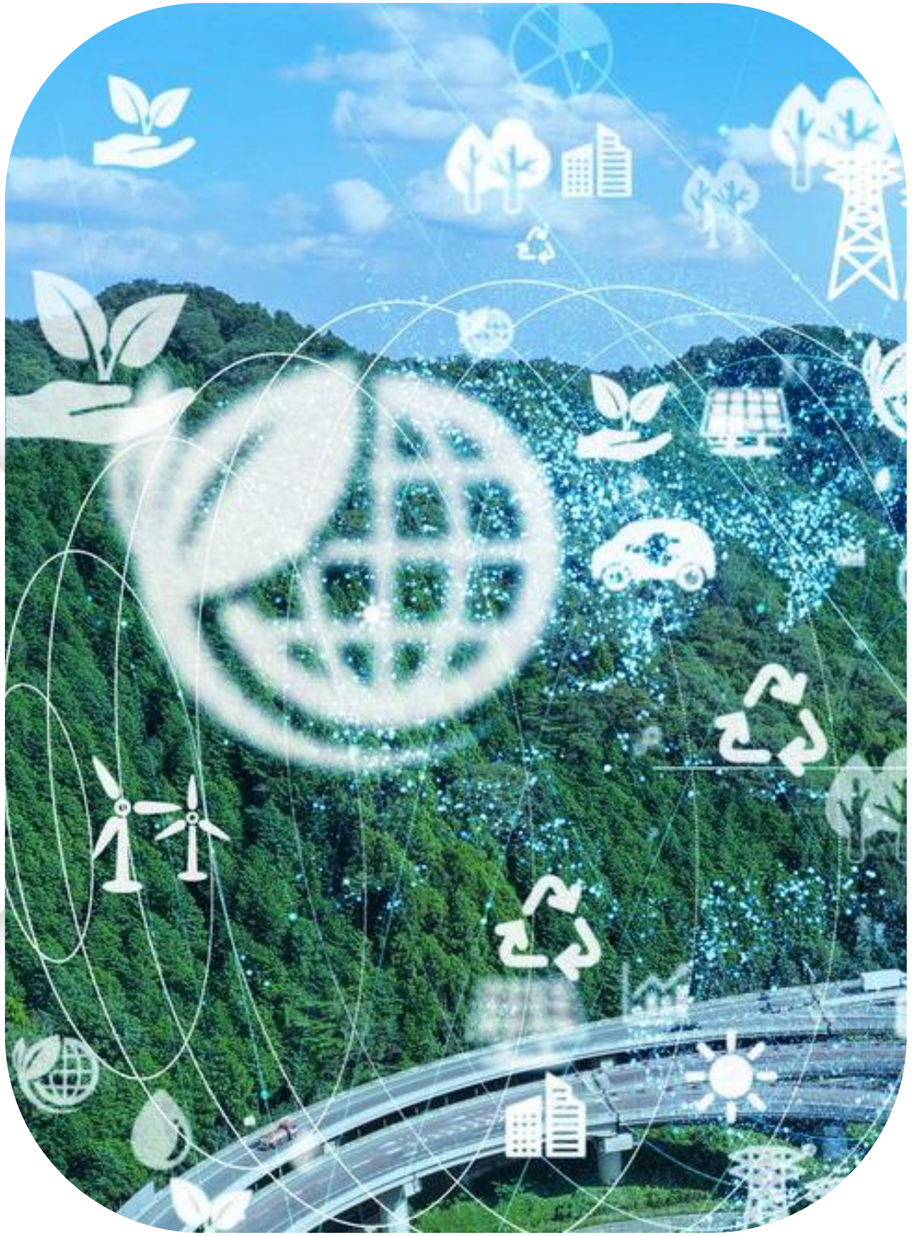
Outline

Background → Objective → Methodology → Results → Conclusions

Background

Background

- **Transport sector contributes:**
  - **~25% of EU CO_2 emissions**
  - **~30% of total energy consumption**
- **Urban mobility** is a key contributor to environmental impact
- **Fuel consumption** is influenced by:
  - **Driver behavior**
  - **Vehicle characteristics**
  - **Road environment**
- **Driving behavior** is the most flexible and impactful factor
- **Key variables**:
  - **Speed**
  - **Acceleration**



Research Gap

- Existing studies focus on:
  - Fuel modeling OR
  - Optimal control (e.g., DP, MPC)

- Limitations:
  - Often require high computational cost
  - Limited application to real-world large datasets
  - Lack of behavior-level optimization at trip scale

- Need for:
  - Scalable optimization frameworks
  - Based on real driving data
  - Preserving trip characteristics

Objective & Methodology

Objective

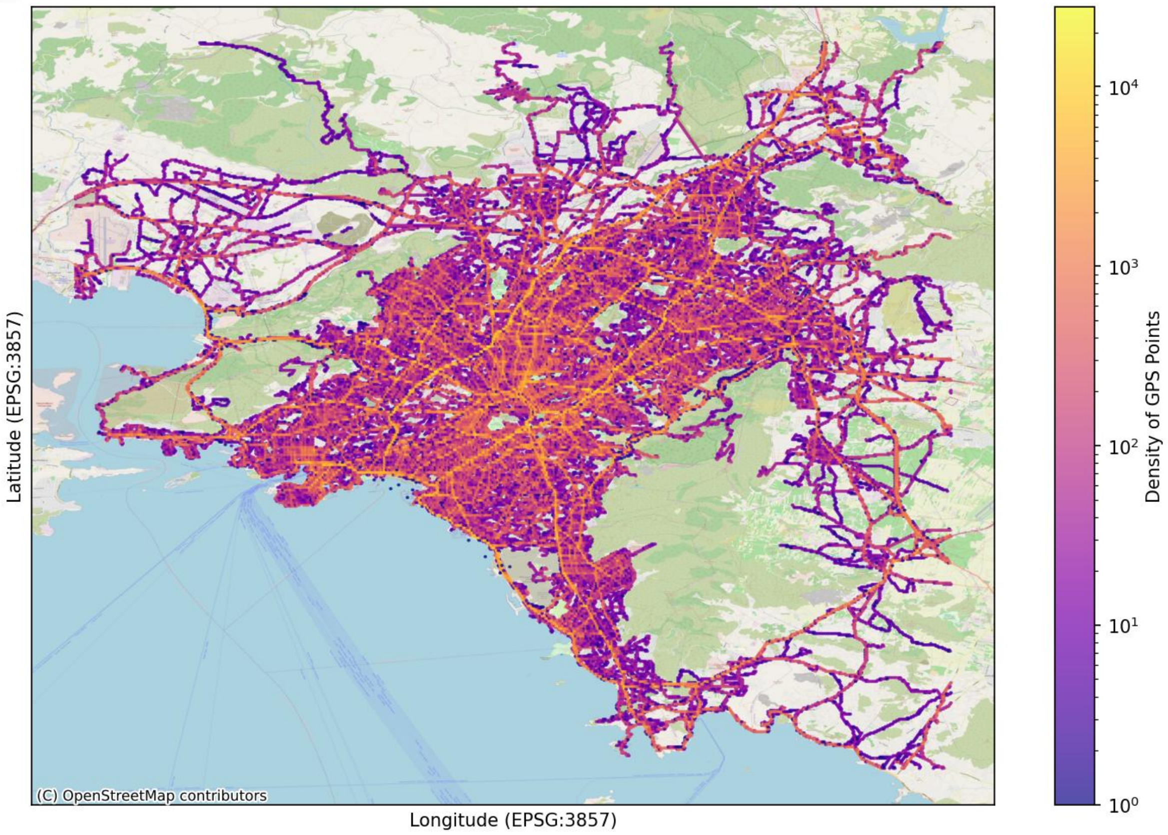
Develop a trip-level driving behavior optimization framework in order to:

- **Minimize fuel consumption**
- **Without affecting**:
  - **Travel time**
  - **Distance**
  - **Driving realism**

Methodology

Data Collection

- **Dataset:** 32,815 trips (Athens, Mar–May 2024)
- **Source:** Smartphone sensors (Oseven Telematics Company)
- **Data:**
  - **Speed**
  - **Acceleration**
- **Resolution:** 1-second level
- **Naturalistic** driving conditions



Methodology

Fuel Consumption Model

- Based on **VT-Micro model**
- **Inputs:**
  - **Speed**
  - **Acceleration**
- Captures **nonlinear driving behavior**
- Used as **objective function** basis

$$MOE(v,a) = \begin{cases} \exp\left(\sum_{i=0}^{3}\sum_{j=0}^{3} k_{ij}\, v^i a^j\right), & a \geq 0 \\ \exp\left(\sum_{i=0}^{3}\sum_{j=0}^{3} \ell_{ij}\, v^i a^j\right), & a < 0 \end{cases}$$

- υ = instantaneous vehicle speed (m/s)
- α = instantaneous acceleration (m/s²)
- k_{ij} = calibrated coefficients used when the vehicle is accelerating (α≥0)
- l_{ij} = calibrated coefficients used when the vehicle is decelerating (α<0)
- The model uses all terms up to cubic in both υ and α.

Methodology

Optimization Algorithms

Metaheuristic Optimization Approach

- Used to solve a **complex, nonlinear optimization problem**
- Suitable for:
  - **Large search spaces**
  - **Non-convex problems**
  - **No explicit analytical solution**

Ant Colony Optimization (ACO)

- Inspired by **ant foraging behavior**
- Explores multiple solutions using **pheromone-based learning** and balances:
  - **Exploration (searching new solutions)**
  - **Exploitation (refining best solutions)**
- Effective in finding **near-optimal driving profiles**

Latin Hypercube Sampling (LHS)

- Statistical sampling technique for **efficient search space exploration**
- Generates **representative solutions** with fewer samples
- Improves:
  - **Convergence speed**
  - **Computational efficiency**

Methodology

Optimization Problem

Objective

- Minimize **fuel consumption at trip level**

Decision Variables

- Instantaneous **speed profile**
- Instantaneous **acceleration profile**

Constraints

- Preserve **trip distance** (no route changes)
- Maintain **realistic travel time bounds**
- Respect **feasible driving behavior patterns**

Penalization Strategy

- Strong penalties applied to:
  - **Unrealistic speed/acceleration values**
  - **Deviations from original trip duration**
- Ensures **feasible and realistic optimized solutions**

Results

Optimized Driving Profiles

Speed Profile Optimization

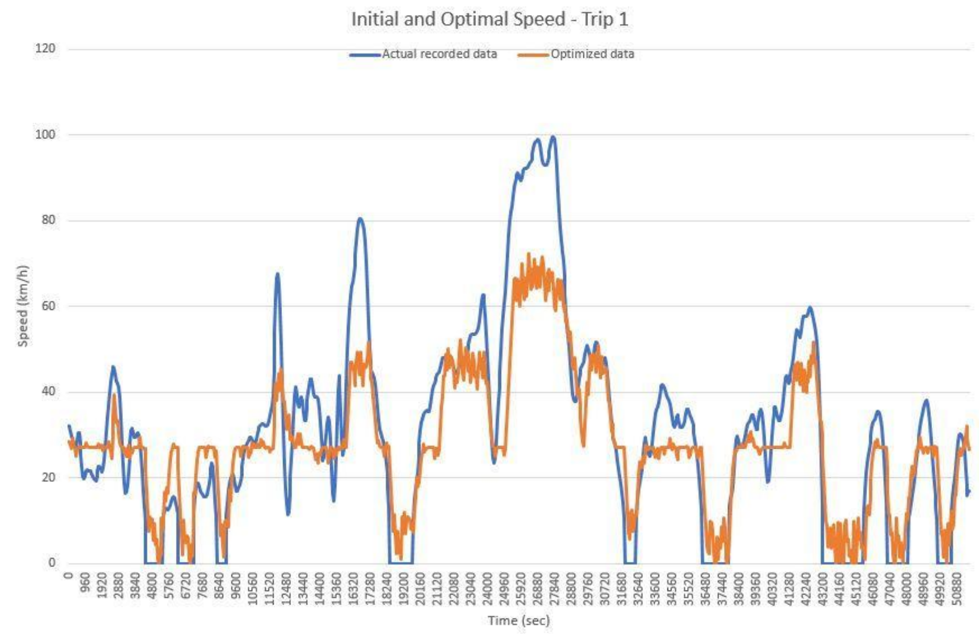
- Optimized trips show **smoother speed trajectories** over time
- Significant reduction in:
  - **Harsh acceleration and deceleration events**
  - **Sudden speed fluctuations**

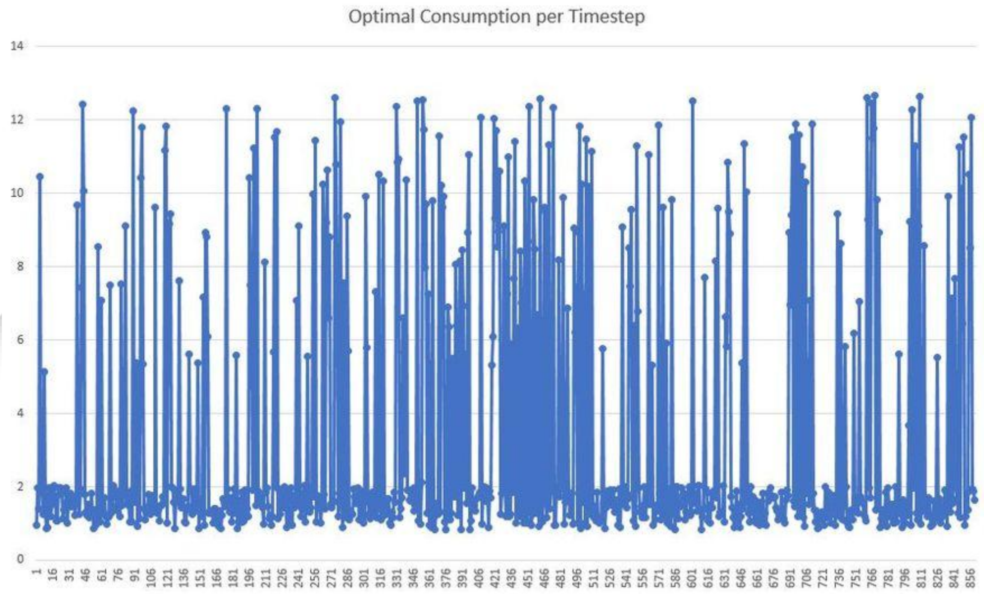
Behavioral Changes

- Driving becomes:
  - **More stable and continuous**
  - **Less aggressive**
- Reduction of **stop-and-go patterns**

Impact on Driving Dynamics

- Lower variability in speed and acceleration
- Improved **energy-efficient driving patterns**





Fuel Consumption Reduction

- **Significant reductions achieved across all examined trips:**
  - **Trip A: –31.97%**
  - **Trip B: –32.98%**
  - **Trip C: –27.01%**
- **Reduced fuel consumption is mainly due to:**
  - Smoother acceleration profiles
  - Elimination of unnecessary speed fluctuations
  - More consistent driving patterns

	Trip A	Trip B	Trip C
Average Consumption of the Initial Trip (L/100km)	4.755	6.254	5.466
Average Consumption of the Optimal Trip (L/100km)	3.235	4.197	3.991
Reduction Percentage	-31.97%	-32.98%	-27.01%

Conclusions

Conclusions

- Driving behavior is a **primary determinant of fuel consumption**, and optimizing speed and acceleration can significantly improve energy efficiency
- The proposed framework demonstrates that **substantial fuel savings (≈27–33%)** can be achieved **without altering trip characteristics** (distance, duration)
- Metaheuristic algorithms effectively handle **complex, nonlinear driving behavior optimization problems**, providing robust near-optimal solutions
- The results highlight strong potential for **personalized eco-driving strategies** and integration into real-time driver assistance systems
- Supports development of:
  - **Eco-driving guidance systems**
  - **Sustainable mobility policies**
- Enables **behavior-level interventions** instead of infrastructure changes

Limitations & Future Directions

- Fuel consumption is estimated using a **physics-based model (VT-Micro)** with assumed parameters, without vehicle-specific calibration

- The analysis is based on a **specific dataset** (Athens, 3-month period), which may limit generalizability to other contexts

- The optimization framework does not explicitly account for:
  - **Traffic interactions**
  - **Road geometry or network conditions**

- Future work should focus on:
  - **Real-time implementation using live data**
  - Integration of **vehicle-specific and traffic data**
  - Development of **decision-support systems for drivers**

Thank you!

Dimitrios Nikolaou
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Re-Generation in transport