# A Workflow for Cost- and Time-Aware Refueling Itinerary Optimization

Marco Savarese[1,2], Carmine Zaccagnino[1,2], Antonio De Blasi[1], Giacomo Salici[1,2], Silvia Cascianelli[2], Roberto Vezzani[2], Carlo Augusto Grazia[2]
*Department of Engineering "Enzo Ferrari", University of Modena and Reggio Emilia*
[1]{name.surname}@pieno.dev, [2]{name.surname}@unimore.it

***Abstract*—The complete workflow of the RI-PIENO framework is presented, a system for refueling itinerary optimization that extends the original PIENO design. While prior work introduced the conceptual modules of RI-PIENO, their operational pipeline was not described in detail. This study makes the workflow explicit, covering the end-to-end process from CAN Bus data acquisition and stop detection to the construction of daily trip graphs, refueling optimization, and mileage prediction. By clarifying the sequence of operations, the contribution provides a reproducible and extensible foundation for future research and development.**

***Index Terms*—Intelligent Transportation Systems, IoT, Refueling Path Optimization, Time Series Analysis, V2X**

## I. Introduction

Optimizing refueling decisions is a critical challenge in modern transportation.

PIENO demonstrated the feasibility of optimizing refueling decisions by integrating intra- and inter-vehicle data, but it lacked explicit modeling of user mobility.

RI-PIENO addressed this limitation by incorporating mobility-aware modules, including daily trip graphs, fuel stop optimization, and weekly mileage prediction. However, the original RI-PIENO paper focused on the design and results of these modules, leaving the detailed workflow largely implicit.

The aim of this work is therefore to present the complete operational pipeline of RI-PIENO, highlighting how each step, from CAN Bus signal acquisition to high-level optimization, fits into a coherent workflow.

## II. From PIENO to RI-PIENO

The *Petrol-filling Itinerary Estimation aNd Optimization* (PIENO) [5] framework was a proof of concept that optimized refueling decisions by integrating intra-vehicle and inter-vehicle information. On the intra-vehicle side, a **CAN Access Module** (CAM) based on an ESP32 [2] microcontroller was developed to retrieve fuel level data directly from the CAN Bus [1]. This module provided a unified interface to abstract the heterogeneity of different vehicles. On the inter-vehicle side, the system integrated **government-provided data** on fuel stations,[1] an **Open Source Routing Machine** (OSRM) [3] for path-finding, **Meta Prophet** [7] for predicting fuel price trends, and a **Flutter**[2] application to interface with the user.

[1]https://www.mimit.gov.it/it/open-data/elenco-dataset/carburanti-archivio-prezzi

[2]https://flutter.dev

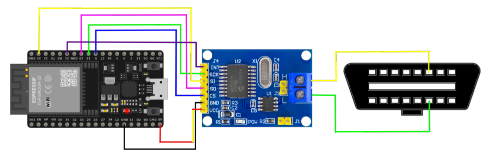

Fig. 1: CAN Access Module.

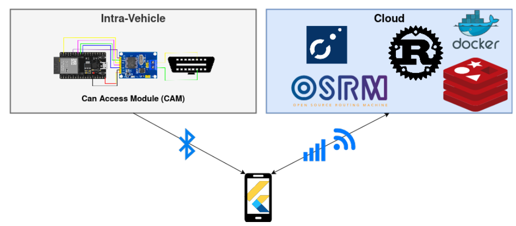


Fig. 2: PIENO's structure.

The resulting system (Fig. 2) identifies the most cost-effective fuel station and recommends the optimal refueling route, combining real-time vehicle status with predictive fuel price models. This allows the user to make well-informed refueling decisions.

However, PIENO is not a perfect system: it does not take user mobility into account and, as a consequence, operates as a one-off optimization engine. Furthermore, OEMs often do not adhere to standards such as SAE-J1979 [4], which define the mapping between a CAN message identifier and the meaning of the contents of the message. While addressing the latter issue requires active collaboration with OEMs or collective community efforts to establish reliable mappings across different vehicle models, the former is a tractable problem. In particular, it can be effectively solved by modeling user mobility patterns, which is the cornerstone of the RI-PIENO framework [6], a Revised and Improved PIENO.

RI-PIENO extends PIENO by embedding user-centric mobility modeling into the optimization pipeline. It introduces three core components: the **Daily Trip Graph**, which identifies frequent *Points of Interest* (POIs) and reconstructs daily flows as directed graphs; the **Weekly Mileage Prediction** component, which forecasts a user's mileage using an ensemble of models; and the **Fuel Stop Optimization** module, which integrates these graphs with a routing engine to compute refueling stops consistent with the user's habitual routes balancing two tunable constants, $K_1$ and $K_2$, which refer to time and

| | Cost [€] | Time [min] |
|---|---|---|
| Baseline | 44.53 ± 2.20 | 6.61 ± 1.01 |
| PIENO | 43.24 ± 2.09 | 7.10 ± 2.23 |
| RI-PIENO | 43.01 ± 2.13 | 4.98 ± 0.80 |

TABLE I: Comparison between the approaches.

cost respectively.

Together, these enhancements transform PIENO from a static decision-support tool into a continuously adaptive engine for refueling path optimization.

## III. Workflow

The RI-PIENO framework builds on the foundations of PIENO with a refined workflow. The CAM first captures the traffic on the CAN Bus and isolates the fuel-level signal, whose identifier can be inferred by correlating the fuel gauge behavior with the transmitted values. This approach, validated during PIENO's development on two Citroën vehicles [5], proved to be highly reliable.

In parallel, the CAM also detects vehicle stops by monitoring the CAN Bus. Since message transmission halts when the car is turned off, the absence of messages can be reliably associated with a stop event. These detected stops form the basis for constructing the **Daily Trip Graph**: each stop is stored in the application as a candidate Point of Interest (POI). Every entry is enriched with metadata, including a unique **identifier**, the **coordinates** of the stop (subject to clustering within a predefined threshold to merge nearby locations), the **visit frequency**, which is incremented at each occurrence, the corresponding **frequency category**, an automatically assigned label, and the **days visited**, which specify on which days the stop occurs. In this study, a candidate stop is promoted to a POI when it recurs at least two times per week within the observation period, which corresponds to the `MEDIUM` frequency category. The graph is then created thanks to the temporal information of the POIs. Fig. 3 and Fig. 4 provide further details.

The mobile application acts as the central hub, aggregating data from the CAM, the Prophet price prediction, and government sources. By leveraging the user's mobility patterns from the **Daily Trip Graph** and the **Weekly Mileage Prediction** modules, the improved **Fuel Stop Optimization** module suggests the best fuel station.

A validation of RI-PIENO, based on 15 different paths from 3 users, confirms its effectiveness. As shown in Tab. I, RI-PIENO provides significant improvements in both cost and travel time compared to PIENO and a baseline strategy that relies on the closest fuel station.

## IV. Conclusion

This paper has detailed the entire workflow of the RI-PIENO framework, filling the gap left by earlier work, where the process remained implicit. By clarifying the sequence of data acquisition, stop detection, POI promotion, graph construction, optimization, and prediction, we provide a transparent view of how RI-PIENO operates in practice. Beyond enabling reproducibility, this workflow description establishes a solid baseline for future extensions, including the integration of multi-day trips, real-time V2X data, and cooperative fleet optimization.

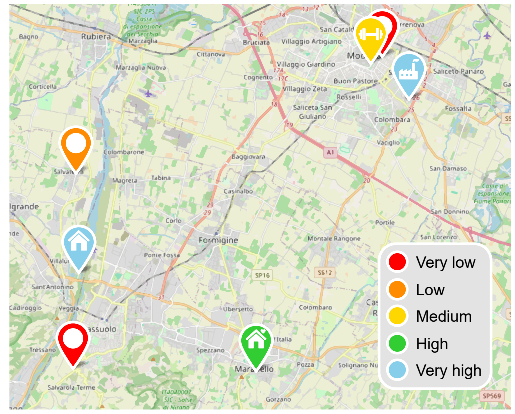


Fig. 3: Example of candidate stops and their frequency categories.

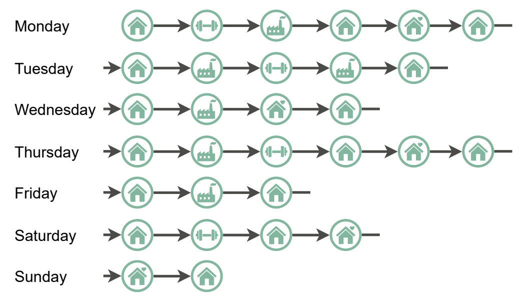


Fig. 4: Example of flow creation from POIs.

## Acknowledgment

This work was partially supported by MOST – Sustainable Mobility National Research Center and received funding from the European Union Next-GenerationEU (Piano Nazionale di Ripresa e Resilienza (PNRR) – Missione 4 Componente 2, Investimento 1.4 – D.D. 1033 17/06/2022, CN00000023).

## References

[1] R. Bosch GmbH, *CAN Specification Version 2.0*, Stuttgart, Germany, Sep. 1991.

[2] Espressif Systems, *ESP32 Series Datasheet*, 2023.

[3] D. Luxen and C. Vetter, "Real-time routing with OpenStreetMap data," in *Proceedings of the 19th ACM SIGSPATIAL International Conference on Advances in Geographic Information Systems*, ser. GIS '11. New York, NY, USA: ACM, 2011, p. 513–516. [Online]. Available: https://doi.org/10.1145/2093973.2094062

[4] SAE International, "E/E Diagnostic Test Modes," SAE International, Tech. Rep. J1979_201702, 2017.

[5] M. Savarese, A. De Blasi, C. Zaccagnino, and C. A. Grazia, "P.I.E.N.O.–Petrol-Filling Itinerary Estimation aNd Optimization," *IEEE Access*, vol. 12, pp. 158 094–158 102, 2024.

[6] M. Savarese, A. De Blasi, C. Zaccagnino, G. Salici, S. Cascianelli, R. Vezzani, and C. A. Grazia, "RI-PIENO – Revised and Improved Petrol-Filling Itinerary Estimation aNd Optimization," *IEEE CCNC*, 2026.

[7] S. J. Taylor and B. Letham, "Forecasting at Scale," *The American Statistician*, vol. 72, no. 1, pp. 37–45, 2018. [Online]. Available: https://doi.org/10.1080/00031305.2017.1380080