Integrating AI-based fleet optimization with mixed reality to enhance last-mile delivery

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***Abstract*—The expansion of e-commerce services and urbanization has intensified challenges in Last-Mile Delivery (LMD) regarding cost, timeliness, and sustainability. Increasingly, Artificial Intelligence is being employed to optimize fleet management, while the use of Augmented and Mixed Reality (MR) is growing to enhance warehouse operations. This work introduces an integrated LMD framework that combines AI-based optimization for shipment allocation and vehicle route planning with an MR-based headset interface to assist warehouse operators in vehicle loading and facilitate real-time information sharing with fleet managers. A case study of LMD in the Apulia region demonstrates the feasibility of the proposal.**

***Index Terms*—Last mile delivery, mixed reality, route optimization**

I. Introduction

The convergence of steep growth trends for both e-commerce and urbanization has been leading to a significant increase of Last-Mile Delivery (LMD) sustainability and effectiveness issues, driven by increasing operating costs, customers' time pressure and environmental impact [1]. In recent years, researchers and industry practitioners have increasingly turned to Artificial Intelligence (AI) techniques to address the complex challenges associated with warehouse management and fleet planning [2]. Current AI-based approaches provide global optimization capabilities, including warehouse operations, vehicle loading and path planning. Nevertheless, in order to foster seamless collaboration between fleet planning managers and warehouse operators, it is essential to facilitate the exchange of information. The integration of advanced interfaces such as Head-Mounted Display (HMD) in Augmented Reality (AR) and Mixed Reality (MR) can also provide significant benefits enabling operators to effortlessly visualize digital overlays on real warehouse environments, facilitating interaction with physical objects and virtual controls.

This work introduces a novel LMD framework integrating AI-based fleet management and MR-supported warehouse operations. The main AI-based features include fleet load optimization and vehicle route planning, which leverage and extend open source tools. Fleet load optimization is solved by means of meta-heuristic methods through a specialization of Capacitated Vehicle Routing Problem (CVRP), taking into account the requirements of LMD scenarios. Route planning extends a general-purpose vehicle routing engine with the integration of customizable traffic prediction models. The overall architecture is based on a client-server platform exploiting Web technologies to allow real-time coordination between fleet managers and warehouse operators. A case study on LMD problems in the city of Bari and the Apulia region has been developed for early validation of the framework prototype implementation, exploiting synthetic data for delivery problem generation and real historic traffic data for model training and solution planning. The remainder of the paper is as follows: the proposed architecture is described in Section II, whereas the case study in Section III highlights the peculiarities of the framework, before conclusion.

II. Proposed Framework

The proposed framework is designed as a REpresentational State Transfer (REST) multitenant client-server architecture responsible for the optimization of the vehicle fleet, providing basic Create Read Update Delete (CRUD) primitives to configure the initial state of the solver, start and stop the optimizer, and retrieve the schedule of the fleet. The *optimizer* component is built on top of *OptaPlanner* (https://optaplanner.org), an open-source AI-based optimization engine, and *GraphHopper* (https://graphhopper.com), an open-source routing engine designed for fast and efficient pathfinding and navigation. The estimated time for each route is subsequently adjusted by means of the *traffic predictor* component, leveraging historical traffic data to refine the time estimation provided by GraphHopper. Users can interact with the system exploiting different client software. A *mixed-reality application* for the Microsoft HoloLens 2 (https://www.microsoft.com/hololens) headset platform enables *warehouse operators* to receive real-time information about the allocation of each parcel to specific vehicles. Moreover, a *Web-based client* (Figure 1) allows *managers* to manage the optimization process and configure the system, setting parameters such as the locations of distribution hubs and shipments, the distribution of the fleet among hubs, the capacity of each vehicle, the daily departure time, and more. Following the initial setup, the optimization process can be initiated via this interface, which is then refreshed periodically to present the best solution available at each given moment. A read-only variant of the interface can finally be displayed in mixed reality to warehouse operators, allowing them to access information about the current state of the fleet and shipments.

III. Case study: AI-enhanced Last-Mile Delivery

The reference case study involves a fleet of 10 vehicles, a single warehouse, and a schedule encompassing 100 shipments

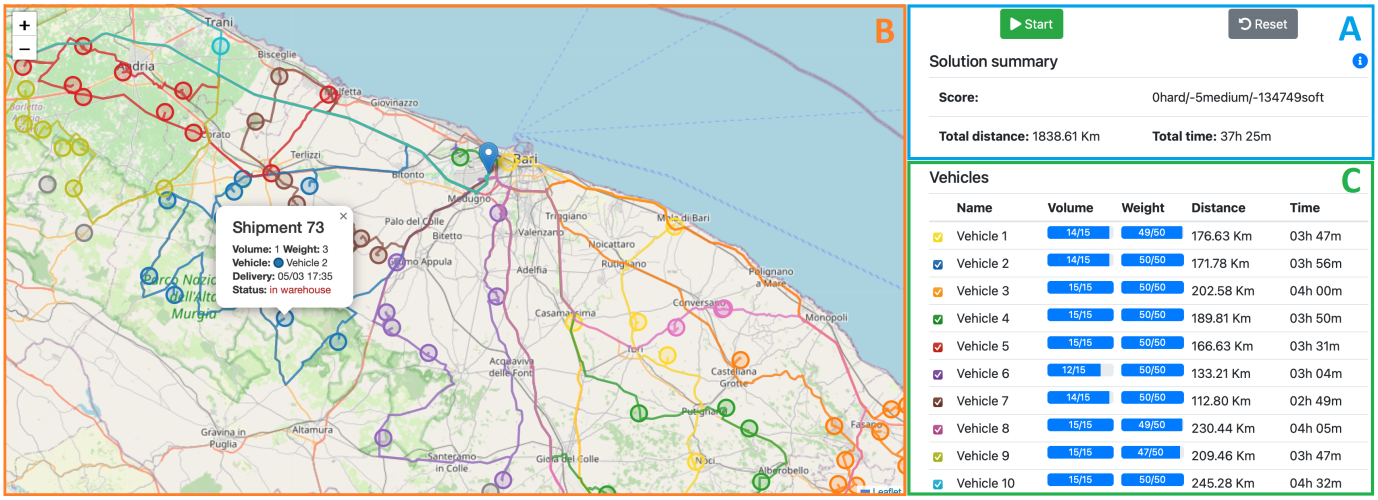

Fig. 1. Last mile delivery Web application.

that need to be fulfilled. A pseudo-random synthetic data generation method has been used to instantiate variable values dynamically. Additionally, the geographical location of each shipment is randomly generated within a bounding shape delimited by a polyline, delineating the confines of the Apulia region. Upon defining the problem instance, the manager can initiate the optimization procedure by interacting with the Web application (box A in Figure 1) The highlighted routes (box B) represent the optimal scheduling for the vehicles, accounting for specific constraints (*e.g.*, volumetric limitations, load restrictions, maximum duration of routes). The optimizer systematically iterates to enhance the existing solution (score, total time and cumulative travel distance, as shown in box A) until either a halt condition is reached, or the manager manually stops the solver. The final optimized schedule for the vehicles is reported in box C, providing comprehensive details about the total load volume and weight, as well as the distance and time required to fulfill the respective deliveries. The warehouse operator, equipped with a HoloLens 2 headset, interacts with an MR interface (Figure 2) consisting of several panels. *Proximity Menu* (box A) notifies the operator when the optimization process is finished, offering details about the cumulative number of parcels loaded onto the available vehicles. *Parcel Information Panel* (box B) provides details about the estimated delivery date-time, assigned vehicle and loading status. Using the *Parcel Picking Button* (box C), the operator can notify to the system the loading of the tracked parcel onto the designated vehicle. *Parcel Detail Button* (box D) provides additional details about shipments and assigned vehicles, ensuring all operators have access to the real-time information, potentially contributing to a reduction in errors and enhancing the overall operational efficiency of the workforce.

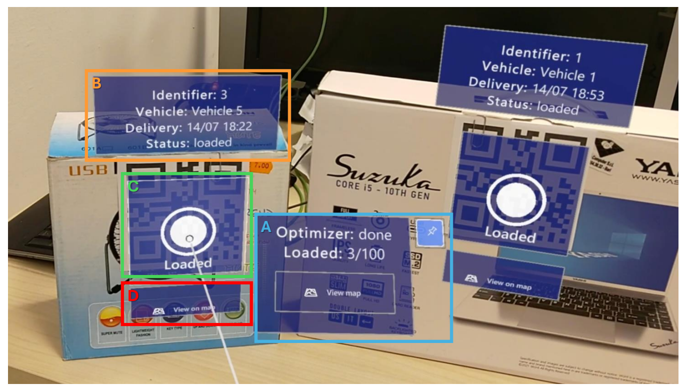

Fig. 2. HoloLens 2 Mixed Reality client.

IV. Conclusion

This work has presented a novel framework for Last-Mile Delivery, integrating AI-based fleet load optimization with MR warehouse management assistance. Benefits of the proposed approach include: seamless real-time information sharing for an end-to-end visibility of the delivery process; enhancement of open-source tools with customized problem configuration implementations. Further research directions will involve: integration of delivery drones in LMD to support mixed vehicle-drone scenarios [3]; development of blockchain-based traceability functionalities.

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