DRIVER-IN-THE-LOOP ELECTRIC VEHICLE ROUTING: SIMULATION, OPTIMIZATION, AND DRIVER TRAINING MODELS

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1 INTRODUCTION

Driver behavior represents the decisions, actions, and reactions made by vehicle drivers on public roads. It includes a broad spectrum of attitudes and habits that affect the driver's overall performance, safety, and fuel consumption while operating a vehicle [1], [2]. Most traffic accidents are caused in a significant extent by the behavior of drivers [3]. Driver behavior affects the fuel efficiency by about 10-15% [4]. [5] showed that driving style significantly impacts the fuel consumption of battery-based electric vehicles. The behavior of drivers is influenced by various factors, including traffic congestion, monotonous driving, long driving time, weather and road condition, and fatigue. These factors may have an impact on the drivers' decision-making regarding route selection, driving speed, and driving style (e.g., aggressive, defensive, etc.) [6].

Electric Vehicle Routing Problem (EVRP) is a mathematical modeling problem that is concerned about finding the best routes for a fleet of electric vehicles (EVs) to service a group of customers. Where every route begins and finishes at a certain depot node, and the fleet services a set of consumer nodes. EVRP's goal usually is to determine the optimal route plan for the EVs that minimizes a specified objective function (usually total cost, time, or fuel consumption) and complies with various regulations and electric vehicle operating procedures (e.g., short driving range) [7], [8]. However, drivers and their behavior are still ignored while planning for those routes [6], [9]. Dündar et al. (2021) presented a review paper on the sustainable urban vehicle routing, and the authors stated that there were no studies that examined the driving behaviors, opinions, and preferences for route planning of the drivers. Furthermore, there is no research in the relevant literature examines issues such as driver job satisfaction, driver health and safety, and drivers' schedules.

It is crucial to study drivers' behavior, take it into consideration when planning for logistical routes, and develop training environments to enhance drivers' behavior and performance. Studying the delivery drivers' behavior and the challenges they experience not only helps the delivery companies in planning for their delivery routes, but also can support the city planners and policy makers in designing the infrastructure, implementing compliance laws, and many more [2], [10]. Furthermore, it improves the driver safety and satisfaction.

Considering the driver-in-the-loop and the driver behavior, while planning delivery routes, will help providing more realistic, economic, and driver-friendly logistical solutions. First, giving the drivers some autonomy in selecting the route in congested areas and selecting the speed in non-congested areas in some cases reduce the trip time and fuel consumption because of the driver awareness about the situation [6]. For instance, Quirion-Blais & Chen (2021) found that experienced drivers, instead of cutting-edge algorithms, could frequently identify better routes in congested areas in last-mile delivery. Second, this will allow better planning for the driver frequent or infrequent breaks which helps preventing fatigue-related accidents.

Delivery drivers' training is also an important aspect especially for higher-order (none-technical) cognitive skills that demand the person to keep an eye on the environment's general circumstance, plan out future actions, make important decisions, remain conscious of the bigger picture, and evaluate how risky the present situation is [12]. Driving simulators were used previously for evaluating driving actions, driver behavior analysis, and drivers' decision-making in risky situations [13]. For example, training the drivers on selecting the optimal speed and on changing to better routes in congested areas will help providing fuel-efficient, safe, and more comfortable behavior.

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This dissertation will be executed over the following three phases:

- **Phase I: Understanding and Modeling of EVs Delivery Drivers' Behavior**

In this phase, a simulated driving experiment will be conducted using one of the simulation technologies to collect multimodal data (e.g., Electroencephalography (EEG) and Eye-tracking) to better understand and model the driver behavior under different conditions and scenarios (e.g., congested areas, running out of battery). After that, an agent-based simulation model (ABM) will be developed to demonstrate the EV's delivery driver behavior dynamics regarding their higher-order cognitive skills. The agents' rules and action in the model will be based on the findings from the simulated experiment and some theories from psychology, social, and human sciences.

- **Phase II: Integrating the driver behavior's ABM model with the EVRP Model**

In this phase, the driver behavior's agent-based model will be integrated into the EVRP model in a stochastic simulation model using AnyLogic software. EVRP will be formulated and solved within AnyLogic, and a case study for a small to medium routing network will be solved under different scenarios of driver's behavior. The model performance measures will include total cost, time, and fuel consumption. The findings from testing different scenario will be used also to develop the training guidelines.

- **Phase III: Drivers Training using Simulation**

This phase will provide training protocol recommendations that logistical companies could use to train their EV drivers and enhance their behavior in speed-choices and route-choices to maximize their comfort, fuel-efficiency, and safety while driving. A research experiment will be conducted on a driving simulator to measure the effectiveness of the training. The training effectiveness will be measured by comparing the eye-tracking, EEG, and drivers' opinions data before and after the training.

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