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Assessment of Sustainable Transportation Model Using Energy-Efficient Algorithm

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Abstract

The proliferation and extensive utilization of vehicles have escalated energy use and increased environmental damage. Utilizing large amounts of information on metropolitan traffic patterns can enhance vehicle transportation's environmental and financial aspects. This can be achieved through an efficient decrease in fuel consumption and contaminants. This study aims to present a novel framework for evaluating the Sustainable Transportation Model with Energy-Efficient Algorithm (STM-EE) by utilizing Route Planning Algorithms (RPAs) in a simulated environment. The CARLA simulator was used to compare the widely used conventional Dijkstra technique and an Integrated Genetic Algorithm (IGA) that integrates Genetic Algorithm (GA) with Particle Swarm Optimization (PSO) in different driving scenarios. This study aims to quantify the effects of RPA decisions on the energy consumption of vehicles. The efficiency of comparing the two RPAs has been enhanced by employing an offline energy estimate methodology. The proposed architecture is assessed through EE simulations to demonstrate its efficacy and adaptability. The results support the development of energy-efficient RPA solutions, which contribute to advancing the STM field.

Keywords: Sustainable Transportation, Route Planning Algorithms, Energy Efficiency, Genetic Algorithm, Dijkstra's Algorithm.

1 Overview of the Sustainable Transportation Model

Much of the world's energy consumption and air pollution comes from transportation. According to previous data, it meets 60% of the world's oil demand and provides 30% of its energy. In addition, it should be mentioned that road cars are responsible for almost 80% of the transportation sector's overall energy consumption (Amin et al., 2020). There are a lot of different things that different countries are doing right now to deal with transportation energy and air pollution (Praveenchandar et al., 2024). A

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portfolio approach is suggested to lessen the amount of pollution in the air caused by transportation. Diminishing the use of fossil fuels in transportation is critical for easing the transition to a carbon-neutral economy. Many groups and individuals, including companies, universities, and governments, believe in the benefits of electric transportation (Raman et al., 2023; Ramachandaran et al., 2023).

One viable option for developing low-carbon transportation networks is STMs. STMs have suggested a realistic way to lessen the impact of greenhouse gas emissions in response to the pressing problems of air pollution and the worldwide scarcity of fossil resources. Renewable energy sources have a more enduring impact on the environment when used as a main source by countries (Xu et al., 2021). Regarding renewable energy sources (RES), STMs are a huge step forward regarding environmental friendliness. STM approaches pave the way for renewable energy sources to power vehicles.

RES and STMs have the potential to decrease significantly greenhouse gas emissions in power production, logistics, and transportation (Prashanth et al., 2024). Nations worldwide have established ambitious objectives to promote STMs, and some are even considering banning the sale of gasoline-powered automobiles (Giji Kiruba et al., 2023). By 2026, Norway mandates that zero-emission vehicles must make up 99 percent of the sales of new vehicles. China aims to reach a yearly selling volume of 8 million sustainable cars by 2026, which would account for about one-sixth of the total domestic demand in the nation.

To accurately forecast energy utilization, it is important to consider the primary elements that drive or influence it (Qi et al., 2018). The energy use of STMs is affected by various factors that can be categorized into two main groups: (i) vehicle-specific internal variables such as vehicle layout factors, features, utilization of additional devices, effectiveness, and momentum of vehicle equipment, and (ii) outside driving-related variables like driving conditions, road kinds and conditions, surroundings, and traffic conditions (Trivedi et al., 2023). The outside components displayed varying levels of ambiguity in practical driving circumstances. Prior research has investigated the correlation between energy use and multiple vehicle factors, including velocity, halting, and supplementary loads. According to the authors, there is a strong correlation between energy usage and the mean velocity of traffic. Additionally, the energy utilization of STMs is greater on roads inside a city than on highways (Pan et al., 2023; Subrahmanyam et al., 2024).

Technology, highway atmosphere, and driving competence primarily influence automobile fuel usage. Among these elements, road setting, which encompasses road category, automobile movement, and junctions, significantly contributes to higher fuel expenditure and pollutants (Kim et al., 2023). Automobiles on various roads exhibit notable disparities in energy usage and pollutants. So far, much research has examined the vehicle routing issue and specifically examined how varied road conditions affect energy usage and pollutants (Punriboon et al., 2019). These studies aim to develop RPA models that optimize various objectives. Furthermore, several additional study fields prioritize the primary goal of using optimum control approaches for route planning.

This work aims to fill a significant need in the current research on energy-efficient RPA for STM (Subrahmanyam et al., 2024). This study diverges from present research patterns that primarily examine theoretically accurate metrics such as shortest route length. This analysis focuses on the influence of route planning decisions on energy consumption. The proposed model introduces an innovative approach to evaluate the effects of different RPAs on energy efficiency in a simulated practical application. This study focuses on analyzing two widely acknowledged RPA methods: the conventional Dijkstra technique and IGA (Babu et al., 2023).

2 Related Works on RPA and STM

Chu et al., (Chu et al., 2015) suggested a way to plan routes for self-driving cars that aims to make moving around in open areas easy and useful. A graph-based searching paradigm and a discrete kinetic vehicle paradigm have been used to find a safe, non-holonomic, and non-collision-prone primitive route. After that, the program uses local shortcuts to make the route that was found smoother and better (Kim et al., 2023). We show examples and give real-world results for calculating a trajectory in real-time on a nonlinear route using a driverless car. Although the amount of freedom has been raised, the cost functions still need to be considered.

In 2021, researchers (Tammvee & Anbarjafari, 2021) did tests on many different neural network models, each with a different level of intricacy. Each model is retrained using a fresh collection of information from AGVs equipped with the newest and cheapest sensors common in self-driving cars. How well the end motion detection works is used to choose the best model. The best model's workflow is combined with YOLOv3 to improve the accuracy of finding people. Several movement directions estimate methods have been proposed to improve pipelines. Even though it uses a lot of energy, the procedure is very effective.

Azadani & Boukerche (Azadani & Boukerche, 2023) developed the Spatio-Temporal Attention Graph (STAG) in 2022. It is a revolutionary graph-based method for predicting where vehicles will go. In particular, STAG immediately starts social relationship modeling and relationship reasoning by looking at spatial connections and moving disposition features around using an ordered graph. We test STAG's success on three types of roads: organized roadways, complicated intersections, and very busy crossings without signals. Based on the information, STAG shows better success in predicting routes than some test methods. The primary advantage is the high-performance economy, though it drops when used on roads that aren't properly built up.

Liu et al., (Liu et al., 2022) suggested an approach that uses a locally optimal motion driver with an MDP (Markov Decision Process) model to make transportation paths. This method can combine info at the network level. The suggested design makes the journey safer while reducing costs, including time and gas. The modeling results show that vehicles and the cars around them in all test cases may be more efficient in various traffic situations. This study shows that data can be used in transportation planning through link and liberty, which is a proof of concept. The main pro is the lower cost, and the main con is that it makes the network less efficient because of several factors.

In (Ma et al., 2021), authors created a system in 2021 that could plan the routes of Connected and Autonomous Vehicles (CAVs) in an area with Human-driven Vehicles (HVs). An independent time-based bi-level optimization framework has been created to improve the transverse and axial paths (Suvarna & Deepak, 2024). A sliding horizon device makes the suggested approach work well when road conditions change. The suggested planning of the paths model is useful through numerical studies. Based on the risk evaluation, the proposed approach will work well with a limited region size of 250 m. The greatest advantage is that it is more efficient, while the main drawback is that it can cause traffic jams (Mada & Abdulatif, 2023).

The STM has parts for sensing, management, and making decisions. Looking into different route planning methods is important and hard, especially when things are complicated, like when the environment is changing (Jazem, 2023). Scholars have developed RPAs that can be easily used to solve guidance problems in models or simple situations. These old ways might help you figure out potential routes, but keeping up with the moving vehicles is hard.

3 Sustainable Transportation Model with Energy Efficiency Algorithm (STM-EE) by Using Route Planning Algorithms (RPAs)

The CARLA simulator compared the widely used conventional Dijkstra technique and an IGA that integrates GA with Particle Swarm Optimization (PSO) in different driving scenarios. The project aims to quantify the influence of RPA decision-making on the energy consumption of cars, allowing data-driven enhancements to decrease energy use. This model is specifically built to match the trajectories provided by the two RPAs included in it. Figure 1 illustrates the STM-EE framework using RPAs.

As a structure, users may choose between two RPAs. The Dijkstra technique efficiently calculates the shortest route according to proximity in a minimal amount of time. On the other hand, the IGA algorithm looks for routes that meet three specific conditions: distance, time determined by the slowest speed on the geographical map, and an arbitrary score given to each vertex of the directed graph, which determines the plot layout for route variation. It has been offered the choice of using two RPAs. One RPA is dedicated to a single simulation run to identify the best pathways. These paths are then assessed using the EE model. This suggests a change of both RPAs to present alternative routes instead of only one, which is traditionally considered the best choice.

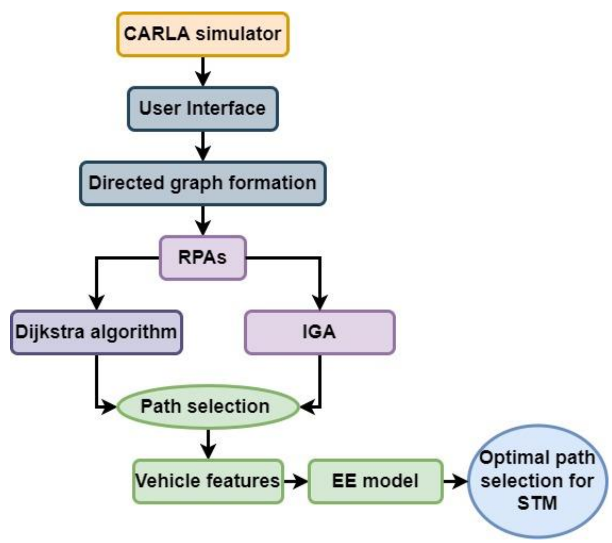

Figure 1: STM-EE Framework Using RPAs

In certain situations, the additional path may have a greater distance but less energy usage, for instance, since it has fewer stops. Therefore, the final choice step evaluates the optimal route by considering the combined factors of anticipated energy and time, as well as the precise length of the journey. Using this approach, we can identify the optimal route option and make valuable contributions to developing environmentally friendly self-driving vehicle networks. The proposed framework may be considered a method and foundation for employing Carla in route planning and EE (Dosovitskiy et al., 2017).

At first, the RPA processes are activated, and the outcomes are analyzed to identify connections. The connection consists of four stages that depict various actions of a vehicle: velocity, maintaining an unchanged speed, slowing, and being static. However, it is important to note that not all stages automatically form a single connection since topological factors might influence their order and incorporation. If a traffic signal is recognized after the connection, the relevant stages are retardation and motionless. However, if there is no stop, the speed and constant velocity stages are carried out. Remarkably, the method of creating such connections is not given explicit consideration despite its substantial impact on energy results and vehicle performance. An approach to delineate this limitation is examining the velocity change rate throughout increasing velocity. Every road enforces a speed restriction that cars must adhere to, acting as a mechanism to control the highest attainable velocity while driving on the route. To reach the specified speed limit, it is necessary to calculate the speed for each distinct phase after evaluating what stages relate to the total EE. Routes in the Carla simulator are 3D-directed markers that store data regarding their position and direction inside a certain lane. We may also determine the features of that lane, such as prominent landmarks like stoplights, traffic signals, speed restrictions, intersections, height, and so on. The EE model necessitates the inclusion of these elements to establish the separate stages and compute specific physical quantities.

1) Dijkstra Algorithm

The Dijkstra algorithm is highly regarded and extensively used for optimum route design. Nevertheless, due to its broad-first search framework, the search region becomes too vast, leading to an overwhelming number of traversed nodes. Therefore, it is classified as a blind pursuit method and cannot achieve an efficient optimum RPA. The approach suggested in this research employs a rectangular region, the narrowest bounding rectangle of an ellipse, to restrict the search field and enhance the algorithm's performance.

2) IGA

The integration of GA and PSO algorithms in IGA further strengthens the synergy between the processes of exploration and extracting. The objective of combining these two algorithms is to integrate the global search capabilities of GA with the intellectual skill of PSO.

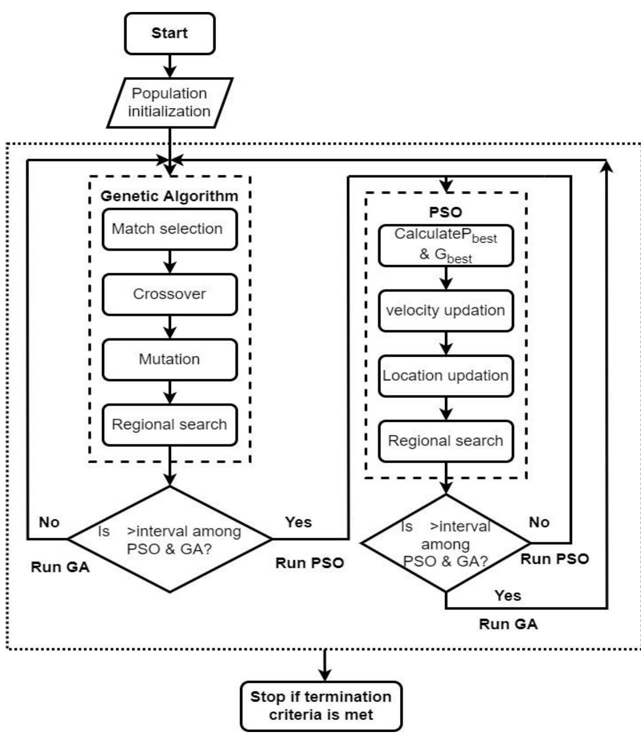

Figure 2: Flowchart of IGA for STM-EE Framework

Figure 2 illustrates the flowchart of the IGA for the STM-EE framework. The procedure commences by generating the initial population, which is then subjected to GA operations. These operations encompass selection, crossover, and mutation. An additional feature has been implemented in the GA algorithm to improve its effectiveness, which is a local search capability. The PSO algorithm generates random velocities for the populations, also called swarms, starting from the initial population. An enhanced swarm of particles has been generated, featuring increased speed and the integration of a local search technique to enhance performance by updating velocity and position. Once a certain number of iterations has been reached, the procedure is repeated, and the most optimum solution is chosen based on its suitability for the situation at hand.

4 Results

The evaluation was performed on a solitary system equipped with the most recent iteration of the Carla simulator (Deschaud, 2021). This allowed the use of pre-existing modules inside the virtual environment and other contributions. A virtual rendition of the Audi E-Tron in the simulator has been used, specifically configuring the automobile model to possess certain attributes of the Audi E-Tron, which served as a benchmark for the outcomes.

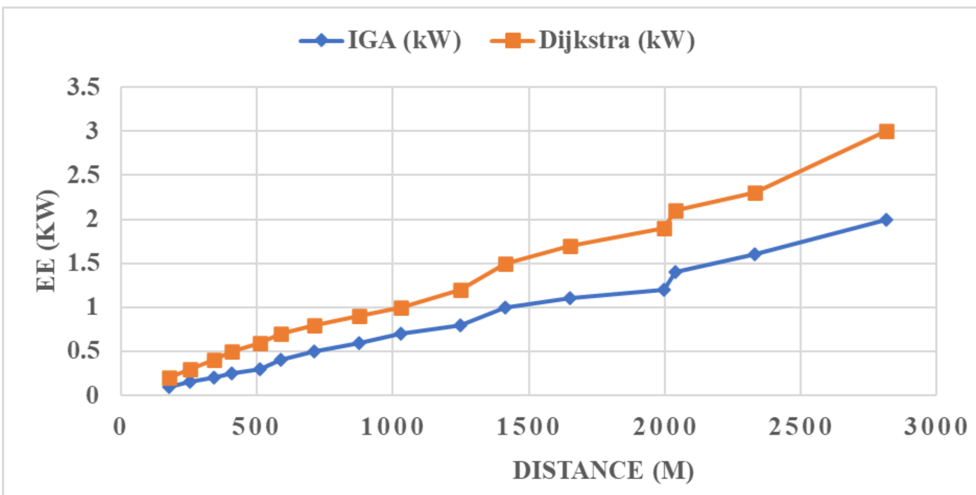

Figure 3: EE Results of STM Framework Using Dijkstra and IGA RPAs Considering All Available Maps

Figure 3 illustrates EE results of the STM framework using Dijkstra and IGA RPAs considering all available maps. Figure 3 demonstrates a direct correlation between the EE and the distance covered by the journey. The EE rises in proportion to an elevation in the distance. The selection of RPA has a noticeable impact on EE, and their effectiveness may vary considerably based on environmental complexity and features, indicating that HGA typically exhibits lower EE than Dijkstra's method over various distances. Given that all maps are components of the graph, we may infer conclusions on the influence of the surroundings. To be more precise, our attention might be directed to regions with mountains and intersections, as well as large-scale maps that depict multi-lane roads. These particular maps exhibit the most significant variations in outcomes. The first category (map factors and topography) provides more challenges for Dijkstra's method, resulting in higher EE values. These factors can lead Dijkstra's method to calculate pathways that require numerous pauses, launches, and shifts in altitude, all of which contribute to increased EE in the STM framework.

5 Conclusion

This paper presents a novel framework for evaluating the Sustainable Transportation Model with Energy Efficiency Algorithm (STM-EE) utilizing Route Planning Algorithms (RPAs) in a simulated environment. The CARLA simulator compared the widely used conventional Dijkstra technique and an IGA that integrates GA with Particle Swarm Optimization (PSO) in different driving scenarios. The Dijkstra technique efficiently calculates the shortest route according to proximity in a minimal amount of time. On the other hand, the IGA algorithm looks for routes that meet three specific conditions: distance, time determined by the slowest speed on the geographical map, and an arbitrary score given to each vertex of the directed graph, which determines the plot layout for route variation. The selection of RPA has a noticeable impact on EE, and their effectiveness may vary considerably based on environmental complexity and features, indicating that HGA typically exhibits lower EE than Dijkstra's method over various distances.

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Authors Biography

Dr. Arasu Raman, is a senior lecturer in Marketing and Management at INTI International University, holding a Ph.D. in Business Administration with a specialization in Marketing. His international educational background includes degrees from institutions in New Zealand, Australia, and the Philippines, which contribute to his global perspective. With over 27 years of teaching experience, he is certified as a Professional Trained Teacher by the University of Hertfordshire and in Case Teaching by Harvard Business School. Dr. Arasu has published 26 research articles in prestigious journals on topics such as entrepreneurship, digital marketing, and marketing information systems, including Scopus and WOS listed journals. As the university's sole entrepreneurial scientist and an active industry consultant, he is renowned for his innovative curricula and extensive international teaching experience. Dr. Arasu is honoured for his excellence in teaching, research leadership, and collaboration with major multinational companies.

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Dr. Stephen Antoni Louis, is a distinguished academician and corporate professional with over 25 years of experience in both sectors. He is currently the Director of the MBA program at Knowledge Institute of Technology, Salem. Dr. Stephen holds multiple qualifications, including a Ph.D., MBA, M.A, M.Phil and certifications such as a Six Sigma Green Belt from Benchmark, Australia. He has served in various leading institutions and played pivotal roles in academic and industry bodies like the Confederation of Indian Industry (CII) and Madras Management Association (MMA). Dr. Stephen is also an approved research supervisor for Anna University, Chennai, and active mentors Ph.D. scholars in HR, Marketing, and Finance. His expertise spans institution building, change management, and consultancy, with a strong focus on education and skill development was Recipient of Organisational Citizenship Behaviour (OCB) Award for Voluntary Commitment in the Educational Institution.

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