OPTIMIZING CROSS-BORDER SUSTAINABLE TOURISM ROUTES FOR ELECTRIC VEHICLES

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ABSTRACT

Purpose: Introduce a novel hybrid optimization model, combining Genetic Algorithms and Simulated Annealing, for designing efficient and sustainable cross-border electric vehicle tourism routes.

Design/methodology/approach: Develop an optimization model, integrates a hybrid approach that combines Genetic Algorithms (GA) and Simulated Annealing (SA) to find the best tourism routes for electric vehicles, using a case study in Ubon Ratchathani province in Thailand and Champasak province in Laos. The chosen routes begin and end at Ubon Ratchathani Airport, pass through the Chong Mek – Vang Tao border checkpoint. Data were collected from official tourism websites, online travel platforms, and Google Maps. The performance of this hybrid method was subsequently evaluated against key metrics, demonstrating superior results in terms of travel time, energy consumption and tourist satisfaction.

Findings: The study shows that the hybrid GA-SA method can effectively optimize cross-border tourism routes for electric vehicles that reduced travel time and distance while connecting important cultural and natural attractions. Compared to other planning methods, the hybrid approach offered better performance in terms of route efficiency and tourist satisfaction.

Research limitations/implications: This study is limited to one case area and assumes constant travel conditions. It does not include real-time factors or user preferences.

Practical implications: The model supports low-carbon route planning, EV infrastructure development, and sustainable tourism in cross-border regions.

Originality/value: It supports sustainable tourism, enhances route efficiency, and expands the application of metaheuristic techniques in transportation and tourism planning, particularly in environmentally sensitive and regional development contexts.

Keywords: Cross-Border Tourism, Genetic Algorithms, Simulated Annealing, Electric Vehicles, Sustainable Tourism

Introduction

The tourism sector is very important for the growth of the economy, contributing significantly to job creation and local economies. In recent years, tourists have shown a growing interest in discovering new destinations that are not widely popular (Timothy et al., 2023). This trend reflects a desire to avoid overcrowded areas and to engage with more authentic cultural and natural experiences. At the same time, many travellers are becoming more aware of environmental concerns, such as reducing carbon footprints and supporting sustainable tourism practices. As a result, the combination of rural tourism and electric vehicles presents a unique opportunity to promote eco-friendly travel while enhancing local economies.

Ubon Ratchathani, located in the lower northeastern region of Thailand, renowned for its long history, rich Buddhist traditions, and unique cultural festivals such as the Candle Festival, which attract both domestic and international visitors. With its natural beauty, including Phu Chong Na Yoi National Park and Pha Taem National Park, and the enchanting Wat Sirindhorn Wararam Phu Phrao, the city reflects both natural and cultural charm. Sharing a border with Laos, Ubon Ratchathani also serves as a gateway for cross-border tourism, encouraging cultural exchange and regional connectivity.

However, although Ubon Ratchathani has strong tourism potential, there is still no systematic route planning that fully considers eco-friendly practices, reduction of carbon emissions, and respect for cultural values. Existing tourism development strategies in the region often overlook the use of advanced optimization methods that can balance environmental sustainability with the satisfaction of tourists. To fill this gap, the present study proposes an optimization model that applies a hybrid approach, combining Genetic Algorithms (GA) and Simulated Annealing (SA), in order to identify the most efficient and sustainable tourism routes for electric vehicles.

Literature review

Traveling Salesman Problem (TSP)

The Traveling Salesman Problem (TSP) is one of the most widely studied problems in combinatorial optimization. It seeks the shortest possible route that visits a set of locations once and returns to the starting point. Due to its computational complexity, the TSP is classified as an NP-hard problem, meaning that the time required to find an exact solution grows exponentially with the number of locations (Lawler et al., 1985). This problem is not only a theoretical challenge but also has practical applications in logistics, transportation planning, tourism, and energy-efficient routing for electric vehicles (EVs). In the context of tourism, the TSP framework can model the problem of designing routes that maximize tourist satisfaction while minimizing travel distance and time.

Optimal Solutions

Several exact methods have been proposed to solve the TSP optimally, such as dynamic programming, branch and bound, branch and cut, and integer linear programming (ILP). These methods can guarantee optimality but are computationally expensive, especially for large-scale problems with many nodes. For small to medium-sized datasets, tools such as Concorde TSP Solver have achieved significant results (Applegate et al., 2006). However, the applicability of exact methods in real-world tourism planning is limited because route planning often involves large datasets, dynamic conditions, and multiple constraints (e.g., energy consumption, charging stations, or time windows). Therefore, heuristic and metaheuristic approaches are more practical in addressing these complexities.

Heuristic and Metaheuristic Approaches

Heuristic methods, such as nearest-neighbor and savings algorithms, provide fast but often suboptimal solutions. Metaheuristic techniques, on the other hand, are designed to explore the solution space more effectively and are widely used in large-scale routing problems. Among these, Genetic Algorithms (GA) and Simulated Annealing (SA) are two well-established approaches. GA is inspired by natural selection and operates through mechanisms such as crossover, mutation, and selection. It is effective in global search and avoids premature convergence by maintaining a population of solutions (Goldberg, 1989). SA, based on the principle of thermodynamic annealing, performs local search and allows occasional acceptance of worse solutions to escape local minima (Kirkpatrick et al., 1983).

Hybrid GA–SA Methods

While GA provides strong global exploration, it sometimes lacks efficiency in fine-tuning local solutions. Conversely, SA is effective in local refinement but may get stuck if not properly tuned. To overcome these limitations, hybrid GA–SA approaches have been developed. In such models, GA is typically applied to generate diverse candidate solutions, and SA is then used to refine them by exploring the local neighborhood. Studies have demonstrated that hybrid GA–SA models outperform single methods in terms of convergence speed, solution quality, and robustness (Xiao et al., 2013; Chen & Chien, 2011).

In the tourism and transportation domains, hybrid GA–SA approaches have been applied to problems such as vehicle routing, logistics distribution, and sustainable tourism planning. Suanpang et al. (2022) developed a hybrid genetic algorithm (HGA) combining a genetic algorihm (GA) and simulated annealing (SA) with a gradient search method to optimize complex tourism service scheduling processes in smart cities in Thailand. For EV-related applications, hybrid methods are particularly promising, as they can balance multiple objectives such as minimizing travel distance, reducing energy consumption, and maximizing tourist satisfaction. The combination of GA and SA allows models to handle both large problem sizes and real-world uncertainties, making them suitable for cross-border route planning where infrastructure and constraints differ across countries (Arafa & Eltobgy, 2021).

Methodology

Data Collection

Tourist attraction lists were identified from the Tourism Authority of Thailand and official Laos tourism portals. For each location, two additional types of data were gathered from Google Maps: (1) driving distance (2) tourist satisfaction scores based on the Google Maps rating.

To capture seasonal availability, each destination was assigned a seasonal score: a value of 1 if the destination was open all year round, and 0 if it was seasonal or had restricted periods of accessibility.

Finally, destinations were classified into four categories to support route diversity and analysis: nature attractions, cultural sites, markets, and historical landmarks. This grouping allows the model to balance travel efficiency with different types of tourist experiences, ensuring a richer and more representative route design.

Mathematics

Step 1:

The hybrid GA model approach incorporates dynamic components. This model will specifically cater to optimization problems Find the multi-day tourist route for EVs that **maximizes tourist satisfaction, seasonal reliability, and category diversity** while **minimizing distance,** according to the chosen weight balance

$$\max Z = \alpha \cdot \mathrm{Sat} + \varepsilon \cdot \mathrm{Mix} + \delta \cdot \mathrm{Season} - \beta \cdot D_{\mathrm{Dist}}$$

Where:

Sat	average tourist satisfaction score (from ratings × reviews)
Mix	category diversity score (nature, cultural, market, historical)
$Season$	proportion of all-year-round attractions visited
D_{Dist}	normalized travel distance
$\alpha, \varepsilon, \delta, \beta$	routes with **long travel times**.

Algorithm Steps:

Step 1: Initialize population

Build the first population (P_0, size 50–200) with

- Random permutations with day-breaks.
- Greedy routes (Nearest Neighbour).
- A few routes improved by simple 2-opt.

Step 2: Fitness evaluation

For each route:

- Compute $Sat, Mix, Season, Dist$
- Normalize values (so different metrics are comparable).
- Apply objective Z
- Penalize if rules are broken.

Step 3: Selection

- Use tournament or rank selection to choose parents.
- Higher-Z routes have higher chance, but diversity is kept.

Step 4: Crossover

- Recombine two parents (order-based crossover).
- Repair day-breaks so children still have N-1 breaks

Step 5: Mutation

With small probability (10–20%), apply:

- Swap two tourist destinations, insert a tourist destination elsewhere.
- 2-opt inside a day.
- Move a day-break to rebalance daily travel.

Step 6: SA Local Search (the hybrid part)

After crossover + mutation, each child is refined with SA:

- Pick a local move (2-opt, swap, re-insert, day-break shift).
- Compute new Z
- If better → accept.
- If worse → accept with probability $p = exp(-\Delta Z/T)$
- Gradually cool down T (e.g., T=0.95T)

Step 7: Stopping criteria

End when:

- Max generations reached (e.g., 500), or

- Best solution does not improve for many generations, or
- Distance reached.

Step 8: Output

Best n-day EV tourist route with:

- Total distance & travel time,
- Tourist satisfaction,
- Category diversity (Mix),
- Season share,
- Final Z

Optionally: show alternative routes (e.g., shortest vs. highest satisfaction).

Step 2: Compare Results and each method's route and total travel time.

Methods for Comparison

Nearest Neighbor (NN) Algorithm

Simulated Annealing (SA) Algorithm

Genetic Algorithm (GA)

Hybrid Genetic Algorithm and Simulated Annealing (Hybrid GA)

Differential Evolution (DE)

Steps3: to Analyze Real-World Travel Condition Impacts

Identify Key Factors:

Traffic Congestion

Road Conditions

Speed Limits

Stops and Delays

Adjust Travel Speeds: Different route segments might have different average speeds based on the above factors. Next, Calculate Adjusted Travel Times:

Adjusted speeds should be used to recalculate travel times for each route segment. Then, to quantify the impact, compare the adjusted travel times with those calculated under ideal conditions.

Assume adjustments based on conditions:

Urban areas: Reduce speed by 40%.

Suburban areas: Reduce speed by 10%.

Highways: No change

To analyze the cost efficiency of each route, we'll consider factors such as travel time, fuel/energy consumption, and potentially other costs associated with the routes. Assume the following:

Fuel/Energy Rate: 0.2 per kilometer

Result

The Hybrid GA algorithm provides a detailed itinerary with distances and travel times for each segment of the route and the total distance and travel time for the entire route.

Route 1:

Ubon Ratchathani International Airport->Wat Phra That Nong Bua->Wat Maha Wanaram->Wat Pah Nanachat->Wat Nong Pa Phong->Wat Pa Phu Pang->Pha Chana Dai->Pha Taem National Park->Wat Sirindhorn Wararam->Chong-Mek->Tad Fane Waterfall->Tad Yeung Waterfall ->Wat Phou->Ubon Ratchathani International Airport

Total Distance: 626 km
Satisfaction: 60.1
Diversity: Nature,Cultural/Religious,Historical
Recommended as a 3-days cross-border route.

With average speed 40km/hr total driving time is about 15 hr 39 mins, The GA–SA result shows high satisfaction for tourists **which allow tourists to explore** a beauty of Ubon Ratchathani with **Laos highlights** that are reachable within the shorter loop. **Bolaven Plateau** (**Tad Fane + Tad Yeung**) adds strong nature value with relatively efficient detours after crossing at Chong-Mek, then the route pivots to **Wat Phou** for the historical/UNESCO component before returning.

Route 2:
Ubon Ratchathani International Airport->Wat Maha Wanaram->Wat Tai Phrachao Yai Ong Tue->Sao Chaliang->Pha Taem National Park->Wat Tham Khuha Sawan->Wat Tham Heo Sin Chai->Kaeng Tana National Park->Wat Sirindhorn Wararam->Chong-Mek->Wat Phou->4,000 ISLANDS (Si Phan Don)->Wat Pa Sai Ngam->Wat Nong Pa Phong->Wat Pah Nanachat->Ubon Ratchathani International Airport
Total Distance: 720 km
Satisfaction: 72.3
Diversity: Nature,Cultural/Religious,Historical
Recommended as a 4-days cross-border route.

The extended route enhances the itinerary by including additional Thai natural landmarks such as Sao Chaliang and Kaeng Tana, together with the 4,000 Islands segment in Laos, which increases both the average satisfaction score and the richness of the overall travel experience. At the same time, it maintains the UNESCO heritage site of Wat Phou as a cultural anchor and ensures the essential cross-border connection through Chong-Mek. The main strengths of this route lie in its ability to deliver the highest tourist satisfaction, provide a diverse combination of river landscapes, geological formations, and heritage sites, and create a strong narrative for cross-border tourism development. However, the longer total travel time of about 18 hours and the complexity of island logistics make the route more sensitive to delays and require careful planning to ensure smooth operations.

Cost efficiency analysis

Route	Algorithm	Total distance (km)	Total Cost ($)
1	Hybrid GA-SA	626	125.2
1	Differential Evolution (DE)	643	128.6
2	Hybrid GA-SA	720	144
2	Differential Evolution (DE)	732	146.4

Table 1: Cost efficiency analysis

The table shows the cost efficiency analysis for the routes generated by the Hybrid GA and Differential Evolution (DE) algorithms.

The Hybrid GA-SA route has a total travel distance of approximately 626 km for route 1 and 720 km for route 2, and a total cost of approximately $125.2 and $144 respectively.

The Differential Evolution (DE) route has a total travel distance 643 km for route 1 and 732 km for route 2, and a total cost of approximately $128.6 and $146.4 respectively.

The Hybrid GA algorithm is more cost-efficient in terms of travel time and total cost than the Differential Evolution algorithm.

Conclusion

This study investigates the development of sustainable cross-border tourism routes for personal electric vehicle (EV) trips between Thailand and Laos by applying a hybrid optimization approach that combines Genetic Algorithms (GA) and Simulated Annealing (SA) to the Traveling Salesman Problem (TSP). While GA and SA have been widely used in routing problems, their application to personal EV-based cross-border tourism remains limited, particularly when considering sustainability and practical travel conditions. To address this gap, the research incorporates real-world factors such as traffic congestion, varying road quality, border crossing delays, and accessibility of remote attractions into the travel time matrices. The main objective is to design cross-border routes that minimize travel time, distance, and energy consumption while enhancing tourist satisfaction and providing balanced access to cultural, historical, and natural destinations. The methodology involves adjusting travel time matrices to reflect actual conditions and testing multiple optimization methods, including Nearest Neighbor (NN), Simulated Annealing (SA), Genetic Algorithm (GA), Hybrid GA+SA, and Differential Evolution (DE). Fixed stops at Chong-Mek checkpoint, and key attractions in southern Laos and Ubon Ratchathani were incorporated to ensure route relevance. Simulation results show that the Hybrid GA+SA method outperforms other approaches in reducing total travel time and distance while improving cost and energy efficiency. The findings highlight that Hybrid GA+SA provides a robust framework for optimizing cross-border EV tourism routes under TSP conditions. By integrating eco-friendly practices, reducing carbon emissions, and respecting cultural and natural sensitivities, this approach contributes to sustainable tourism development and offers practical insights for cross-border travel planning between Thailand and Laos.

However, it should be noted that this paper does not include a detailed analysis of the existing infrastructure and acknowledges the current lack of sufficient charging stations in many cross-border areas, which remains a limitation that future studies and development plans must address.

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