Optimizing Tourist Itineraries in Bali: Applying a Green Orienteering Problem with Time-Dependent Factors

For my final thesis project, I tackled a complex, real-world optimization challenge rooted in Bali's thriving tourism industry. As Indonesia's primary tourist destination, accounting for over 75% of foreign arrivals, this rapid growth presents significant challenges. The Tour and Travel Agencies (BPW), which serve approximately 50% of these visitors, are at the nexus of this complexity. They face a crucial trilemma: maximizing tourist satisfaction by creating rich itineraries, minimizing operational costs and travel time, and adhering to the Indonesian government's ambitious goal of halving tourism-related carbon emissions by 2030.

My research was born from identifying the critical factors that complicate this balancing act. Firstly, Bali's traffic is highly dynamic; travel time between two points can vary dramatically, as exemplified by a trip from the airport to Kuta taking 20-25 minutes at noon but up to 60 minutes in the evening. Secondly, there is a rising global consciousness around sustainable travel, with tourists themselves inquiring about the carbon footprint of their journeys. My thesis aimed to develop and implement a sophisticated optimization model to provide BPWs with a data-driven tool to navigate these competing objectives effectively.

A Holistic Approach to Itinerary Optimization

My research methodology was comprehensive, beginning with problem identification through interviews with a local BPW in Bali and culminating in the development of a fully functional, interactive web-based decision support system. The project integrated advanced mathematical modeling, metaheuristic algorithms, and robust data analysis to provide a powerful solution to this multifaceted logistical challenge.

I. Problem Formulation & Mathematical Modeling

The core of my work was formulating a mathematical model capable of capturing the competing objectives of modern tour planning. I developed a model based on the

Green Orienteering Problem with Time-Dependent (GOPTD) framework. This model is built on three essential pillars:

1. **Orienteering Problem (OP):** Derived from the Traveling Salesman and Knapsack problems, the model's primary goal is to select a subset of destinations (nodes) that maximizes a total "satisfaction score" within a given time budget (Tmax).
2. **Green Component:** The model incorporates an environmental objective by aiming to minimize the total carbon emissions (CO_2) generated by the tour vehicle.
3. **Time-Dependent Factors:** To reflect reality, the model treats travel duration between two points as a variable function dependent on the time of day, using unique weight factors for five distinct periods (Subuh, Pagi, Siang, Sore, Malam) to account for traffic patterns.

The final objective function was designed as a multi-objective maximization problem, structured as

`max Z = Q1(Satisfaction) - Q2(Cost) - Q3(Emissions)`, to find the best possible trade-off among these goals.

II. Data Collection & Preparation

To power the model, I collected and processed a wide range of data:

- **Destination Data:** I compiled a database of **120 tourist destinations in Bali**. For each location, I gathered data on visitor satisfaction scores (from Google Maps, TripAdvisor, and a direct questionnaire), entrance fees, recommended visit durations, operational hours, and geographic coordinates.
- **Vehicle Parameters:** My model was based on a **Toyota Hiace**. I defined its specific parameters, including operational cost at
  Rp 1320/km, average speed of **35 km/h**, and a calculated CO_2 emission factor of **221 g/km**.
- **Time-Dependent Data:** Using Google Maps simulations, I established weight factors for traffic congestion. My analysis revealed that the Subuh (dawn) period had the highest

travel time factor due to market activities and limited street lighting, making travel slower than other periods.

No	Nama Tempat	Kategori	Lama Kunjungan (jam)	Kepuasan	Biaya Kunjungan	Latitude	Longitude
1	Element by Westin Bali Ubud	Depot	0	0	Rp0	-85.039.694	11.527.178
2	Uma Desa Canggu	Desa Wisata	2	8.7	Rp10,00	-86.307.137	1.151.446.923
3	Desa Wisata Sidan	Desa Wisata	2	8.9	Rp35,00	-85.389.017	1.153.478.897
....	....	....	....	....	....	....	....
120	Atlas Beach Club	Wisata Budaya, Edukasi & Gaya Hidup	4	8.6	Rp450,00	-86.651.553	1.151.399.233

Kecepatan Rata-Rata = 35 Km/Jam
Biaya Oprasional/ Km = Rp1320
Faktor Emisi Kendaraan = 221 g/Km CO2
Waktu Maksimum =16 Jam
Waktu Mulai Perjalanan = 06.00

III. Solution Algorithm & Implementation

Due to the NP-hard nature of this problem, I used a metaheuristic approach for efficient computation:

- **Ant Colony Optimization (ACO):** I selected the ACO algorithm, highly effective for TSP-like problems, to find near-optimal solutions. The algorithm simulates digital "ants" that collaboratively build and refine routes, depositing "pheromone" on better paths to guide the search.
- **2-Opt Local Search:** To further enhance the quality of the solutions from ACO, I implemented a **2-Opt algorithm**. This algorithm systematically refines the chosen route by swapping pairs of edges to check for and implement improvements, ensuring the final path is locally optimal.

To translate this complex model into a tangible and practical tool, I developed and deployed a fully interactive web-based decision support system. The entire system was built using

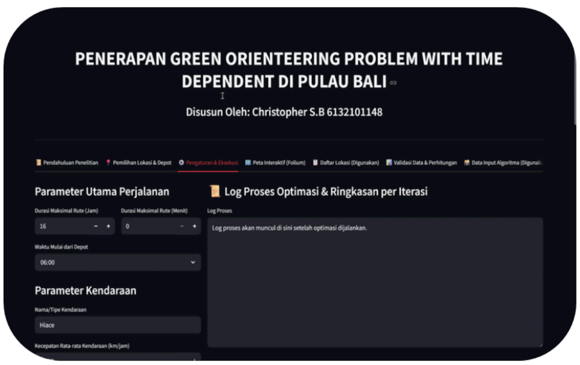
Python in a Google Colab environment. For the user interface, I utilized the

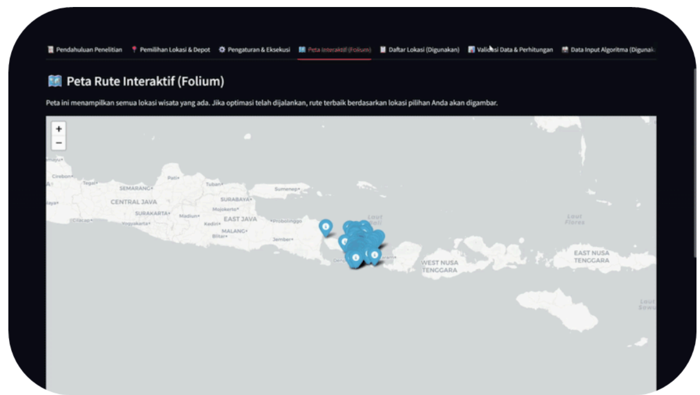
Streamlit framework to create an intuitive dashboard where users can adjust key parameters such as maximum tour duration (Tmax), vehicle type, start time, and even the ACO algorithm settings. The optimized route is then visualized on an interactive map built with

Folium. The platform was made accessible online via an

ngrok endpoint, demonstrating a complete proof-of-concept from data input to final visual output.

A demonstration of this interactive website can be arranged upon request. For access or inquiries, please feel free to contact me at christophersb63@gmail.com.





IV. Results & Sensitivity Analysis

The model was successfully executed and validated against manual calculations. For a case study of a 16-hour tour, the model produced the following optimal results:

- **Optimal Route:** A path visiting **8 distinct tourist locations**.
- **Objective Score:** A final, normalized objective score of **17.8936**.
- **Detailed Metrics:** The route yielded a total raw satisfaction score of **100.59**, a combined cost (transport and visits) of **Rp 509,190**, and total emissions of **19,320 g CO2**, all completed within a total time of 14 hours and 34 minutes. To put the environmental impact into perspective, this optimized, lower-emission route, when compared to a less optimal alternative, results in an annual carbon saving equivalent to the amount absorbed by **91 trees**

My sensitivity analysis revealed that the three most critical parameters influencing the final route were the **maximum tour duration (Tmax)**, and the **pheromone weight (alpha)** and **heuristic**

weight (beta) from the ACO algorithm, confirming their significant impact on the solution's structure.

Project Conclusion and Professional Development

My thesis successfully demonstrates the effective application of a GOPTD model to solve the complex challenge of tourist itinerary planning in Bali. The project's primary contribution is a functional decision support tool that translates complex mathematical theory into a practical application for BPWs. A key strategic benefit of this model is its ability to position BPWs to capitalize on the powerful and growing trend of "green" or "sustainable tourism". My research identified that foreign tourists are increasingly conscious of their environmental impact, often inquiring directly about the carbon footprint of their travels. By using this tool, BPWs can offer verifiably eco-friendlier itineraries, transforming sustainability from an operational constraint into a powerful market differentiator that attracts environmentally-conscious travelers.

This thesis represents a culmination of my academic journey, allowing me to synthesize my analytical and quantitative skills. It builds upon my foundational experience in human-centered problem-solving—including my previous award-winning project in Design Thinking —by applying rigorous mathematical modeling to a complex, real-world business challenge.

Acknowledged Limitations and Future Research Directions

I acknowledge that while this thesis provides a robust proof-of-concept, it also sets the stage for future research. Based on my findings and feedback received during my thesis defense review, I have identified several key directions for enhancement:

- **Incorporating Probabilistic Modeling:** The current model is deterministic. A significant future enhancement would be to incorporate probabilistic modeling to account for real-world uncertainties like sudden road closures or weather changes, as suggested during my thesis review.
- **Expanding Dynamic Variables:** The model could be expanded to include other dynamic variables, such as real-time weather forecasts or event schedules, to further increase its real-world accuracy.
- **Benchmarking Algorithms:** As noted in my own recommendations, future iterations could benchmark the performance of Ant Colony Optimization against other metaheuristic algorithms to ensure the most efficient solution method is used.
- **Enhancing User Interface:** Based on testing feedback, a key suggestion for practical implementation is to further simplify the user interface of the web tool, making it even more intuitive for BPW staff who may not have a technical background.

Acquired Competencies

Through this rigorous research project, I developed and honed the following skills:

- **Advanced Mathematical Modeling:** Formulating and implementing a complex, multi-objective optimization model (GOPTD).
- **Metaheuristic Algorithm Implementation:** Applying and tuning advanced algorithms like Ant Colony Optimization and 2-Opt.
- **Full-Stack Data Application Development:** Building an end-to-end web application using Python, Streamlit, Folium, and ngrok.
- **Data Analysis & Visualization:** Collecting, cleaning, and normalizing multi-source data; performing sensitivity analysis; and creating intuitive visualizations.
- **Problem-Solving & Systems Thinking:** Deconstructing a complex business problem into its core components and designing an integrated system.
- **Technical Communication:** Translating complex technical concepts and results into a clear, understandable format for both academic and practical audiences.