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Application of Green Orienteering Problem for Tourism Case in Yogyakarta

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Abstract

Indonesia has a rapidly growing tourism industry, supported by numerous destinations with extraordinary natural beauty. According to the Travel Tourism Development Index (TTDI) 2024, Indonesia ranks 22nd globally and second in ASEAN. One of its prominent provinces is the Special Region of Yogyakarta, which recorded 3.2 million tourists in May 2024. The tourism industry contributed 4.1% to Indonesia's Gross Domestic Product (GDP) in 2023, with the government targeting an increase to 4.6% by 2025. Despite its economic value, tourism accounts for 8% of global carbon emissions, with 49% of those emissions originating from transportation. The government is committed to reducing carbon emissions by 50% by 2030 and achieving net-zero emissions between 2045 and 2060. Many tourists rely on travel agencies to purchase tour packages. Travel agencies design these packages by considering routes, costs, time, and tourist satisfaction. The selection of destinations aligns with the Orienteering Problem (OP), which aims to maximize scores within a time constraint, while minimizing carbon emissions and trip days. This study applies a green team orienteering model to 65 destinations in Yogyakarta to maximize tourist satisfaction while minimizing costs and carbon emissions over a 3-day tour (8 hours per day). The model is solved using AMPL software and Gurobi. The optimal route includes 5 destinations on the first day, 4 destinations on the second day, and 5 destinations on the third day, achieving a total score of 3,521. Sensitivity analysis shows that increasing tour hours and the number of days leads to higher total scores. Weighting significantly influences each objective function, potentially resulting in trade-offs among objectives or dominance over others.

Keywords: Green team orienteering problem, Sustainability, Tourism, Travel agencies, Yogyakarta.

1 | Introduction

Indonesia is renowned for its tourism industry, supported by various tourist destinations with abundant natural beauty. It is evidenced by Indonesia's tourism index, which ranks 22nd out of 119 countries and is even the second-best in ASEAN, according to the Travel Tourism Development Index (TTDI) released by

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the World Economic Forum (WEF) in May 2024 [1]. This ranking further reinforces Indonesia's strong reputation in the tourism industry, not only at the local level but also on the global stage.

Over time, the number of both international and domestic tourists visiting Indonesia's tourist destinations has increased. In June 2024, a total of 1.17 million international tourist arrivals were recorded, a 2.05% increase from May 2024 [2]. The growing interest in Indonesia's tourism industry aligns with its contribution to the Gross Domestic Product (GDP), which reached 4.1% in 2023 and is projected to rise to 4.5% in 2024 [3]. The government has also set a target of 4.6% for 2025. Various regions in Indonesia continue to attract frequent visits from domestic tourists. In the period from January to September 2024, the number of domestic tourist trips in Indonesia peaked at 104.5 million in April, with a difference of 10 to 20 million visits compared to other months [2], [4].

Table 1. 10 Provinces with the highest number of tourist trips [2], [4].

No	Province	Total Trips
1	Jawa Timur	155,340,647
2	Jawa Barat	132,260,394
3	Jawa Tengah	98,689,495
4	DKI Jakarta	66,738,598
5	Banten	44,707,496
6	Sumatera Utara	31,454,132
7	Sulawesi Selatan	26,503,717
8	Yogyakarta	22,109,721
9	Bali	16,027,876
10	Riau	14,762,619

Based on the number of tourist trips in *Table 1*, the Special Region (DI) of Yogyakarta is among the top ten provinces most visited by domestic tourists. It indicates that DI Yogyakarta is one of the favorite destinations for domestic travelers. Despite its relatively small land area compared to other provinces, it remains one of the most visited regions. The ratio of land area to the number of trips is shown in *Table 2*.

Table 2. Ratio of tourists per unit of land area.

No	Province	Ratio of Number of Tourists Per Land Area
1	DKI Jakarta	100,969.164
2	Yogyakarta	6,973.245
3	Banten	4,780.134
4	Jawa Barat	3,570.276
5	Jawa Timur	3,233.781
6	Jawa Tengah	2,874.103
7	Bali	2,867.163
8	Sulawesi Selatan	584.676
9	Nusa Tenggara Barat	569.770
10	Sumatera Utara	434.085

Based on *Table 2*, Yogyakarta ranks second in the ratio of tourists per land area. A high ratio indicates that the region receives a significantly large number of visitors, far exceeding its land size. While the top 10 provinces remain the same, the rankings have shifted, with Yogyakarta rising from eighth to second. This further solidifies Yogyakarta's Position as a favourite tourist destination despite its relatively small land area.

According to data from Pariwisata Daerah Istimewa Yogyakarta [5], DI Yogyakarta covers a total area of 3,185.80 km^2, consisting of one city and four regencies. A small land area does not mean a limited number of tourist destinations; Yogyakarta offers 274 tourist sites. Accommodation options for tourists are also abundant. In 2023, 187 star-rated hotels accommodated up to 126,198 international tourists and 5,419,030 domestic tourists. Additionally, 1,550 non-star hotels housed 23,216 international tourists and 2,172,245 domestic tourists [5]. Beyond hotels, in 2023, Yogyakarta International Airport ranked among the top 10 airports in Indonesia for international tourist arrivals, with the majority of visitors coming from Malaysia (42,094), Singapore (17,215), and China (4,492). The large number of both domestic and international tourists in Yogyakarta contributes to high transportation intensity between accommodations and tourist destinations. It is due to the high frequency of travel as tourists visit various attractions. Travel agencies 'Biro Perjalanan Wisata (BPW) play a crucial role in offering the best services in terms of pricing, transportation, and carefully selected tourist destinations that are considered the most appealing and satisfying for visitors. Their contributions to the tourism industry include offering well-structured travel packages and ensuring smooth and detailed travel arrangements [6]. BPW does not purchase products and services directly; instead, it represents its customers (tourists) by purchasing products from suppliers and receiving a commission [7].

In generating their tour packages, travel agencies BPW often focus solely on minimizing costs and travel time. This narrow emphasis on cost and travel time creates new challenges, particularly concerning environmental issues. The tourism industry today must not focus solely on constraints such as time and cost; environmental concerns are now a critical issue. Neglecting environmental aspects leads to destructive effects on natural resources and local [8]. According to Sustainable Travel International [9], extreme climate change (climate emergency) has been occurring recently, with 8% of its causes attributed to carbon emissions from tourism. Within this contribution, transportation accounts for 49%, the largest among all components. Recognizing the environmental urgency in tourism, the Indonesian government, through the Ministry of Tourism and Creative Economy (Kemenparekraf), has set a target to reduce carbon dioxide emissions from the tourism sector by 50% by 2030 and achieve net-zero emissions between 2045 and 2060 [10].

BPW's goal of maximizing tourist satisfaction through travel experiences while adhering to constraints, such as time, can be modeled as an Orienteering Problem (OP) [11]. The selection of tourist destinations under these constraints (time and cost) aligns with the OP's definition, which aims to maximize the total score from visiting various points while considering multiple constraints [12]. Another objective is to minimize time and distance while visiting as many points as possible [13]. The OP can also be modeled in a team-based form to collect higher scores, commonly known as the Team Orienteering Problem (TOP) [14], which has been applied to various problems, including UAVs and ride-sharing [15]. Other variants of the OP used include time-dependent OP [16], correlated arc OP [17], capacitated TOP [12], OP with variable profits [18], clustered OP [19], and multi-agent OP [20]. One of its developments, specifically for tourism, is the Tourist Trip Design Problem (TTDP), which is based on OP [21]. The TTDP aims to design travel itineraries for tourists by maximizing their benefits without exceeding the available budget [22].

However, existing OP models do not incorporate environmental considerations. To mitigate negative environmental impacts, additional factors related to environmental effects must be included when selecting destinations and routes. A new model, known as the green OP (green tourist trip design), is referred to by [8]. Unlike traditional models that focus only on satisfaction, profit, travel time, and cost, the green OP also considers carbon emissions as a constraint when selecting the most satisfying destinations and routes. This paper will discuss research focusing on the practical application of the green OP model in tourist destinations within Yogyakarta Province. The green OP model used in this study will consider tourist satisfaction, costs (transportation and entrance fees), carbon dioxide emissions, and time. This research aims to generate optimal solutions in the form of recommended destinations and travel routes in Yogyakarta based on the implementation of the green OP model.

2 | Literature Review

2.1 | Orienteering Problem

Golden et al. [23] stated that the OP originates from an outdoor sport typically played in forested areas. These forests contain multiple control points, each with its own value. Players must visit these control points, starting from an initial point, to maximize their score and return to the final point within a given time limit. Thus, the objective of this game is to maximize the score while adhering to time constraints. This sport was later modeled as the OP problem, which has practical applications to similar optimization challenges.

The goal of the OP, to maximize the score by visiting multiple points while minimizing time and distance, is often described as a combination of the knapsack and traveling salesman problems [13]. According to Vansteenwegen et al. [13], not all points in the OP need to be visited. Instead, the problem requires considering the proximity between points and visiting as many as possible within the available time. Given its fundamental structure, the OP has been widely applied to various problems using both exact and heuristic solution approaches. One of the problems commonly solved using the OP framework is the mobile crowdsourcing problem, in which a worker or a group of people completes outsourced tasks to earn compensation [24]. Additionally, the OP is frequently applied to the TTDP. According to Panagiotakis et al. [21], the TTDP involves selecting locations to visit while maximizing customer (tourist) satisfaction. These benefits are obtained at each visited location while considering constraints such as costs, operating hours, starting and ending points, and the available time for tourism activities [21]. Given these examples, the OP model is highly applicable, particularly in optimizing the selection of tourist destinations.

The OP can be used to determine how to visit tourist destinations and their respective routes. The objective of maximizing satisfaction while incorporating various constraints can be formulated mathematically. The mathematical model of the OP provides a more precise representation of achieving its primary objective while incorporating the necessary constraints. According to Vansteenwegen et al. [13], the OP can be mathematically modeled.

Parameter

N = Control points

S_i = Score at control point i

t_{ij} = Travel time from point i to point j

T_{max} = Maximum available travel time

Decision variable

x_{ij} = 1 if moving from point i to point j, otherwise 0

u_i = Position of point i in the route (subtour elimination function)

Formulation

$$\text{Max} \sum_{i=2}^{N-1} \sum_{j=2}^{N} S_i x_{ij}. \tag{1}$$

$$\sum_{j=2}^{N} x_{1j} = \sum_{i=1}^{N-1} x_{iN} = 1. \tag{2}$$

$$\sum_{i=1}^{N-1} x_{ik} = \sum_{j=2}^{N} x_{kj} \leq 1, \qquad \text{for all } k = 2, \dots, N-1. \tag{3}$$

$$\sum_{i=1}^{N-1} \sum_{j=2}^{N} t_{ij}\, x_{ij} \leq T_{max}. \tag{4}$$

$$2 \leq u_i \leq N, \qquad \text{for all } i = 2, \dots, N. \tag{5}$$

$$u_i - u_j + 1 \leq (N-1)(1 - x_{ij}), \text{for all } i, j = 2, \dots, N. \tag{6}$$

$$x_{ij} \in \{0,1\}, \text{for all } i, j = 1, \dots, N. \tag{7}$$

The objective is to maximize the total score (1). Ensures that the route starts at point 1 and ends at point N (2). Ensures that each point has a path and that each point is visited at most once (3). Time budget constraint (4). (5) and (6) prevent subtours. (7) values of each decision variable in the model.

2.2 | Green Orienteering Problem (Green Tourist Trip Design Problem)

The green OP can be considered a development of the TTDP, which is initially based on the OP. The TTDP aims to design travel itineraries for tourists by maximizing their benefits without exceeding the available budget [22]. It includes planning visit hours, budget allocation, maximum duration per tourist, and other constraints. Furthermore, it is also necessary to consider the three aspects of sustainability, including economic, social, and environmental, within its modeling [22]. In line with the previous statement, Divsalar et al. [8] highlighted the need to reduce pollutants generated by tourism activities. Therefore, a new model of the OP or TTDP should be introduced to achieve pollution reduction.

Divsalar et al. [8] proposed a multi-objective OP to address this issue. Within the TTDP framework, in addition to maximizing customer satisfaction, two other factors were introduced: minimizing travel costs and minimizing carbon dioxide emissions from transportation. This model still includes time constraints, so the total available travel time remains a key consideration, as in the TTDP. This new model is also referred to as the green tourist trip design or green OP, which incorporates environmental aspects (in this case, pollution) into its mathematical model. As previously explained, this problem aims to solve the TTDP using a multi-objective mixed-integer linear programming model [8]. The objectives are to maximize the total score/satisfaction while minimizing costs and emissions. Tourists can choose from various modes of transportation for travel between destinations, but their choices may affect the amount of pollution generated during the trip. Modeling the OP by introducing new variables and additional objectives makes the model more complex while providing broader interpretative insights. Apart from adding new objectives, the rest of the green OP model remains the same as the classical OP, including time budget constraints. By defining how to visit destinations through routes that maximize customer satisfaction, minimize carbon footprint and costs, and comply with additional constraints, the green OP also comes with its mathematical model. Similar to the OP, the green OP includes three objective functions. The mathematical model of the green OP provides a more precise representation of achieving its three main objectives while incorporating the necessary constraints. According to Divsalar et al. [8], the green OP can be mathematically formulated.

Parameter

V, E = V is the set of N control points, and E is the set of edges.

S_i= Score at control point i

VC_i= Cost at control point i

K= Type of transportation set for moving between points

P_{ijk}= amount of carbon dioxide emissions produced when traveling from point i to point j using transport mode k

C_{ijk}= Transportation cost for moving from point i to point j using transport mode k

t_{ijk}= Travel time from point i to point j using transport mode k

T_{max}= Maximum available travel time

Decision variable

x_{ijk}= 1 if moving from point i to point j using transport mode k, otherwise 0

δ^+= Outgoing edges from set S

δ^-= Incoming edges to set S

u_i= Position of point i in the route (subtour elimination function)

Formulation

$$\text{Max} \sum_{(i,j)\in E} \sum_{k\in K} S_i X_{ijk}. \tag{8}$$

$$\text{Min} \sum_{(i,j)\in E} \sum_{k\in K} \left(VC_i x_{ijk} + C_{ijk} X_{ijk}\right). \tag{9}$$

$$\text{Min} \sum_{(i,j)\in E} \sum_{k\in K} \left(P_{ijk} X_{ijk}\right). \tag{10}$$

$$\sum_{(i,j)\in E} \sum_{k\in K} t_{ijk} X_{ijk} \leq T_{max}. \tag{11}$$

$$\sum_{k\in K} X_{ijk} \leq 1, \text{for all } (i,j) \in E. \tag{12}$$

$$\sum_{k\in K} x(\delta^{+}(1))_k = 1. \tag{13}$$

$$\sum_{k\in K} x(\delta^{-}(N))_k = 1. \tag{14}$$

$$\sum_{k\in K} x\left(\delta^{-}(j)\right)_k = \sum_{k\in K} x\left(\delta^{+}(j)\right)_k \leq 1, j \in V. \tag{15}$$

$$U_i - U_j + 1 \leq (N-1)\left(1 - \sum_{k\in K} X_{ijk}\right), \text{for all } (i,j) \in E. \tag{16}$$

$$2 \leq U_i \leq N;\ \ \text{for all } i \in V. \tag{17}$$

$$X_{ijk} \in \{0,1\};\ \text{for all } (i,j) \in E, k \in K. \tag{18}$$

The objective functions are maximizing the score (8), minimizing the cost (9), and minimizing carbon dioxide emissions (10). Restricts travel time to ensure it stays within the time budget (11). Ensures that each route from point i to point j can only select one mode of transportation (12). (13) and (14) ensure that point 1 is the starting point and point N is the ending point. (15) ensures that each point is visited at most once. (16) and (17) ensure that no subtour exists in the route. (18) values of each decision variable in the model.

2.3 | Sensitivity Analysis

According to Saltelli [25], sensitivity analysis is the study of how different input sources influence the uncertainty in a model's output. Similarly, Breierova and Choudhari [26] state that sensitivity analysis is used to measure how responsive a model is to changes in its parameter values or structure. Sensitivity analysis examines changes in output resulting from variations in variables, parameters, or the model structure.

Sensitivity analysis enables assessment of a parameter's accuracy, ensuring the model remains useful and valid [26]. If testing indicates that the model is not highly sensitive, estimated values may be used instead of precise ones. Additionally, sensitivity analysis helps identify which parameters are crucial in the model by determining whether changes in their values significantly or insignificantly impact the model.

Sensitivity analysis is an essential tool in model development, as it demonstrates whether a system is strongly affected by parameter changes. If a model shows minimal sensitivity, its uncertainty is reduced [26]. It helps modelers understand how dynamic a system or model is. Experiments conducted over different value ranges may result in extreme changes to the system. If a model exhibits significant variation with parameter changes, it indicates that the parameter has a substantial influence on the model.

3 | Methodology

This research begins by establishing the green OP model to be used, which combines classic OP (tourist trip design) and green OP (green tourist trip design). The model has several variables. N represents control points or tourist destinations in Yogyakarta; the set N consists of 65 tourist destinations with two depot points serving the start and end location. M represents the number of travel days, with a total of three days allocated for the trip in Yogyakarta. X_{ijm} is a binary variable which indicates whether a tourist moves from destination i to destination j on day m, and the presence of a tourist at destination i (if a tourist visits destination i) on day m is represented by the binary variable Y_{im}. The carbon emissions P_{ij} and transportation cost C_{ij} Generated from traveling between destinations i and j are included, with travel time t_{ij} constrained by a maximum allowed time T_{max}. While at a tourist destination, visitors incur a visit cost VC_i and visit duration VE_i at each location. The experience at each destination contributes to a tourist satisfaction score S_i.

Parameter:

N = Tourist destination

M= Day of tourism

P_{ij}= Carbon emission (normalized min-max) of traveling from location i to j

C_{ij}= Transportation cost (normalized) of traveling from location i to j

t_{ij}= Travel time from location i to j

S_i= Tourist satisfaction score (normalized) at destination i

T_{max}= Maximum time budget

VC_i= Visiting cost at destination i

VE_i= Visiting time at destination i

Decision variable

X_{ijm} = Value 1 if moving from destination i to j on day m (otherwise, 0)

Y_{im}= Value 1 if visiting destination i on day m (otherwise, 0)

u_{im}= Used to eliminate sub tour

Objective function

$$\text{Max} \sum_{m=1}^{M} \sum_{i=2}^{N-1} S_i Y_{im}. \quad \textbf{(19)}$$

$$\text{Min} \sum_{m=1}^{M} \sum_{i=2}^{N-1} \sum_{j=2}^{N} \left(VC_i x_{ijm} + C_{ij} X_{ijm}\right). \quad \textbf{(20)}$$

$$\text{Min} \sum_{m=1}^{M} \sum_{i=2}^{N-1} \sum_{j=2}^{N} P_{ij} X_{ijm}. \quad \textbf{(21)}$$

The objective function maximized tourist satisfaction score (19) while minimizing transportation and visiting costs (20) and carbon emissions (21). The three objectives are combined using the weighting specified by W (22).

$$\text{Max } Z = W_1 \sum_{m=1}^{M} \sum_{i=2}^{N-1} S_i Y_{im} + W_2 (-\sum_{m=1}^{M} \sum_{i=2}^{N-1} \sum_{j=2}^{N} (VC_i Y_{im} + C_{ij} Y_{jm})) + W_3 (-\sum_{m=1}^{M} \sum_{i=2}^{N-1} \sum_{j=2}^{N} P_{ij} Y_{im}) \tag{22}$$

$$\sum_{m=1}^{M} \sum_{j=2}^{N} X_{1jm} = \sum_{m=1}^{M} \sum_{i=1}^{N-1} X_{iNm} = M. \tag{23}$$

$$\sum_{m=1}^{M} Y_{km} \leq 1 ; \text{ for all } k = 2, \ldots, N-1. \tag{24}$$

$$\sum_{i=1}^{N-1} X_{ikm} = \sum_{j=2}^{N} X_{kjm} \leq Y_{km}, \text{ for all } k = 2, \ldots, N-1, \text{for all } m = 1, \ldots, M. \tag{25}$$

$$\sum_{i=1}^{N-1} \sum_{j=2}^{N} (t_{ij} X_{ijm} + VE_i Y_{im}) \leq T_{max}, \text{for all } m = 1, \ldots, M. \tag{26}$$

$$2 \leq u_{im} \leq N, \quad \text{for all } i = 2, \ldots, N, \text{for all } m = 1, \ldots, M. \tag{27}$$

$$u_{im} - u_{jm} + 1 \leq (N-1)(1 - X_{ijm}), \text{for all } i, j = 2, \ldots, N, \text{for all } m = 1, \ldots, M. \tag{28}$$

$$X_{ijm}, Y_{im} \in \{0,1\}; \text{ for all } i, j = 1, \ldots, N; \text{ for all } m = 1, \ldots, M. \tag{29}$$

The green OP has several constraints: the entire route must start at destination 1 and end at destination N within the allocated number of days (23). Each destination can only be visited once (24). The routes need to be connected, which ensures that if a location is visited, it will be worth 1; otherwise, 0 (25). Time budget constraint, ensuring that total travel time and visiting time do not exceed the time limit (26). Subtour elimination constraint (27) and (28). Ensure that the decision variable is a binary value (29).

The distance between each tourist destination in Yogyakarta is assumed to be symmetric, so the Euclidean distance formula is used to calculate the distance between two points [27]. Euclidean distance is proper when the data set is incomplete, i.e., when some distance points are missing. Typically, Euclidean distance is used to complete the missing (incomplete) distances between points, making it a common method for calculating the distance between points in variables euclidean [28].

Integer programming provides a comprehensive model for decision-making, especially for problems that require discrete choices [29], such as the OP, which can be solved using a mixed-integer programming approach (exact method) [30]. Given the sensitivity of the results due to changes in the priorities of the tourism agency BPW in decision-making (changes in weights), daily time duration (adjusting to the availability of destinations and resources), and the number of days (BPW adjusts the tour package based on available days); a sensitivity analysis is also conducted to account for uncertainties in the model's output from varying input sources [25]. The main reason is to measure how sensitive a model is to changes in its parameter values or its structure [26].

4 | Results and Discussion

The itinerary data needed are the coordinates of destinations (latitude and longitude), the distance between destinations, ratings of destinations (Google and TripAdvisor), the cost of travel and visiting, the carbon generated by Toyota HiAce Commuter for each trip, and the time spent traveling and visiting. This case consists of 65 destinations with 2 nodes as the start and end locations (these 2 are the same destination). All data and models were solved using Gurobi and modeled in AMPL. The coordinate data for each destination are shown in Appendix A; the whole dataset can be accessed at Yogyakarta Tourism Case [31].

The model is coded in AMPL, assuming a three-day tour duration (M) with each day lasting eight hours. The AMPL model is then executed with Gurobi for 7 hours using 3GB of memory.

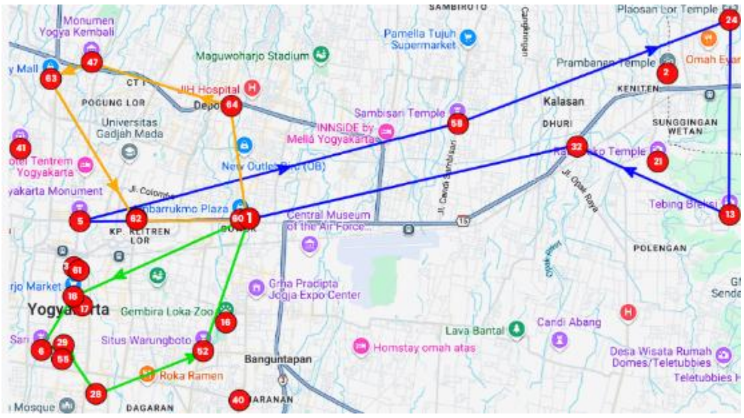

Fig. 1. Visualization of the result.

Based on *Fig. 1*, there are three routes, each represented by a different color corresponding to a specific day. The blue route represents the first day, following the path 1-5-58-24-13-32-65. The yellow route represents the second day, covering 1-64-47-63-62-65. The green route represents the third day, following 1-18-6-29-28-52-65. All routes start and end at the same depot, points 1 and 65 (Royal Ambarrukmo Yogyakarta). These three routes represent the optimal paths for each respective day. The routes and names of the tourist destinations are listed in *Table 3*.

Table 3. Optimal destinations and routes.

Day	Destination and Routes	Total Score
1	Depot-Tugu Jogja-Candi Sambisari-Candi Plaosan-Tebing Breksi-Candi Kalasan-Depot	3,521
2	Depot-Pakuwon Mall Jogja-Monumen Jogja Kembali-Jogja City Mall-Galeria Mall-Depot	
3	Depot-Pasar Beringharjo-Taman Sari Yogyakarta-Keraton Yogyakarta-Prawirotaman-Situs Warungboto-Depot	

The total score (objective function incorporating tourist satisfaction, cost, and carbon emissions) obtained is 3.521. Based on the results, tourists need to visit 5 destinations on the first day, 4 on the second day, and 5 on the third day, for a total of 14 destinations over three days. The satisfaction score achieved by tourists is 12.850, with a cost of 1.480 and carbon emissions of 0.700. When weighted equally (0.33), the scores are 4.240 for satisfaction, 488.400 for cost, and 0.231 for carbon emissions. By denormalizing the data back to its original scale (instead of 0-1), the obtained satisfaction score is 119.505, the cost is Rp 407,000, and the carbon emissions are 16,046.161 grams.

The green OP model is then modified by adjusting specific parameters to analyze their effects. The selected parameters for sensitivity analysis include the objective function weights, the maximum time limit (travel duration per day), and the number of travel days (number of teams). First, the changes in weights. The weight values are adjusted using several options that allow prioritizing one objective over others (e.g., cost versus tourist satisfaction and carbon emissions). The assigned weight values (W) used in the model are listed in *Table 4*, with the results available in Appendix B. The conversion value can be checked in Appendix C.

Table 4. Weight changes.

No.	W_1	W_2	W_3
1	0.33	0.33	0.33
2	0.6	0.2	0.2
3	0.2	0.6	0.2
4	0.2	0.2	0.6
5	0.4	0.4	0.2
6	0.1	0.45	0.45
7	0.5	0.25	0.25

Next, changes in travel duration are applied with variations of -20%, -10%, 10%, 20%, 30%, 40%, and 50%, keeping the number of days constant at three and using balanced weights. The results are presented in Appendix D, and the conversion value is available in Appendix E. The graphical visualization of the results is presented in *Fig. 2*.

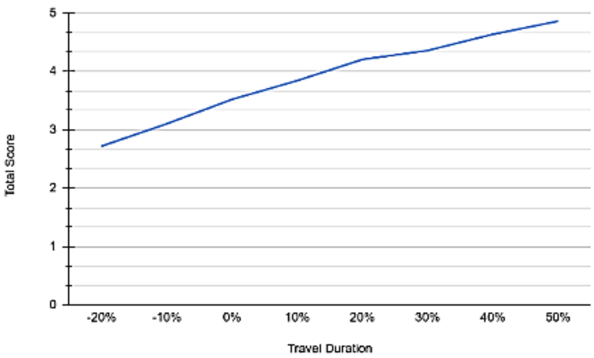

Fig. 2. Travel duration on the total score.

Last adjustments are made to the number of travel days, ranging from 1 to 5 days under the same conditions. The results are shown in Appendix F; the conversion value can be checked at Appendix G. The graphical visualization of the results is presented in *Fig. 3*.

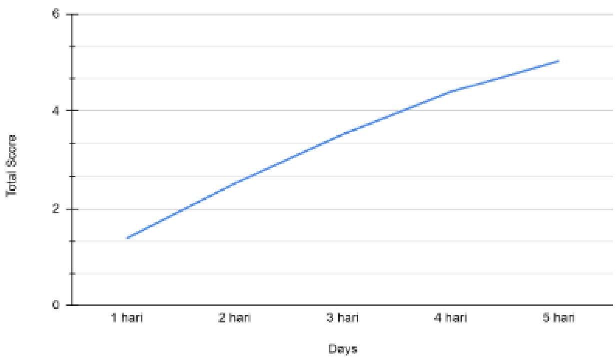

Fig. 3. Travel days on the total score.

Based on *Figs. 2* and *3*, it is evident that increasing the duration and number of travel days increases the total score and significantly affects each objective function (satisfaction, cost, and carbon emissions). It is due to the expanded opportunity to include more destinations and routes, which affects all three aspects. Meanwhile, adjusting the weights provides valuable insights for decision-makers, enabling them to tailor their choices based on the required priorities. The omission of obstacles and terrain, along with the use of estimated distances based on the Euclidean formula (rather than actual distances), requires decision-makers to carefully adjust the model to ensure that the optimization results are more relevant to the expected objectives. Inaccurate distance estimates may affect the selection of optimal tourist destinations and routes, although the applied approach generally prioritizes nearby destinations over distant ones. Decision-makers can incorporate actual distances to obtain results that better reflect real conditions. It was found that the solution process with a 7-hour runtime and a 3GB memory limit resulted in a relatively small gap (relative MIP gap below 5%), with absolute and relative MIP gaps of 0.116 and 0.033, respectively. Extending the process to 8 hours led to a further reduction in the gap, though not as significant as the decrease observed between 1 and 7 hours, with an absolute MIP gap of 0.095 and a relative MIP gap of 0.027. Aside from the MIP gap, the selected destinations, routes, and total score remained the same at 3.5211 (with a satisfaction score of 12.85, cost of 1.48, and carbon emissions of 0.7). Given that the 7-hour process produced results equivalent to those of the 8-hour process, it was deemed sufficient for the solution.

5 | Conclusion

Based on the exact solution, the total score obtained from all visits over three days (each lasting eight hours) is 3.521. The tourist route for the first day includes Tugu Jogja, Candi Sambisari, Candi Plaosan, Tebing Breksi, and Candi Kalasan. The second-day route consists of Pakuwon Mall Jogja, Monumen Jogja Kembali, Jogja City Mall, and Galeria Mall. The third-day route covers Pasar Beringharjo, Taman Sari Yogyakarta, Keraton Yogyakarta, Prawirotaman, and Situs Warungboto. Each set of destinations visited within a single day consists of geographically close locations, making them feasible to visit within a day.

A sensitivity analysis was conducted on the objective function weights, the maximum time limit (travel duration), and the number of travel days. Variations in the objective function weights were tested to observe different score outcomes based on decision-makers' preferences, including cases where one objective dominates, trade-offs between objectives, and balanced weight distribution. The maximum time limit was adjusted by -20%, -10%, 10%, 20%, 30%, 40%, and 50% (relative to the eight-hour reference), while the number of travel days ranged from 1 to 5. The results indicate that different weight configurations yield different optimal route options, while increasing the maximum time limit and the number of travel days lead to higher tourist satisfaction scores, costs, and carbon emissions, due to the possibility of adding more destinations and routes.

Based on the data and the implementation process of the green TOP model, several recommendations can be proposed for future research development. The model can be further enhanced by incorporating time dependencies and implementing time windows to better represent real-world situations. This approach enriches the variety of selectable points compared to assuming uniform opening and closing times for all locations or neglecting road conditions that may affect travel time. The model should also consider tourists' preferences to ensure the selected destinations align with their expectations and interests, thereby making the itinerary more personalized. Additionally, when solving the model using exact methods through software, the feasibility of the available hardware should be taken into account as the model complexity and data volume increase, higher computing power is required, which may lead to longer computational times. Lastly, it is advisable to explore heuristic and/or metaheuristic methods as alternatives to exact methods for solving the model.

Conflicts of Interest

The authors reported no potential conflict of interest.

References

[1] World Economic Forum (2024). *Travel & tourism development index 2024*. https://www.weforum.org/publications/travel-tourism-development-index-2024/

[2] Badan Pusat Statistik. (2024). *Kunjungan wisatawan mancanegara pada Juni 2024*. https://www.bps.go.id/id

[3] Anggela, N, L. (2024). *Target kontribusi PDB pariwisata 4,6% di era prabowo-gibran, realistis?* https://ekonomi.bisnis.com/read/20240425/12/1760041/target-kontribusi-pdb-pariwisata-46-di-era-prabowo-gibran-realistis

[4] Badan Pusat Statistik. (2024). *Jumlah perjalanan wisatawan nusantara menurut provinsi Tujuan.* https://www.bps.go.id/id/statistics-table/2/MjIwMSMy/jumlah-perjalanan-wisatawan-nusantara-menurut-provinsi-tujuan--perjalanan-.html

[5] Dinas Pariwisata Daerah Istimewa Yogyakarta. (2023). *Statistik kepariwisataan daerah istimewa Yogyakarta*. https://drive.google.com/file/d/1W6oSiqt0unLSUKQUEZpkGm2gdAzIFq87/view?usp=sharing

[6] BMWI. (2024). *Memahami peran BPW dalam industri pariwisata*. https://lsupariwisata.com/2023/08/07/memahami-peran-bpw-dalam-industri-pariwisata/

[7] Chan, G. S. H., & Guillet, B. D. (2015). Implementing revenue management for travel agencies. *Journal of management and sustainability, 5*, 17. https://doi.org/10.5539/jms.v5n4p17

[8] Divsalar, G., Divsalar, A., Jabbarzadeh, A., & Sahebi, H. (2022). An optimization approach for green tourist trip design. *Soft computing, 26*(9), 4303–4332. https://doi.org/10.1007/s00500-022-06834-1

[9] Sustainable Travel International. (2024). *Sustainable travel international carbon footprint of tourism*. https://sustainabletravel.org/issues/carbon-footprint-tourism/

[10] Sahira, W, S. (2023). *Indonesia targetkan emisi karbon di sektor pariwisata berkurang hingga 50 persen pada 2030*. https://www.liputan6.com/lifestyle/read/5483388/indonesia-targetkan-emisi-karbon-di-sektor-pariwisata-berkurang-hingga-50-persen-pada-2030

[11] Alberto, G., Sitompul, C., & others. (2023). Dynamic scoring and costing in the orienteering problem: A model based on length of stay. *Jurnal optimasi sistem industri, 22*(2), 114–125. https://doi.org/10.25077/josi.v22.n2.p114-125.2023

[12] Gunawan, A., Lau, H. C., & Vansteenwegen, P. (2016). Orienteering problem: A survey of recent variants, solution approaches and applications. *European journal of operational research, 255*(2), 315–332. https://doi.org/10.1016/j.ejor.2016.04.059

[13] Vansteenwegen, P., Souffriau, W., & Oudheusden, D. Van. (2011). The orienteering problem: A survey. *European journal of operational research, 209*(1), 1–10. https://doi.org/10.1016/j.ejor.2010.03.045

[14] Gunawan, A., Ng, K. M., Yu, V. F., Adiprasetyo, G., & Lau, H. C. (2019). The capacitated team orienteering problem. *Proceedings of the 9th international conference on industrial engineering and operations managementbangkok, Thailand,* (pp. 1630–1638). IEOM Society. https://ink.library.smu.edu.sg/sis_research/4328/

[15] Herrera, E. M., Panadero, J., Carracedo, P., Juan, A. A., & Perez-Bernabeu, E. (2022). Determining reliable solutions for the team orienteering problem with probabilistic delays. *Mathematics, 10*(20), 3788. https://doi.org/10.3390/math10203788

[16] Khodadadian, M., Divsalar, A., Verbeeck, C., Gunawan, A., & Vansteenwegen, P. (2022). Time dependent orienteering problem with time windows and service time dependent profits. *Computers & operations research, 143*, 105794. https://doi.org/10.1016/j.cor.2022.105794

[17] Agarwal, S., & Akella, S. (2023). The correlated arc orienteering problem. *Algorithmic foundations of robotics xv* (pp. 402–418). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-031-21090-7_24%0A%0A

[18] Erdoğan, G., & Laporte, G. (2013). The orienteering problem with variable profits. *Networks, 61*(2), 104–116. https://doi.org/10.1002/net.21496

[19] Montemanni, R., & Smith, D. H. (2024). A compact model for the clustered orienteering problem. *Logistics, 8*(2), 48. https://doi.org/10.3390/logistics8020048

[20] Liu, X., Luo, X., Zhang, Z., Hu, Y., & Hang, H. (2023). *A two-stage approach to the multiple-agent orienteering problem with stochastic weight and capacity constraints*. Preprint, 1–19. https://doi.org/10.21203/rs.3.rs-3106253/v1

[21] Panagiotakis, C., Daskalaki, E., Papadakis, H., & Fragopoulou, P. (2022). The tourist trip design problem with poi categories via an expectation-maximization based method. *RecSys workshop on recommenders in tourism (rectour 2022), september 22th, 2022, co-located with the 16th acm conference on recommender systems, Seattle, Wa, USA* (pp. 47–64). CEUR Workshop Proceedings. https://ceur-ws.org/Vol-3219/paper4.pdf

[22] Ruiz-Meza, J., Brito, J., & Montoya-Torres, J. R. (2021). Multi-objective fuzzy tourist trip design problem with heterogeneous preferences and sustainable itineraries. *Sustainability, 13*(17), 9771. https://doi.org/10.3390/su13179771

[23] Golden, B. L., Levy, L., & Vohra, R. (1987). The orienteering problem. *Naval research logistics (nrl)*, *34*(3), 307–318. https://doi.org/10.1002/1520-6750(198706)34:3%3C307::AID-NAV3220340302%3E3.0.CO;2-D
[24] Howe, J. (2009). *Crowdsourcing: why the power of the crowd is driving the future of business*. https://public.summaries.com/files/8-page-summary/crowdsourcing.pdf
[25] Saltelli, A. (2002). Sensitivity analysis for importance assessment. *Risk analysis*, *22*(3), 579-590. https://doi.org/10.1111/0272-4332.00040
[26] Breierova, L., & Choudhari, M. (2001). *An introduction to sensitivity analysis*. https://ocw.mit.edu/courses/15-988-system-dynamics-self-study-fall-1998-spring-1999/abda6cf0e50977bf369a53fe6c4deb0a_sensitivityanalysis.pdf
[27] Knill, O. (2012). *Geometry and distance*. https://people.math.harvard.edu/~knill/teaching/summer2012/handouts/week1.pdf
[28] Liberti, L., & Lavor, C. (2017). *Euclidean distance geometry*. Springer. https://doi.org/10.1007/978-3-319-60792-4
[29] Lee, D. (2023). *Integer programming lecture 1: Introduction*. https://dabeenl.github.io/IE631_lecture1_note.pdf
[30] Tahami, H., & Fakhravar, H. (2022). A literature review on combining heuristics and exact algorithms in combinatorial optimization. *European journal of information technologies and computer science*, *2*(2), 6–12. https://doi.org/10.24018/compute.2022.2.2.50
[31] Yogyakarta Tourism Case. (2025). *Yogyakarta tourism case*. https://docs.google.com/spreadsheets/d/19ZR4SCx8FtVo2xWwl7tqqKmhiDq2xlndA72_Ka4HIvI/edit?gid=1101711006#gid=1101711006

Appendix

Table A1. Coordinate the destination data in Yogyakarta.

No	Destination	Latitude	Longitude
1	Royal Ambarrukmo Yogyakarta	-7.7823772	110.403051
2	Candi Prambanan	-7.752021	110.491467
3	Jalan Malioboro	-7.7926566	110.3658454
4	Obelix Sea View	-8.0252235	110.347132
5	Tugu Jogja	-7.7829218	110.3670757
6	Taman Sari Yogyakarta	-7.8099788	110.3589907
7	Heha Sky View	-7.8496144	110.478324
8	Pantai Drini	-8.1384509	110.577522
9	Obelix Hills	-7.8070987	110.5216184
10	Kids Fun Yogyakarta	-7.7823797	110.3791605
11	Pantai Parangtritis	-8.024608	110.3298045
12	Heha Ocean View	-8.1060664	110.4615101
13	Tebing Breksi	-7.7815714	110.5045827
14	Pantai Slili	-8.1449664	110.6028766
15	Pantai Ngobaran	-8.1184844	110.5028785
16	Gembira Loka Zoo	-7.8041337	110.3979883
17	Taman Pintar Yogyakarta	-7.8006715	110.3676551
18	Pasar Beringharjo	-7.798812	110.3657371
19	Pantai Indrayanti	-8.1506589	110.6126311
20	Kaliurang	-7.5989706	110.4307901
21	Candi Ratu Boko	-7.7705416	110.4894158
22	Goa Pindul	-7.9293861	110.6489884

Table A1. Continued.

No	Destination	Latitude	Longitude
23	Pantai Kukup	-8.132883868	110.5544
24	Candi Plaosan	-7.7407807	110.5046772
25	Agrowisata Bumi Merapi	-7.6400756	110.4264098
26	Pantai Gesing	-8.1085778	110.4679367
27	Candi Mendut	-7.6053138	110.2295345
28	Prawirotaman	-7.8191529	110.3706155
29	Keraton Yogyakarta	-7.8090256	110.363649
30	Pantai Baron	-8.1288246	110.5487763
31	Pantai Depok	-8.0137087	110.2914777
32	Candi Kalasan	-7.7672505	110.4723365
33	Pantai Nglambor	-8.1827028	110.6792399
34	Pantai Pok Tunggal	-8.1554468	110.6217582
35	Candi Ijo	-7.783827	110.5118835
36	Bukit Bintang	-7.845713151	110.4798672
37	Pantai Sadranan	-8.145668	110.6043914
38	Pantai Sundak	-8.147072	110.6079043
39	Gumuk Pasir Parangkusumo	-8.01845	110.3195509
40	Kotagede Yogyakarta	-7.8205288	110.4009845
41	Sindu Kusuma Edupark	-7.7678784	110.3545667
42	Hutan Pinus Pengger	-7.8712041	110.4595144
43	Candi Pawon	-7.6061348	110.2195624
44	Pantai Baru	-7.988938	110.2210403
45	Pantai Krakal	-8.145019	110.5998857
46	Pantai Kesirat	-8.0961535	110.4350483
47	Monumen Jogja Kembali	-7.7495904	110.3696068
48	Pemandian Tirta Budi	-7.70267332	110.4490996
49	Pantai Sadeng	-8.190427	110.7988565
50	Makam Raja-raja Imogiri	-7.9204974	110.3957999
51	Puncak Becici	-7.9020355	110.4374627
52	Situs Warungboto	-7.8101941	110.3932803
53	Sendang Sono	-7.668004	110.225523
54	Pantai Wediombo	-8.1862462	110.709901
55	Alun-alun Kidul	-7.8119393	110.3632767
56	Studio Alam Gamplong	-7.8057936	110.2367304
57	Museum Ullen Sentalu	-7.598228	110.422825
58	Candi Sambisari	-7.7624548	110.4470446
59	Taman Sungai Mudal	-7.7628136	110.1161626
60	Ambarrukmo Plaza	-7.7825776	110.4010956
61	Malioboro Mall	-7.7933702	110.3668603
62	Galeria Mall	-7.78258561	110.3791733
63	Jogja City Mall	-7.7532424	110.3609091
64	Pakuwon Mall Jogja	-7.7588094	110.3992739
65	Royal Ambarrukmo Yogyakarta	-7.7823772	110.403051

Table A2. Results of weight adjustment.

No.	Days	Destinations and Routes	Total Score	Percentage Change in Total Score
	1	1-5-58-24-13-32-65		
1	2	1-64-47-63-62-65	3.521	0.00%
	3	1-18-6-29-28-52-65		
	1	1-32-21-35-24-58-65		
2	2	1-60-5-63-47-65	7.294	107.16%
	3	1-18-6-29-28-52-65		
	1	1-64-47-63-62-65		
3	2	1-40-61-3-5-65	1.634	-53.59%
	3	1-18-6-29-28-52-65		
	1	1-61-3-5-62-65		
4	2	1-18-6-29-28-52-65	1.855	-47.32%
	3	1-64-58-24-21-32-65		
	1	1-32-13-24-58-5-65		
5	2	1-52-28-6-29-18-65	4.408	25.19%
	3	1-62-63-47-64-65		
	1	1-18-29-6-28-52-65		
6	2	1-64-63-60-65	0.526	-85.06%
	3	1-62-5-3-61-65		
	1	1-18-6-29-28-52-65		
7	2	1-5-58-24-13-32-65	5.88	67.00%
	3	1-64-47-63-62-65		

Table A3. Results of travel duration/time.

No.	Travel Duration	Days	Destinations and Routes	Total Score	Percentage Change in Total Score
1	6.4	1	1-64-47-63-65	2.721	-22.72%
		2	1-32-24-58-5-65		
		3	1-18-6-29-52-65		
2	7.2	1	1-52-28-18-3-65	3.104	-11.84%
		2	1-32-35-24-58-65		
		3	1-64-47-63-5-65		
3	8	1	1-5-58-24-13-32-65	3.521	0.00%
		2	1-64-47-63-62-65		
		3	1-18-6-29-28-52-65		
4	8.8	1	1-28-29-6-18-3-65	3.843	9.15%
		2	1-58-24-35-13-32-65		
		3	1-64-47-63-5-52-65		
5	9.6	1	1-5-3-18-29-6-28-65	4.206	19.45%
		2	1-64-47-63-62-52-65		
		3	1-58-24-35-13-21-32-65		
6	10.4	1	1-28-6-29-18-61-5-65	4.359	23.80%
		2	1-58-32-24-35-13-52-65		
		3	1-62-3-63-47-64-65		
7	11.2	1	1-64-47-63-62-60-65	4.637	31.70%
		2	1-5-3-18-6-29-28-52-65		
		3	1-40-13-35-24-32-58-65		
8	12	1	1-60-17-29-28-40-52-65	4.861	38.06%
		2	1-62-6-18-3-5-63-47-65		
		3	1-32-21-13-35-24-58-64-65		

Table A4. Results of travel days.

No.	Days	Destinations and Routes	Total Score	Percentage Change in Total Score
1	1	1-52-28-18-3-5	1.387	-60.61%
2	1	1-18-6-29-28-52-65	2.512	-28.66%
	2	1-58-32-24-47-5-65		
3	1	1-5-58-24-13-32-65	3.521	0.00%
	2	1-64-47-63-62-65		
	3	1-18-6-29-28-52-65		
4	1	1-62-63-47-64-65	4.398	24.91%
	2	1-40-61-3-5-65		
	3	1-58-24-35-21-32-65		
	4	1-18-6-29-28-52-65		
5	1	1-58-24-35-21-32-65	5.038	43.08%
	2	1-64-47-63-62-65		
	3	1-55-6-18-3-65		
	4	1-40-52-5-60-65		
	5	1-28-29-17-61-65		

Table A5. Conversion results of weight adjustment.

Weight Scenario	Satisfaction	Cost	Carbon Emission (gr)
1	119,505	Rp407,000	16046.161
2	121,095	Rp540,650	14372.776
3	107,703	Rp270,600	10521.697
4	118,594	Rp487,850	12997.391
5	119,505	Rp407,000	16046.161
6	100,896	Rp232,925	9054.620
7	119,505	Rp407,000	16046.161

Table A6. Conversion results of travel duration/time.

No.	Travel Duration	Satisfaction	Cost	Carbon Emission (gr)
1	6,4	94.004	Rp335,775	14670.776
2	7,2	104.104	Rp318,725	14418.622
3	8	119.505	Rp407,000	16046.161
4	8,8	128.805	Rp420,750	15427.238
5	9,6	145.499	Rp609,950	15587.700
6	10,4	144.801	Rp452,100	16390.008
7	11,2	152.501	Rp452,650	16023.238
8	12	169.697	Rp766,700	16665.085

Table A7. Conversion results of travel days.

No.	Number of Days	Satisfaction	Cost	Carbon Emission (gr)
1	1	42.799	Rp67,100	3530.155
2	2	85.802	Rp294,525	12470.160
3	3	119.505	Rp407,000	16046.161
4	4	151.999	Rp613,800	17994.624
5	5	177.193	Rp792,550	20699.548