GREEDY HEURISTIC ALGORITHMS FOR MULTI-OBJECTIVE TOURIST TRIP DESIGN PROBLEM ON PENANG ISLAND

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ABSTRACT

Tourism is a vital sector in the global economy, significantly contributing to the development of many countries by creating jobs, generating income, and promoting cultural exchange. However, planning a tour itinerary presents a significant challenge due to the necessity of identifying points of interest (POI) and organizing them into a proper itinerary. This study focused on solving the multi-objective TTDP for Penang Island by developing two greedy heuristic techniques: Nearest Neighbour (NN) and Nearest Greedy Insertion (NGI). The study aimed to achieve three objectives: identifying tourists' preferences and constraints relevant to the TTDP, proposing solutions using NN and NGI techniques, and evaluating the effectiveness of these methods. Adopted a hybrid weighted objective, both algorithms balanced maximizing the number of POIs visited and popularity index while satisfying several constraints such as time windows, popularity index, restaurant selection, POI categories, and budget limitations. The findings showed that the NN technique performed better for a one-day tour, delivering a higher popularity index (212.66) compared to NGI (171.43). However, the NGI technique outperformed in a two-day tour by balancing POI coverage and popularity index of 294.91, while NN had 268.68. For a three-day tour, NN achieved a higher popularity index (359.86) than NGI (337.03), while NGI visited more POIs. Future studies should explore metaheuristic methods, broader geographic applications, incorporate time-dependent variables, and tailored solutions for halal-conscious travellers.

Keywords: Nearest Greedy Insertion, Nearest Neighbour, Penang Island, tourist trip design problem.

INTRODUCTION

Tourism has become an essential industry in Malaysia, contributing substantially to the nation's gross domestic product. Tourism in Malaysia has seen significant growth recently, and according to Ho (2024), the visa exemption policy, alongside accessibility and flight connectivity, is expected to achieve the goal of attracting around 36 million international tourists and generating MYR 150 billion in 2026 for Malaysia. According to Themes (2024), UNESCO recognized George Town as a World Heritage City, drawing millions of tourists to Penang. Penang is well known for its tourism assets, such as heritage, historical relics, culture, and food, and it is one of Malaysia's top tourist destinations (Ab Dulhamid et al., 2022).

Planning a tour itinerary in a foreign city presents a significant challenge due to the necessity of identifying captivating POIs and organizing them into a proper itinerary (Gündling & Witzel, 2020). Travel planning involves collecting information from various sources (i.e., travel guides, websites, etc.), prioritizing POIs, and selecting an optimal route that balances multiple factors such as personal preferences, visiting costs, and travel distances (Divsalar et al., 2019). Although tourism-related information is readily available on the internet or through travel guides, these resources often recommend popular POIs or generic itineraries, failing to address individual tourists' specific preferences and constraints (Lim et al., 2019). The overwhelming volume of information available makes trip planning both time-consuming and inefficient. Another alternative is relying on tour agencies, which typically offer standard package tours that do not always align with every tourist's personal interest and constraints (Lim et al., 2019). This growing demand for tailored travel experiences highlights the need for more advanced planning tools.

This type of problem is called the Tourist Trip Design Problem (TTDP). TTDP is designed to help tourists choose the most attractive sites and plan their tour while considering the constraints such as time, distance, and costs (Rahman et al., 2014). TTDP plays a vital role in enhancing tourist travel experiences, improving the quality of attractions, driving economic growth, and strengthening the competitiveness of the tourism supply chain.

This study focused on solving the multi-objective TTDP for Penang Island by developing two greedy heuristic techniques: Nearest Neighbour (NN) and Nearest Greedy Insertion (NGI). The study aimed to achieve three objectives: identifying tourists' preferences and constraints relevant to the TTDP, proposing solutions using NN and NGI techniques, and evaluating the effectiveness of these methods.

LITERATURE REVIEW

The TTDP literature discusses both single-objective and multi-objective models. Common objectives include maximizing profit, level of service, and the number of POIs visited, while minimization objectives focus on cost, distance, travel time, total time, and CO_2 emissions. Most studies prioritize profit maximization, defined as the sum of rewards from visited POIs, followed by minimizing distance, maximizing POIs visited, and reducing costs and emissions (Vu et al., 2022). Only a few studies consider minimizing total or travel time.

Multi-objective models are widely proposed in TTDP studies, as they address multiple goals simultaneously. However, conflicts may arise, such as between maximizing POI scores and minimizing travel distance, potentially leading to suboptimal solutions (Paulavičius et al., 2023). In contrast, single-

objective TTDPs aim to optimize one factor, like total profit, but may not suit all scenarios. For example, while a walking tour benefits the environment, it may exhaust tourists, requiring a trade-off between profit and distance (Choachaicharoenkul et al., 2022). Overall, multi-objective models provide a more balanced approach by integrating multiple factors effectively.

Constraints of TTDP

TTDP incorporates various constraints to model realistic tour-planning scenarios. One of the most common constraints is the time window, which ensures that each customer or location is visited within a specific operating period, as each POI has its opening and closing hours (Choachaicharoenkul et al., 2022). Arriving too early results in unnecessary waiting and wasted time, while arriving too late makes the visit impossible (Paulavičius et al., 2023).

The impact of time dependency has been explored in several TTDP studies (Gavalas et al., 2015; Gündling & Witzel, 2020; Liao & Zheng, 2018). For example, a real-world case in Athens, Greece, demonstrates how travel times fluctuate due to traffic conditions and public transport schedules, affecting tour planning and optimization (Gavalas et al., 2015).

In the study by Souffriau et al. (2013) on the personal routing problem in tourism, the researchers incorporated the POI category into their mathematical model for the TTDP. The POI category included max-n-type and min-n-type constraints, which set upper or lower limits on the number of POIs from each category that could be visited in a single day. Palomo-Martínez et al. (2017) noted that although some TTDP objectives focus on including as many POIs as possible, tourists often prefer not to visit too many POIs with similar characteristics.

Lunch is a critical consideration for many trip planners. Vansteenwegen and Van Oudheusden (2007) highlighted the importance of incorporating meal breaks into itineraries for effective trip planning. To address this issue, several studies proposed the TTDP model that categorizes POIs, including restaurants (Benjamin et al., 2019; Choachaicharoenkul et al., 2022; Filho & Morabito, 2024; Rahman et al., 2014). The model pre-defined the lunch period and supports restaurant selection by specifying the constraints related to the restaurant category.

Additionally, several studies have incorporated popularity ratings into the TTDP as a key constraint for developing effective solutions (Benjamin et al., 2019; Divsalar et al., 2019; Paulavičius et al., 2023; Rahman et al., 2014; Uwaisy et al., 2019). Rachmad et al. (2022) highlighted that visiting highly popular POIs can align more closely with tourists' preferences, improving the overall travel experience.

Techniques for Solving TTDP

Many approaches have been proposed to solve TTDP, including exact methods, heuristic techniques, and metaheuristic algorithms. Among the 23 studies reviewed in Table 1, 11 focus on single-objective optimization, while the remaining 12 address multiple objectives in TTDP-related studies. Additionally, only 2 of these studies utilize benchmark datasets for algorithm testing, with the rest relying on real case studies for TTDP.

The exact solution is feasible only for instances with a limited number of nodes (Gavalas et al., 2015). A detailed study by Ruiz-Meza and Montoya-Torres (2022) shows that approximately 12 to 16% of journals employ exact solution methods for TTDP. Furthermore, exact solution methods are usually

confined to problems with 10 to 100 nodes (e.g., the study conducted by Li and Hu (2011) used only 30 locations with exact solution), and solving such problems is very time-consuming (Ruiz-Meza & Montoya-Torres, 2022). Hence, exact solutions are generally applied to validate approximate methods for smaller cases. Most literature on TTDP focuses on heuristic and metaheuristic algorithms (Benjamin et al., 2019; Choachaicharoenkul et al., 2022; Gündling & Witzel, 2020; Jriji et al., 2020; Liao & Zheng, 2018; Uwaisy et al., 2019).

Several studies have adopted heuristic models, including those by Rahman et al. (2014), Hashim et al. (2018), Benjamin et al. (2019), and Du et al. (2021). Hashim et al. (2018) utilized various greedy heuristic approaches, such as nearest neighbour, cheapest arc greedy, nearest greedy insertion, and ordinal insertion greedy, to optimize routing. Rahman et al. (2014) and Benjamin et al. (2019) applied heuristic models to select POIs and optimize routes, focusing on creating economical tour packages that minimize costs while maximizing the number of POIs visited. Similarly, Du et al. (2021) introduced dynamic programming and clustering-based heuristics to design an integrated and personalized self-driving trip that includes hotel selection and time-dependent constraints to reduce overall costs.

Many studies have applied metaheuristic approaches to solve the TTDP (Expósito et al., 2019; Gavalas et al., 2015; Jriji et al., 2020; Kolaee et al., 2024; Linganathan & Singamsetty, 2024; Ndoloe & Rumlaklak, 2018; Rachmad et al., 2022; Roozbeh et al., 2020; Souffriau et al., 2013; Uwaisy et al., 2019). These metaheuristic methods include iterated local search, tabu search, ant colony optimization, fuzzy greedy randomized adaptive search procedure (GRASP), genetic algorithm, and large neighbourhood search algorithm to solve TTDP.

In addition, Liao and Zheng (2018) proposed a hybrid heuristic algorithm based on random simulation (RS-H2A) to create personalized day tours for tourists visiting Jiu Zhai Valley in a time-dependent stochastic environment. Another recent study by Paulavičius et al. (2023) developed new greedy genetic algorithms that integrate greedy selection within the genetic algorithm framework to address the TTDP in the context of personalized travel recommendations with several constraints, such as mandatory visits, time windows, and tour duration.

Table 1

Summary of the most relevant references and characteristics of TTDP

Journals	Case Study (Y/N)	Total # of POIs	# Objectives	Objective (s)	Main Decisions	Time Window	Time Dependence	Max/Min- n-Type	Restaurant	Popularity	Entrance Fee	Multi-period	Solution Method
Souffriau et al., (2013)	N	150	1	(a)	Routing/select points	✓		✓			✓	✓	Metaheuristic
Rahman et al., (2014)	Y	42	2	(c) & (d)	Routing/select points	✓			✓	✓	✓	✓	Heuristic
Gavalas et al., (2015)	Y	113	2	(b) & (g)	Routing		✓					✓	Metaheuristic
Ndoloe & Rumlaklak (2018)	Y	23	2	(e)	Routing/select points								Metaheuristic
Hashim et al., (2018)	Y	9	1	(e)	Routing								Heuristic
Liao & Zheng (2018)	Y	20	2	(a) & (c)	Routing/select points	✓	✓						Hybrid Heuristic
Divsalar et al. (2019)	Y	24	1	(a)	Routing/select points	✓		✓		✓	✓		Exact
Benjamin et al. (2019)	Y	46	2	(c) & (d)	Routing/select points	✓			✓	✓	✓	✓	Heuristic
Uwaisy et al. (2019)	Y	125	2	(c) & (f)	Routing/select points	✓				✓		✓	Metaheuristic
Jriji et al. (2020)	N	30	1	(a)	Routing/select points	✓		✓			✓		Metaheuristic
Gündling & Witzel (2020)	Y	41	1	(a)	Routing/select points	✓	✓						Exact + Metaheuristics
Divsalar et al. (2021)	Y	10	3	(a), (d) & (h)	Routing/select points								Exact
Ruiz-Meza et al. (2021)	Y	12	4	(a), (b), (e) & (h)	Routing	✓	✓						Exact
Rachmad et al. (2022)	Y	21	1	(e)	Routing/select points								Metaheuristic
Vu et al. (2022)	Y	37	1	(a)	Routing/select points	✓		✓			✓		Exact
Expósito et al (2019)	Y	30	1	(a)	Routing/select points	✓							Exact + Metaheuristics
Tenemaza et al. (2020)	Y	33	1	(b)	Routing	✓	✓					✓	Metaheuristic
Du et al. (2021)	Y	12	2	(a) & (d)	Routing/select points	✓					✓	✓	Heuristic
Choachaicharoenkul et al. (2022)	Y	50	2	(a) & (e)	Routing/select points	✓			✓				Exact + Heuristics
Paulavičius et al. (2023)	Y	40	1	(a)	Routing/select points					✓			Hybrid Heuristic
Filho & Morabito (2024)	Y	36	2	(b) & (e)	Routing/select points	✓			✓			✓	Exact + Heuristics
Pitakaso et al. (2024)	Y	48	3	(a), (d) & (h)	Routing/select points	✓							Exact
Kolaee et al. (2024)	Y	10	3	(a), (d) & (h)	Routing/select points	✓	✓						Metaheuristic

METHODOLOGY

The methodology of this study consisted of five stages to achieve its objectives.

Stage 1: Problem Identification

The study begins with a comprehensive review of existing literature on the TTDP and its constraints, focusing on identifying the challenges in the current model. Based on the literature, an exact solution may not be practical for Penang Island due to its relatively large number of POIs. In contrast to metaheuristic, although they are scalable like greedy heuristic, to handle many POIs and multiple constraints, however, metaheuristic can be overly complex and time-consuming. The greedy heuristic strikes a balance between efficiency and solution quality to develop a practical and near-optimal solutions that align well with the traveller's needs. Therefore, this study will employ a greedy heuristic model using two techniques: nearest neighbour (NN) and nearest greedy insertion (NGI).

Stage 2: Data Collection

Secondary sources were selected to achieve the study's objectives. The collected data encompassed various key data sets crucial to developing the TTDP model. These include data on hotels, POIs, restaurants, time windows, POI category, entrance fees, popularity index, visit duration, and travel time between locations, as listed in Table 2.

Table 2

Key data set related to TTDP

Data Name	Description
Hotel	The starting point of the tour that is the DoubleTree Resort Penang.
POI	46 POIs were selected on Penang Island, including names, location, and category (e.g., beaches, natural, cultural & historical, etc.).
Restaurant	A total of 32 restaurants were selected based on top-ranked recommendations from Wanderlog (2024) for consideration in the itinerary.
Time Windows	Each location's opening and closing times were sourced from Google (2024).
Visit Duration	The average amount of time spent at each POI.
Travel Time	The duration required to travel between locations.
Total Time	The cumulative time, including both visit and travel durations, for the itinerary.
Entrance Fee	The cost required to enter each POI does not include additional expenses such as transportation, accommodation, or meals.
Popularity Index	A composite score representing the popularity of each POI, based on rankings from five travel sites (50%), user reviews (30%), and Google trend data (20%).

The POIs on Penang Island for this study were identified using Tripadvisor (2024), a highly regarded platform for tourist information. 46 POIs were selected, representing diverse attractions showcasing Penang Island's richness. These categories include beaches, natural sites, cultural and historical landmarks, religious sites, fun spots, public spaces, shopping areas, and wildlife and zoos, as detailed

in Appendix A. The geographical coordinates (latitude and longitude) and entrance fees for each POI were obtained from Google (2024) and travel sites (Traveloka, 2023; Tripadvisor, 2024).

The visit duration for each POI on Penang Island was estimated based on the average time tourists tend to spend at each location. Reviews and recommendations informed these duration estimates on popular travel platforms such as Tripadvisor (2024) and Traveloka (2023). For dining, a standardized dining duration of 75 minutes was applied across all selected restaurants.

The travel time between locations in this study was calculated using the Manhattan distance method. Additionally, a base time of 8 minutes was added to the travel time as a buffer in the TTDP solution to address uncertainty across the trip. Thereafter, the total time for each itinerary was calculated by adding the visit duration at each location, the travel time between locations, and an additional 8-minute buffer for each transition.

Stage 3: Greedy Heuristic Algorithms Development

The model integrated multiple objectives: maximizing the number of POIs visited and maximizing the popularity index of those POIs. To achieve these objectives, the model employed a hybrid weighted approach, assigning 60% priority to nearest distance and the remaining 40% to maximizing the popularity index. By balancing these objectives, the model aimed to create itineraries that optimize both the quantity and quality of POIs in line with the tourists' preferences. The greedy heuristic method was implemented through two techniques – NN and NGI, both of which were designed to provide an initial feasible TTDP solution.

The process began by setting several key parameters, as outlined in Table 3. These included the total number of tour days, departure and arrival times, meal periods, entrance fee budgets, and POI categories. Both greedy heuristic techniques must satisfy the following eight constraints: (1) Multi-period scheduling ensures that the number of itineraries matches the number of tour days; (2) The tour must start and end at the same point, which in this case is the hotel, and adhere to the specified departure and arrival times; (3) Itineraries must integrate suitable restaurant options for lunch and dinner; (4) Total entrance fees must not exceed budget set by the tourist; (5) The number of visited POIs in each category cannot exceed the upper limit; (6) The visit times for each POI must fall within their operational time windows; and, (7) Each POI can be visited only once; and, (8) Each restaurant can be visited only once per meal period (lunch or dinner).

Table 3

Parameter setting of the greedy heuristic algorithm for TTDP

| Parameter	Value
Total Tour Day	1-day; 2-days; 3-days
Departure time from the hotel	08:00
Arrival time at the hotel	Before 22:00
Lunch Time	After 11:00
Dinner Time	After 18:00
Entrance Fees	≤ RM 200 per day
POI Category Upper Bound	Beaches: Max 1 POI per day
(Max-n-type)	Natural: Max 2 POIs per day
	Cultural & Historical: Max 6 POIs per day
	Religious: Max 2 POIs per day
	Fun: Max 1 POI per day
	Public Spaces: Max 1 POI per day
	Shopping: Max 1 POI per day
	Wildlife & Zoos: Max 1 POI per day
Popularity Index	The Maximum Value
Number of POIs to be visited	The Maximum Value

Nearest Neighbour

This study adopted the NN technique and integrated it with a hybrid weighted approach as discussed to generate a TTDP solution for Penang Island.

The flowchart of the NN technique in TTDP is illustrated in Figure 1. The tour begins at the hotel area (S), and the start time is predefined in parameter settings. The algorithm then evaluates the available budget (B) to determine if it permits the selection of the next POI (P). The next POI is selected based on the nearest feasible POI with the highest hybrid score. A POI is included in the itinerary only if it satisfies all the abovementioned constraints. The algorithm also integrates meal breaks at predefined intervals for lunch (after 11:00) and dinner (after 18:00). At these times, the nearest feasible restaurant (R) is identified and then added to the itinerary. If no meal break is needed during the current time slot, the algorithm continues to find the next POI (P). This iterative process continues until the tour's end time (E) is reached, at which point the itinerary for the day is finalized. The algorithm then iterates this process for all required itineraries based on the number of tour days.

Figure 1

Nearest Neighbour Flowchart for TTDP
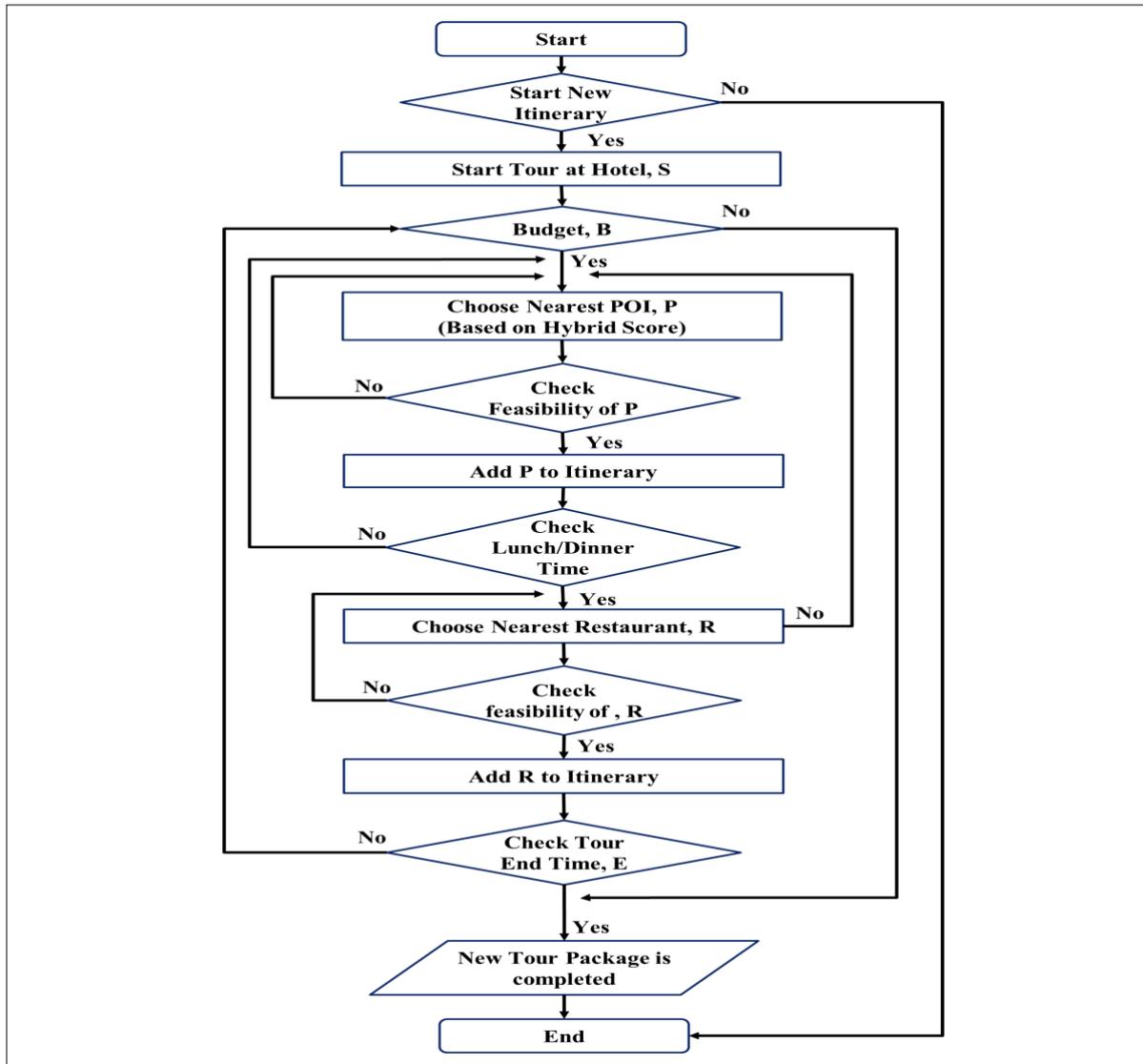

Nearest Greedy Insertion

The NGI technique is one of the greedy heuristic methods used to solve complex routing and optimization problems. The NGI technique works differently from the NN technique by inserting all unvisited nodes into the best position within the current tour (Hasmah et al., 2018).

The flowchart of NGI is illustrated in Figure 2, which outlines the steps involved in generating a feasible TTDP solution. The NGI algorithm begins at the hotel (S) at the predefined start time and checks the available budget (B) to determine whether additional POIs can be included. However, unlike NN, which selects the nearest feasible POI with the highest hybrid score, NGI inserts all POIs into the current tour as a list of permutations (possible solutions), then evaluates which permutation has the highest total hybrid score. The NGI algorithm then selects the permutation with the highest total hybrid score, reflecting the optimal insertion point for the selected POI while adhering to all constraints set above. The integration of meal breaks is handled similarly to NN, with predefined intervals for lunch (after

11:00) and dinner (after 18:00). During these times, the nearest feasible restaurant (R) is identified based on proximity and operational constraints and added to the itinerary. This iterative process continues until the tour's end time (E) is reached, when the itinerary for the day is completed. For multi-day tours, the NGI algorithm generates a separate optimized itinerary for each day until it completes all 3-day tours.

Figure 2

Nearest Greedy Insertion Flowchart for TTDP
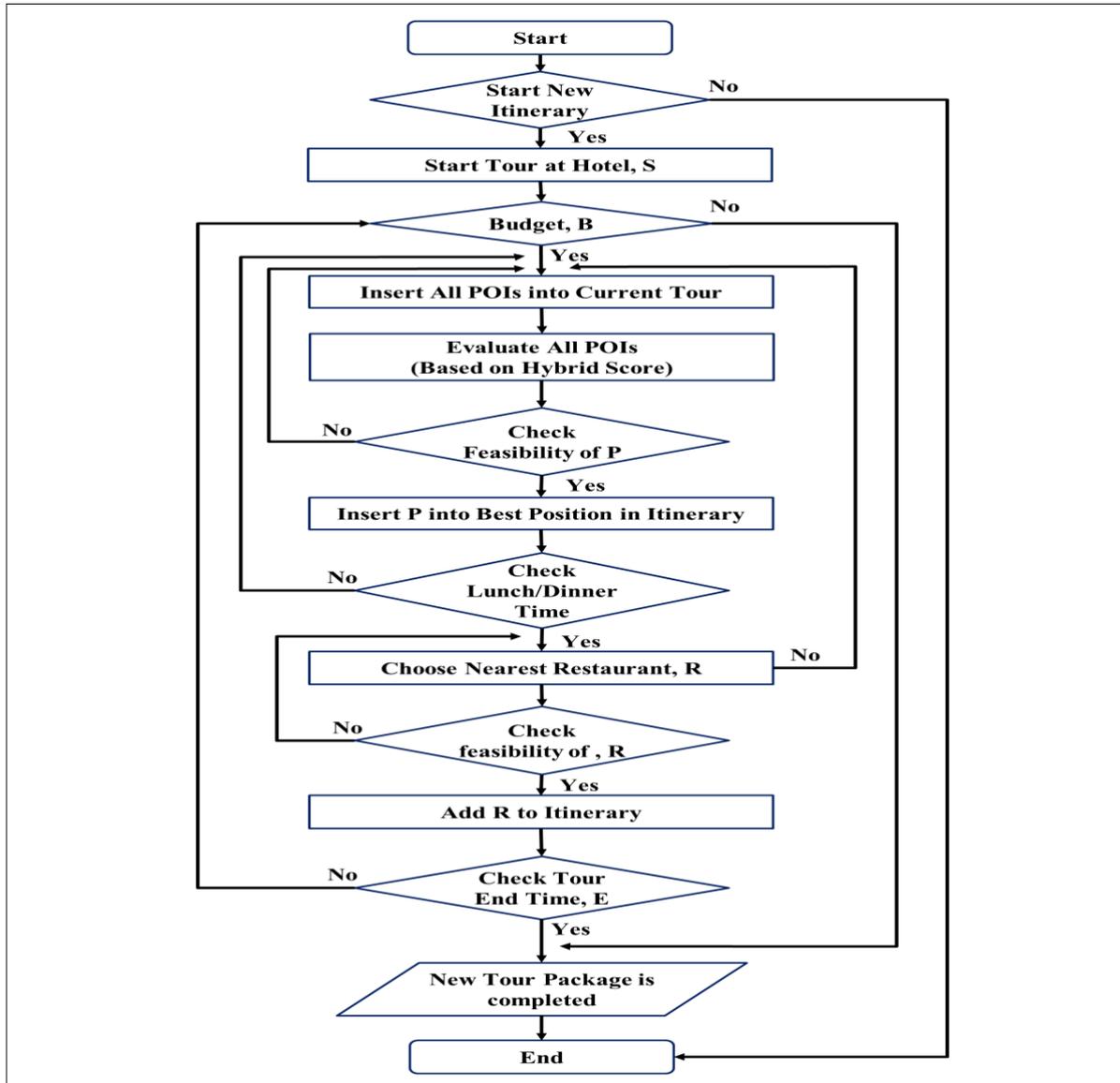
Stage 4: Data Analysis

Both greedy heuristics— the NN & NGI—were executed on an Asus VivoBook 15 with an Intel® Core™ i5-8265U CPU running at 1.60GHz and 8.00GB of memory. Python was chosen as the programming language for these algorithms due to its computational efficiency and compatibility with data-processing workflows. Both techniques were applied to generate initial feasible solutions for the TTDP on Penang Island.

Stage 5: Model Evaluation

The evaluation process began by checking whether both models met all constraints as discussed in the previous section. Once these requirements were verified, the models were then compared based on how well they maximized the popularity index and the number of POIs included in the itinerary.

RESULTS AND DISCUSSION

This section consists of two parts. The first presents the results of the Nearest Neighbour algorithm, while the second presents the results of the Nearest Greedy Insertion.

Result of Nearest Neighbour

Table 4 presents the solution tours generated by the NN algorithm. Based on Table 5, the one-day tour includes visits to 8 POIs, spending 818 minutes (13 hours and 38 minutes), with a cumulative popularity index of 212.66. For the two-day tour package, the itinerary includes 11 POIs across two days, covering a total of 1,571 minutes (26 hours and 11 minutes), and achieving a cumulative popularity index of 268.68. The first day itinerary includes a larger number of POIs, while the second day includes fewer POIs, allowing for quality time spent at each attraction. The three-day tour package offers the most extensive exploration, with visits to 20 POIs over three days. The total duration of traveling amounts to 2,390 minutes (39 hours and 50 minutes), averaging approximately 13 hours per day. This three-day tour package achieves a cumulative popularity index of 359.86.

The total popularity index of all POIs on Penang Island is 502.49. Based on the NN technique's recommendations, the one-day tour achieved 42% of the overall popularity index, the two-day tour achieved 53%, and the three-day tour achieved 72%.
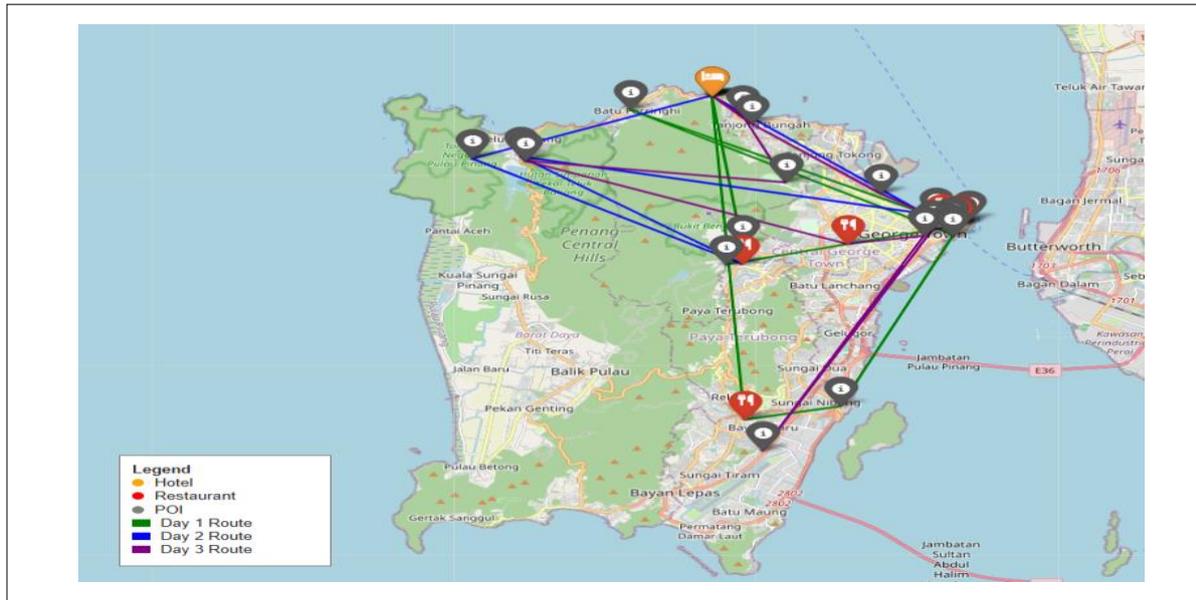
Table 4

Result of Nearest Neighbour

Packages	Model 1 (Nearest Neighbour)				
	No. of POIs Visited	**Total Time (Min)**	**Malaysian Entrance Fee (MYR)**	**International Entrance Fee (MYR)**	**Popularity Index**
1-Day Tour	8	818	66.00	80.00	212.66
2-Day Tour	11	1571	253.00	317.00	268.68
3-Day Tour	20	2390	324.00	408.00	359.86

The map in Figure 3 shows the geographical distribution of POIs, with the majority falling within the northeastern part of Penang Island. This includes a notable concentration around George Town, a key attraction hub. Additionally, some POIs extend towards the northern coastal areas, such as Batu Ferringhi, and the southeastern region near Bayan Lepas.

Figure 3

Itinerary Map based on Nearest Neighbour

Result of Nearest Greedy Insertion

Table 5 presents the solution tours generated by the NGI algorithm. Based on Table 6, the one-day tour package includes visits to 9 POIs, covering a total duration of 820 minutes (13 hours and 40 minutes), with a cumulative popularity index of 171.43. The two-day tour package involves visits to 19 POIs within two days, with two daily meal breaks. The total duration of activities amounts to 1,624 minutes (27 hours and 4 minutes), achieving a cumulative popularity index of 294.91. Across the two days, the package provided a comprehensive mix of heritage, nature, and entertainment while maintaining a balanced daily schedule. The three-day tour package provides the broadest coverage of visits to 21 POIs over three days. The total duration is 2,355 minutes (39 hours and 15 minutes), averaging 13 hours per day, achieving a cumulative popularity index of 337.03.

The total popularity index of all POIs on Penang Island is 502.49. Based on the NGI technique, the one-day tour achieved 34% of the overall popularity index, the two-day tour achieved 59%, and the three-day tour achieved 67%.

Table 5

Result of Nearest Greedy Insertion

Packages	Model 2 (Nearest Greedy Insertion)				
	No. of POIs Visited	Total Time (Min)	Malaysian Entrance Fee (MYR)	International Entrance Fee (MYR)	Popularity Index
1-Day Tour	9	820	16.00	30.00	171.43
2-Day Tour	19	1624	173.00	213.00	294.91
3-Day Tour	21	2355	350.00	430.00	337.03

The map in Figure 4 highlights that most POIs are concentrated in the northeastern part of Penang Island, similar to the NN technique, particularly around George Town, which is rich in cultural and historical attractions. Additionally, some POIs are located in northern areas, such as Batu Ferringhi, known for its scenic coastal appeal. Unlike the NN technique, however, the NGI-generated itineraries include no POIs in the southeastern parts of Penang Island, indicating a shift in focus toward the northeastern and northern regions for greater optimization.

Figure 4

Itinerary Map based on Nearest Greedy Insertion
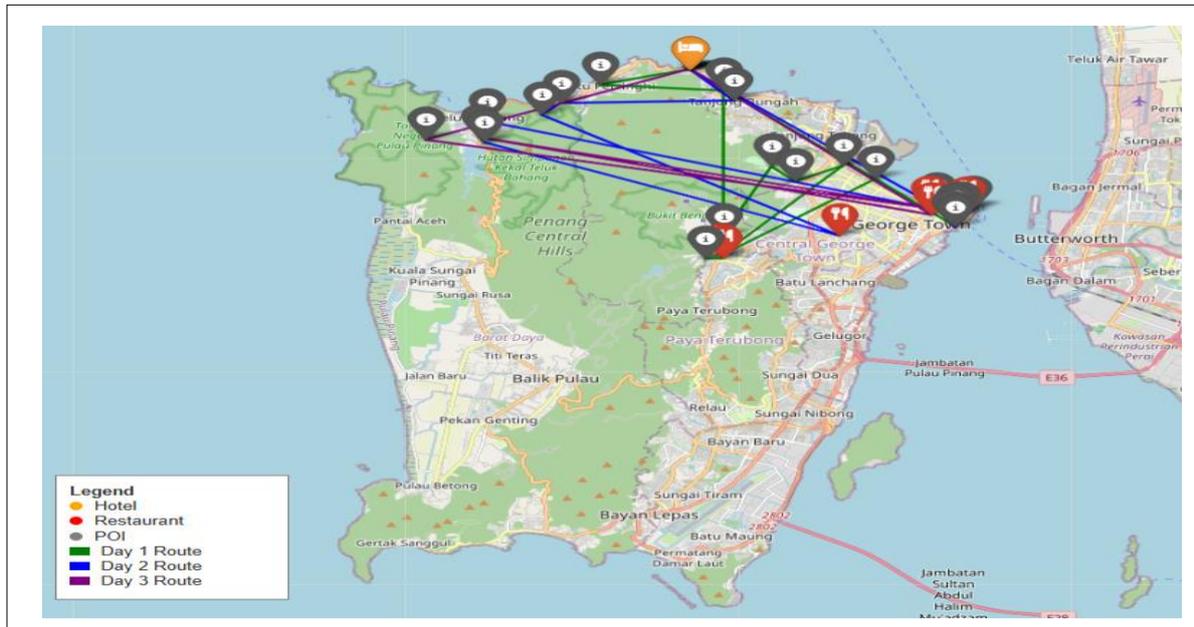
Comparison of Greedy Heuristic Results: NN vs NGI

Based on the findings of NN and NGI techniques, both techniques highlight distinct strengths and trade-offs in addressing the multi-objective TTDP solution. Firstly, in terms of the number of POIs visited, the NGI technique consistently performed better than the NN technique across all tour durations. When evaluating total travel time, both techniques generate itineraries that closely align with the time constraints of each tour duration. For the one-day tour, the total travel time for both techniques is nearly identical, at around 820 minutes. In the two-day tour, the NGI technique requires slightly more time, with a duration of 1624 minutes compared to the NN technique's 1571 minutes. However, in the three-day tour, the NGI technique demonstrates greater efficiency by requiring slightly less time (2355 minutes) than the NN technique (2390 minutes).

In terms of entrance fees incurred for attraction visits, the NGI technique demonstrates cost efficiency in the one-day and two-day tours. However, the NGI technique results in slightly higher costs for the three-day tour than the NN technique.

The popularity index results provide further insight into the differences between the two techniques. The NN technique achieves a higher popularity index for the one-day tour (212.66 vs. 171.43 for the NGI technique), reflecting NN's optimization for shorter tours where proximity and popularity are prioritized. Similarly, the NN technique outperforms the NGI technique in the three-day tour, achieving

a popularity index of 359.86 compared to the NGI technique's 337.03. However, the NGI technique surpasses the NN technique in the two-day tour, with a popularity index of 294.91 compared to the NN technique's 268.68.

CONCLUSION

This study addresses the multi-objective TTDP for Penang Island by developing and analysing two greedy heuristic techniques: NN and NGI. It makes significant contributions to both the theoretical and practical aspects of TTDP. From a theoretical perspective, this study expands the TTDP model by incorporating practical constraints to fill the gaps in existing literature. From a practical perspective, this study offers valuable insights for travel agencies and tour operators by using the TTDP with a hybrid weighted approach to generate itineraries that achieve an optimal balance between quantity and quality, ultimately enhancing the overall travel experience. Furthermore, the NN and NGI algorithms developed in this study can be integrated into backend systems for mobile or web-based applications, enabling dynamic itinerary planning and real-time optimization for tourists visiting Penang Island.

This study poses several limitations that can be addressed in future studies. Firstly, future studies can apply a metaheuristic approach using genetic algorithms or ant colony optimization techniques. This could be explored to refine and improve the initial solutions generated by greedy heuristic methods. These metaheuristic techniques could focus on ongoing optimization, allowing more robust solutions and may achieve globally optimal solutions. Furthermore, it is worth expanding the application of current heuristic algorithms to other regions in Malaysia to test their scalability and flexibility. Another important recommendation is to incorporate time-dependent constraints by taking into consideration that travel times and visit durations are not always fixed. Finally, the study does not consider the specific needs of halal-conscious tourists or dietary requirements, such as the availability of halal food options. Future studies should include options that cater to their specific needs, such as halal-certified restaurants, accommodations, and attractions. Including these considerations in itinerary planning would make the proposed solutions more relevant to Muslim travelers.

ACKNOWLEDGEMENT

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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APPENDIX A

List of POIs in Penang Island

ID#	Point of Interest	Longitude	Latitude	Category
P1	Batu Ferringhi Beach	5.471466	100.246449	Beaches
P2	Tanjung Bungah Beach	5.464820	100.281777	
P3	Bukit Mertajam Recreational Forest	5.356532	100.495306	Natural
P4	Penang National Park	5.449012	100.200542	
P5	Penang Botanic Gardens	5.437943	100.291811	
P6	Penang Municipal Park	5.431760	100.297816	
P7	Tropical Spice Garden	5.463957	100.236283	
P8	Tropical Fruit Farm	5.414814	100.217850	
P9	Penang Hill	5.409316	100.279091	Cultural &
P10	Cheong Fatt Tze MansionF	5.421878	100.335505	Historical
P11	Fort Cornwallis	5.420527	100.345127	
P12	Pinang Peranakan Mansion	5.418052	100.341816	
P13	Sun Yat-sen Museum	5.415966	100.336537	
P14	Penang War Musuem	5.281550	100.289638	
P15	Penang Street Art	5.414748	100.338799	
P16	Penang Little India	5.417390	100.339941	
P17	Clan Jetties	5.413016	100.340192	
P18	Kek Lok Si Temple	5.399895	100.274239	Religious
P19	Khoo Kongsi	5.414596	100.337794	
P20	Dhammikarama Burmese Temple	5.431223	100.314681	
P21	Chaiya Mangalaram Thai Buddhist Temple	5.431923	100.314516	
P22	Snake Temple	5.314149	100.284937	
P23	Kapitan Keling Mosque	5.416818	100.337528	
P24	Penang Floating Mosque	5.468913	100.279224	
P25	St. George's Church	5.420000	100.339648	
P26	Sri Mahamariamman Temple	5.433270	100.366141	
P27	Escape Park	5.449911	100.214585	Fun
P28	The Top Komtar	5.414186	100.331247	
P29	Penang Toy Museum	5.456433	100.216705	
P30	Asia Camera Museum	5.415652	100.337496	
P31	Glass Museum	5.417689	100.330699	
P32	Upside Down Museum	5.416040	100.334388	
P33	Ghost Museum	5.413960	100.335217	
P34	Wonderfood Museum	5.416515	100.341689	
P35	Penang 3D Trick Art Museum	5.419822	100.340554	
P36	Esplanade	5.420079	100.345907	Public Spaces
P37	Gurney Bay	5.432858	100.319143	
P38	Karpal Singh Drive	5.397510	100.332937	
P39	Gurney Plaza	5.438203	100.310663	Shopping
P40	Queensbay Mall	5.334610	100.307658	
P41	1st Avenue Mall	5.413195	100.331824	

P42	Batu Ferringhi Night Market	5.474304	100.248978		
P43	Penang Batik Factory	5.459121	100.230977		
P44	Hin Bus Depot	5.412409	100.328865		
P45	Entopia (Penang Butterfly Farm)	5.447792	100.215885	Wildlife	&
P46	Penang Bird Park	5.394195	100.395346	Zoos	