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Optimization of Flight Routes Employing the Simulated Annealing Method in the Context of the Indonesian National Airline Industry

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A B S T R A C T

This research was conducted in the context of significant air traffic growth in Indonesia, where the increasing number of passengers each year presents an opportunity for airlines to expand their route networks and reach more markets. To seize this opportunity, a national airline based in Jakarta conducted internal research to open new flight routes connecting several important cities in Indonesia, namely Jakarta, Kupang, Pangkal Pinang, Pekanbaru, Makassar, and Banjarmasin.This research aims to obtain an optimal flight route that can enhance the effectiveness and efficiency of the planned airline routes. The research utilizes the Simulated Annealing-Traveling Salesman Problem optimization method to achieve this objective. This method is employed to find the best solution in determining the shortest route that includes visits to each destination city.The initial proposed flight route by the airline was Banjarmasin-Pangkal Pinang-Pekanbaru-Jakarta-Kupang-Makassar, with a total distance of 5,127 km. However, the research yielded a different optimal flight route after conducting the optimization process using the Simulated Annealing-Traveling Salesman Problem method. The discovered optimal flight route is Pekanbaru-Pangkal Pinang-Jakarta-Banjarmasin-Makassar-Kupang, with a total distance of 3,256 km. A comparison between the initial and optimal routes reveals that the new route has a 36.49% shorter distance than the initial route.

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1. INTRODUCTION

The growth of air traffic in Indonesia has seen significant increases in recent years, consequently leading to an uptick in the number of existing airport infrastructures (Pahala, 2019). This growth is attributed to an annual increase in the number of passengers by +5.5% each year between 2014 and 2039 (Hodi et al., 2017). Of course, this presents an opportunity for airlines to expand their route networks and reach a larger market (Eltoukhy, Chan, & Chung, 2017). In light of this opportunity, one national local airline based in Jakarta has

conducted internal research and decided to open a flight route connecting several cities including Jakarta, Kupang, Pangkal Pinang, Pekanbaru, Makassar, and Banjarmasin. The flight route planned by the airline is Banjarmasin-Pangkal Pinang-Pekanbaru-Jakarta-Kupang-Makassar.
To create an optimal flight route that increases effectiveness and efficiency, a study is needed that examines the new flight route in the planned destination cities and tests the route set by the current airline. The objective of this research is to determine the optimal flight route that can enhance the effectiveness and efficiency of the routes planned by the airline, employing the Simulated Annealing-Traveling Salesman Problem optimization method.

2. LITERATURE REVIEW

The examination of flight routes in this study employs a metaheuristic route optimization model (Eltoukhy et al., 2017). Route optimization itself is defined as the use of mathematical methods and analytic techniques to find the best route within a transportation network, taking into account various factors such as distance, travel time, cost, and resource availability (Mahmassani, 2017). The type of metaheuristic employed here is the Simulated Annealing Algorithm-Traveling Salesman Problem. The Simulated Annealing (SA) method is an optimization algorithm inspired by the process of heating and cooling metals to achieve a stable state (Jamili, 2017). According to Kirkpatrick et al. (1983), Simulated Annealing is a stochastic optimization algorithm inspired by the annealing process in metallurgy to search for a global optimum solution in the search space by accepting less optimal solutions with a certain probability initially, then gradually reducing the probability of accepting worse solutions over time. This algorithm has been successfully applied in various problems, including the Traveling Salesman Problem (Santosa, 2017).

According to Applegate et al. (2007), the Traveling Salesman Problem (TSP) is a famous combinatorial optimization problem in the field of computer science and mathematics. In TSP, there are a number of cities to be visited by a salesman, and each city must be visited exactly once with the task of finding the shortest closed path and returning to the original city. According to Drezner & Hamacher (2002), the Traveling Salesman Problem (TSP) can be applied in various industries, such as logistics, parcel delivery, and vehicle route arrangement. By utilizing efficient TSP algorithms, companies can optimize routes and significantly reduce their operational costs. Optimal route planning can reduce the operational costs of an airline's flight (Kenan, Diabat, et al., 2018).

3. RESEARCH METHOD

In this research, the data used originates from a national airline headquartered in Jakarta. The optimization problem-solving in determining flight routes utilizes the Simulated Annealing-Traveling Salesman Problem method.

3.1. Determining Distance Between Target Cities.

The distance matrix in TSP represents a table or matrix that illustrates the distance between each pair of points or cities that need to be visited in the TSP problem. This matrix provides information about the travel distance between each pair of points, and it is used as the basis for calculating the shortest path or route (Russell & Norvig, 2010).

3.2. Initialization:

a. Randomly initialize the initial solution, which is the order of visiting the cities $f(x_i)$
b. Set a high initial temperature based on the average distance between target cities
c. Determine the annealing parameters, including the final temperature (0°), the rate of temperature decrease α (0.995°), and the number of iterations is made floating, starting from $i_1 = 1$ to a certain limit following the number of differences in temperature decrease towards the final temperature (Wang et al., 2019).

3.3. Objective Function Evaluation:

a. Calculate the total route length based on the current solution d_{ij}
b. The objective function in TSP is the sum of the distances covered in the route (Botsali & Alaykiran, 2020).

$$Z_{min} = \sum_{i=1}^{n}\sum_{j=1}^{n} d_{ij} x_i j \quad (1)$$

with constraints,

1. Each place is visited only once,

$$\sum_{i=1}^{n} x_{ij} = 1, \qquad \forall j \neq i \quad (2)$$

$$\sum_{j=1}^{n} x_{ij} = 1, \qquad \forall i \neq j \qquad (3)$$

2. Eliminate any sub-route on the solution,

$u_i - u_j + 1 \leq (n-1)(1 - x_{ij}), \quad \forall i, j = 2, \dots, n$

$1 \leq u_i \leq n - 1, \quad \forall i = 2, \dots, n$

$u_i \geq 0, \quad \forall i = 2, \dots, n$

solution and swap their positions to obtain a neighboring solution $f(x_{i+1})$.

b. Evaluate the total route length for the neighboring solution $f(x_{i+1})$.

c. Calculate the difference in route length change between the neighboring solution $f(x_{i+1})$ and the current solution $f(x_i)$. If the length of $f(x_{i+1})$ is larger than the route length $f(x_i)$, a random number (r) is generated within the interval [0,1] and calculate the probability p (Rere et al., 2015).

$$p = e^{\frac{f(x_{i+1}) - f(x_i)}{T}} \qquad (4)$$

where,

T = control parameter.

If the change (p) is positive (better), accept the neighboring solution as the current solution.

If the change (p) is negative (worse), ignore it.

d. Reduce the temperature based on the

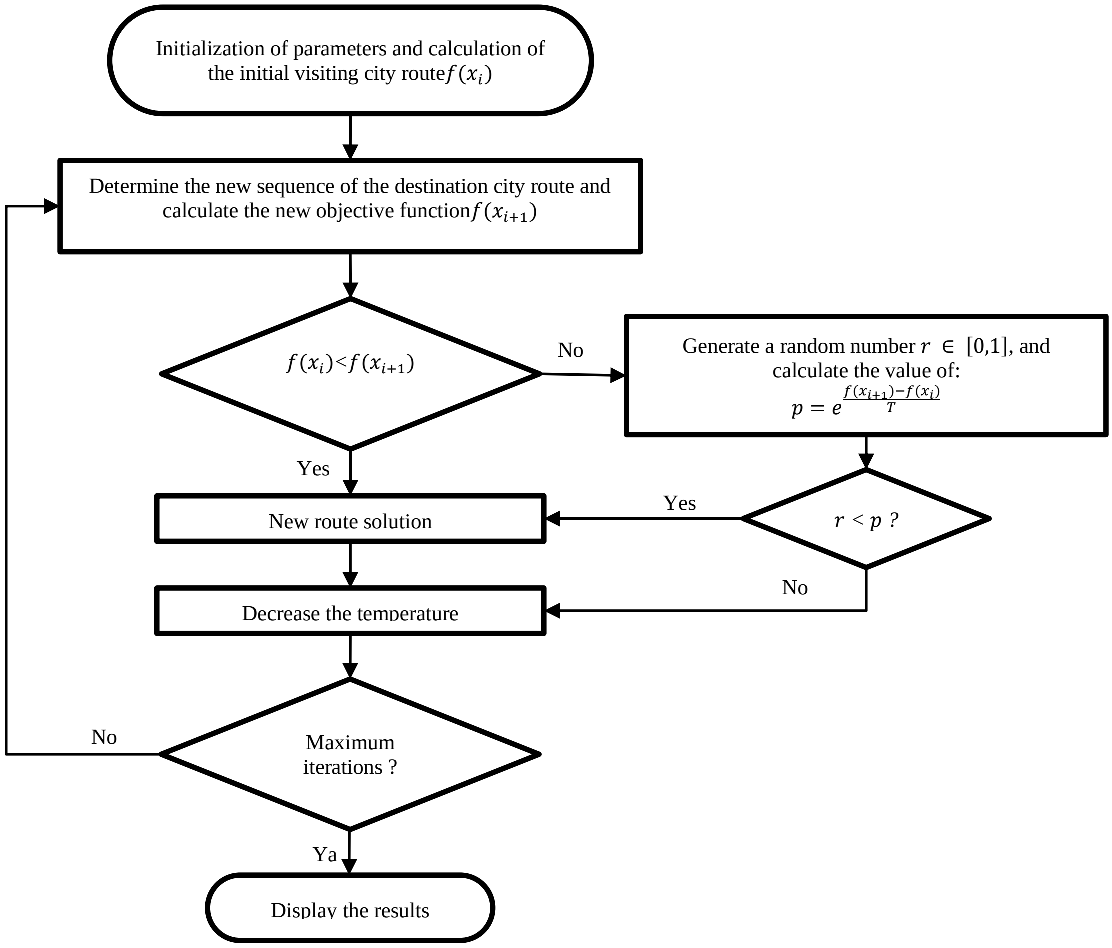


Figure 1. Simulated annealing algorithm flowchart

3. Binary constraint,

$x_{ij} \in \{0,1\}, \forall i = 1,2, \dots, n; \forall j = 1, 2, \dots, n$

where,

n = number of cities to be visited,

d_{ij} = distance from city i to city j

u_i = order of city i in the sub-route.

$$x_{ij} = \begin{cases} 1 \\ 0 \end{cases}$$

3.4. Repetition (Iterative):

Iterate as long as the temperature remains high and the iterations have not reached the final temperature limit (Silalahi et al., 2022):

a. Select two cities randomly in the current determined rate of temperature decrease (Jünger et al., 1995),

$T_k = \alpha . T_{k-1}, 0 < \alpha < 1, k = 1, 2, \ldots$

where α is a constant for obtaining the control parameter.

3.5. Storing the Best Solution, Termination, and Output:

a. Store the best solution found during the iterative process (He et al., 2018).
b. This best solution will become the optimal or near-optimal solution after the process is completed (Ezugwu et al., 2017).
c. Terminate the process when the temperature reaches the final temperature or the number of iterations reaches the determined limit (Redi & Redioka, 2019).
d. Output the best solution found as the final result.

As shown in Figure 1, the flowchart of the Simulated Annealing Algorithm used in this research aligns with the sequence of processes described above.

4. RESULT AND DISCUSSION

This research utilizes the Matlab R2021a software to run the Simulated Annealing algorithm. Based on the results of converting the distance (km) on each destination city route with the help of a live map on Google, a matrix was then constructed as shown in Table 1.

Table 1. Distance matrix of destination [km]

From \ To	**[1]** Jakarta	**[2]** Kupang	**[3]** Pangkal Pinang	**[4]** Pekanbaru	**[5]** Makasar	**[6]** Banjarmasin
[1] Jakarta	0	1.923	443	932	1.400	918
[2] Kupang	1.923	0	2.130	2.725	724	1.254
[3] Pangkal Pinang	443	2.130	0	597	1.515	951
[4] Pekanbaru	923	2.725	597	0	2.095	1.522
[5] Makasar	1.400	724	1.515	2.095	0	574
[6] Banjarmasin	918	1.254	951	1.522	574	0

Below is the coding syntax used:

```
% clear the screen
clc
clear
close all;

% Distance between cities
distances = [
    0       1923   443     932
1400   918;
    1923   0       2130   2725   724
1254;
    443     2130   0       597
1515   951;
    932     2725   597     0
2095   1522;

1400   724     1515   2095   0
574;
918     1254    951     1522   574
0
];

% Initial solution setup
initial_solution =
1:size(distances, 1);

% Determining Simulated Annealing
parameters
initial_temperature = 1094;
cooling_rate = 0.995;

% Simulated Annealing algorithm
and measure the computation time.
tic;
[optimized_solution,
distance_history, num_iterations,
temperature_history] =
simulated_annealing(initial_solut
```

```
ion, initial_temperature,
cooling_rate, distances);
elapsed_time = toc;

% display the results of the
solution
disp('Solusi Optimal:');
disp(optimized_solution);
disp('Jarak Solusi Optimal:');
disp(calculate_total_distance(opt
imized_solution, distances));

% Showing computation time
disp('Waktu Komputasi:');
disp(elapsed_time);
% Menampilkan jumlah iterasi
disp('Jumlah Iterasi:');
disp(num_iterations);

% Generating a distance history
graph
figure;
plot(distance_history, 'b',
'LineWidth', 2);
title('Perubahan Jarak Optimal
Rute Penerbangan');
xlabel('Iterasi');
ylabel('Jarak Total');
grid on;

% Displaying the optimized route
loop
figure;
x = zeros(1,
length(optimized_solution)+1);
y = zeros(1,
length(optimized_solution)+1);
for i =
1:length(optimized_solution)
    x(i) = i;
    y(i) = optimized_solution(i);
end
x(end) = 1;
y(end) = optimized_solution(1);
plot(x, y, 'r', 'LineWidth', 2);
title('Loop Rute Hasil
Optimasi');
xlabel('Iterasi');
ylabel('Kota');
grid on;

% Generating a 3D optimization
plot
figure;
[X, Y] =
meshgrid(1:size(distances, 1));
Z = distances;
surf(X, Y, Z);
title('Grafik Optimasi 3D');
xlabel('Kota A');
ylabel('Kota B');
zlabel('Jarak');
grid on;

% Generating a 3D solution curve
plot
figure;
[X, Y] =
meshgrid(1:size(distances, 1));
Z = distances(optimized_solution,
optimized_solution);
surf(X, Y, Z);
title('Grafik Solusi Kurva 3D');
xlabel('Kota A');
ylabel('Kota B');
zlabel('Jarak');
grid on;

% Creating a temperature cooling
curve graph
figure;
plot(temperature_history, 'r',
'LineWidth', 2);
title('Penurunan Suhu');
xlabel('Iterasi');
ylabel('Suhu');
grid on;

% calculate the total distance
from a given solution.
function total_distance =
calculate_total_distance(solution
, distances)
    total_distance = 0;
    for i = 1:length(solution)-1
        city_a = solution(i);
        city_b = solution(i+1);
        total_distance =
total_distance +
distances(city_a, city_b);
    end
end

% Function to perform the
permutation of two cities in the
solution
function new_solution =
swap_cities(solution, i, j)
    new_solution = solution;
    new_solution(i) =
solution(j);
    new_solution(j) =
solution(i);
end

% Simulated Annealing Fuction
function [best_solution,
distance_history, num_iterations,
```

```
temperature_history] =
simulated_annealing(initial_solut
ion, initial_temperature,
cooling_rate, distances)
    num_cities =
length(initial_solution);
    current_solution =
initial_solution;
    best_solution =
initial_solution;
    current_temperature =
initial_temperature;
    distance_history = [];
    num_iterations = 0;
    temperature_history = [];

    while current_temperature >
0.1
% Selecting two cities randomly
        i = randi(num_cities);
        j = randi(num_cities);

        new_solution =
swap_cities(current_solution, i,
j);

        current_energy =
calculate_total_distance(current_
solution, distances);
        new_energy =
calculate_total_distance(new_solu
tion, distances);

% Calculating the probability of
moving to a worse solution
        acceptance_probability =
exp((current_energy - new_energy)
/ current_temperature);

% Accepting a new solution with a
certain probability
        if new_energy <
current_energy || rand <
acceptance_probability
            current_solution =
new_solution;
        end

% Updating the best solution
        if
calculate_total_distance(current_
solution, distances) <
calculate_total_distance(best_sol
ution, distances)
            best_solution =
current_solution;
        end

% Temperature cooling
        current_temperature =
current_temperature *
cooling_rate;

% Storing distance history
        distance_history(end+1) =
calculate_total_distance(best_sol
ution, distances);

% Storing temperature history

temperature_history(end+1) =
current_temperature;

% calculate the number of
iterations
        num_iterations =
num_iterations + 1;
    end
end
```

After running the above coding syntax, the best route was obtained covering a distance of 3,256 km with 1,856 iterations (Figure 2). The initial temperature used $\bar{x}$ was 1.094°, which kept decreasing until it reached 0° (Figure 3). The new route generated is Kupang-Makassar-Banjarmasin-Jakarta-Pangkal Pinang-Pekanbaru (Figure 4b), which is different from the initial route determined by the airline (Figure 4a). Figure 5 illustrates the comparison between the initial route distance of 5,127 km and the new route distance of 3,256 km as a result of optimization. If converted into a percentage, the new optimized route distance is 63.51% of the initial route distance or 36.49% shorter than the initial route distance.

This research proves that the use of Simulated Annealing in the optimization process can generate the best route with a more efficient travel distance. In this study, the best route found has a length of 3,256 km after running 1,856 iterations. The initial temperature used in the optimization process gradually decreased from 1.094°C until it reached 0°C. The optimization results show a significant difference between the initial route set by the airline and the new route generated.

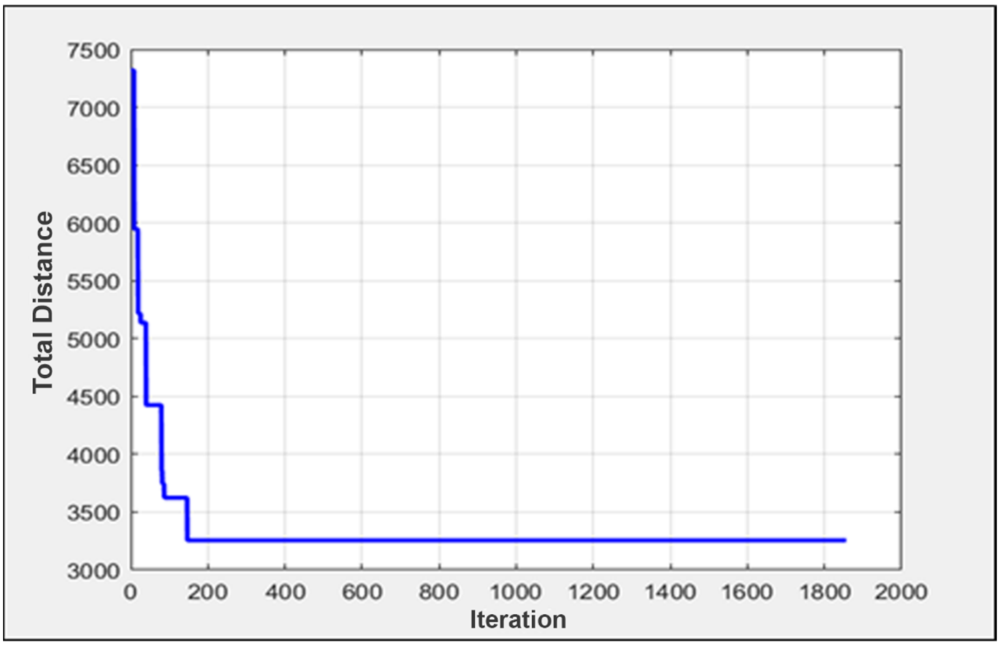


Figure 2. Result of the new optimized route

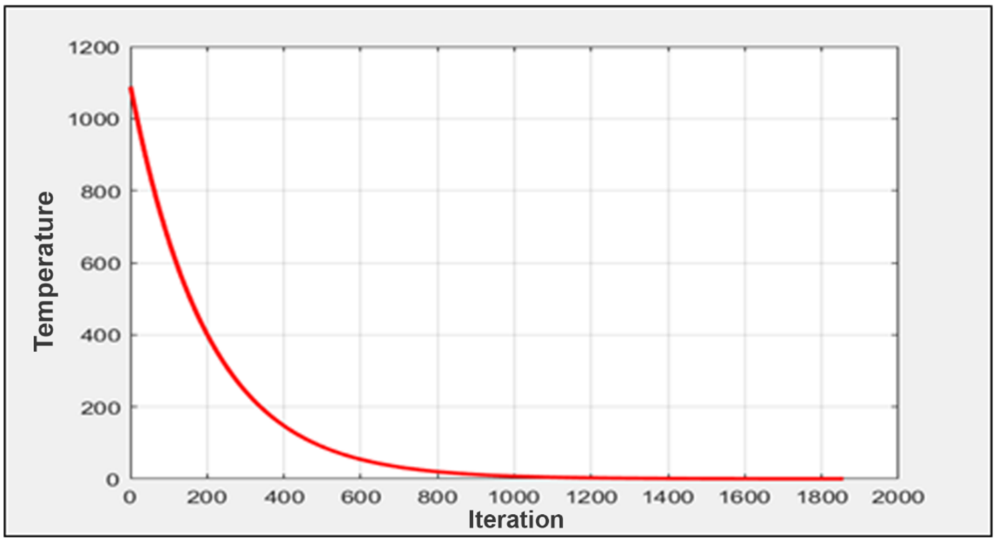
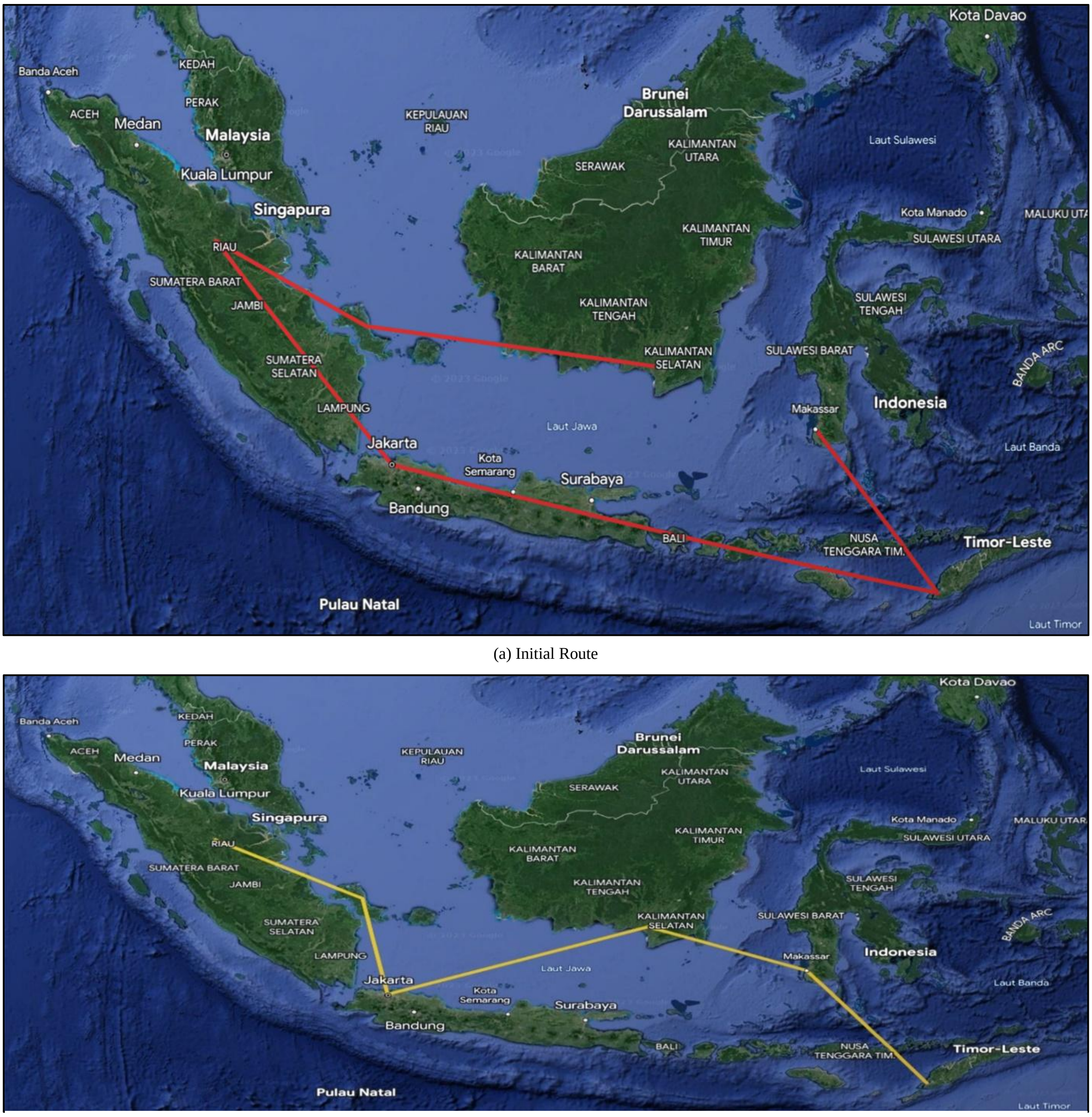


Figure 3. Annealing temperature cooling

The new route discovered through the optimization method is Kupang-Makassar-Banjarmasin-Jakarta-Pangkal Pinang-Pekanbaru. The comparison of distances between the initial route and the new route shows that the new route is 36.49% shorter than the initial route. Based on the findings using AI, it can be said that research on flight route optimization using the Simulated Annealing-Traveling Salesman Problem (SA-TSP) method is rarely published (Ben Ahmed et al., 2017).

This is also evidenced in the process of conducting this research, which uses research references from land transportation modes or outside the aviation world. In the context of the aviation industry, finding the best route with a shorter distance can provide significant benefits (Tang & Hsu, 2016). The more efficient new route can reduce operational costs and travel time, as well as optimize the use of aviation resources (Ozdemir et al., 2012). Based on the calculations conducted by the finance



(a) Initial Route

(b) New Optimized Route

Figure 4. Initial route vs new optimized route

department, implementing the optimized route results in a reduction of operational costs from IDR 310,080,960 to IDR 196,922,880, assuming an occupancy rate of 50% of the available seating capacity, which amounts to 72 seats per flight schedule. Additionally, the time savings based on the calculations of the average travel speed possessed by the company indicate a reduction in travel time from 10 hours 15 minutes to 6 hours 30 minutes.Therefore, the use of optimization methods with Simulated Annealing in flight route planning has the potential to improve the efficiency and overall performance of airlines. However, it's important to note that this research has some limitations, such as weather, airport capacity availability, or other operational constraints may not have been taken into account in this optimization process (Kenan et al., 2018). Thus, further development and adjustments to this model can be carried out to improve the precision and accuracy of optimization results in facing dynamic complexities.

5. CONCLUSION

Based on the findings of this research, it can be concluded that the use of the Simulated Annealing method in flight route optimization produces a more efficient best route. The new route discovered has a distance of 3,256 km with the order of destination cities including Kupang-Makassar-Banjarmasin-Jakarta-Pangkal Pinang-Pekanbaru. The contribution of this research is to produce an optimal flight route with the Simulated Annealing-Traveling Salesman Problem optimization method. The results show that the new route generated has a travel distance 36.49% shorter than the initial route set by the airline. This new route can enhance the operational efficiency of the airline by reducing operational costs by IDR 113,158,080 and travel time by 3 hours 45 minutes. Furthermore, this research provides insights into the application of optimization methods in the aviation industry and expands our knowledge of the use of Simulated Annealing in solving flight route optimization problems. For practical implementation, it is suggested that airlines utilize optimization methods such as Simulated Annealing to plan flight routes. In the context of stiff competition, seeking the most efficient best route can provide a competitive advantage. Based on the results of discussions with stakeholders, there are challenges in realizing the outcomes of this research due to the relatively lengthy process of obtaining the necessary permits.Further research can be undertaken to involve more comprehensive actual data from airlines and to test the optimization model with more complex scenarios. Additionally, modeling considering travel time variables and fuel costs can provide richer insights into flight route planning. With further development and adjustments, this optimization method can become a more effective and practical tool in supporting intelligent and efficient flight route decision-making.

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