

## APPLICATION OF GRAPH NEURAL NETWORKS IN OPTIMIZING FLIGHT TIME FOR THE HO CHI MINH - HANOI ROUTE

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### ABSTRACT

The aviation market worldwide, and in Vietnam in particular, is recovering and developing strongly after the COVID-19 pandemic. To find solutions to reduce air traffic on current ATS routes and discover new, more optimal routes to shorten flight times for aircraft flying from Ho Chi Minh to Hanoi, an optimization model has been built by applying the Graph Neural Network (GNN) model. The research team applied the Graph Neural Network (GNN) model to a specific case that could impact current ATS routes when the PLK (Pleiku) waypoint is unavailable, which may affect the current ATS route. We selected key influencing factors and calculated the shortest and most optimal new route. The application of the GNN model to solutions in the aviation industry is expected to experience significant growth and become more practical in the future, contributing to improving efficiency and operation capacity in the aviation industry.

**Keywords:** GNN model, Flight time optimization, ATS route, Ho Chi Minh- Hanoi route, Flight time calculation.

### 1. Introduction

The aviation industry has become an increasingly popular and essential mode of transportation, experiencing significant growth and continuous development. However, this surge in demand has placed substantial pressure on various aspects of the aviation sector, from infrastructure to personnel, affecting both ground and air operations. In response to the rising demand, air traffic on routes connecting major airports has substantially increased, leading to congestion on critical airways and imposing stricter requirements on flight route planning and management. The Ho Chi Minh City - Hanoi route is the most heavily trafficked domestic route in Vietnam, linking two of the nation's most critical airports, Tan Son Nhat and Noi Bai. This route frequently experiences severe congestion, resulting in regular delays, flight cancellations, and notable disruptions to the operational efficiency of both airports and the airlines operating along it.

In the context of Vietnam's rapidly expanding air traffic volume, which is becoming increasingly vital to the national economy, the lack of optimized routing in terms of distance and efficiency has worsened delays in scheduled take-off and landing times. This issue is particularly pronounced during peak travel periods when the volume of flights surges to levels that strain the system to the brink of overload. The ripple effects of such congestion extend to numerous other aspects of aviation operations, including extended waiting times, increased fuel consumption, passenger dissatisfaction, and a general decline in operational efficiency.

Recognizing the critical nature of these challenges, our research team has undertaken the study titled "Application of Graph Neural Network Models in Optimizing Flight Time for the Ho Chi Minh - Hanoi Route". This research explores the use of advanced algorithms within Graph Neural Network (GNN) models to identify

and optimize flight routes, aiming to minimize flight time while alleviating congestion. Through this study, we seek to provide valuable insights into the application of these cutting-edge models to address and mitigate the persistent issue of airspace congestion, enhance flight route planning, and ultimately contribute to a more efficient and streamlined aviation operation. By improving the management and optimization of flight routes, especially on high-density routes like Ho Chi Minh - Hanoi route, this research has the potential to make a significant impact on the overall operational processes within the aviation industry and specifically in air traffic control and management, paving the way for more efficient, reliable, and sustainable air travel in Vietnam.

## 2. Context of Vietnam's aviation industry and the situation of the Ho Chi Minh -Hanoi route

Currently, the aviation industry is increasingly becoming a popular mode of transportation, expanding and evolving continuously. However, with the growing demand comes increased pressure on all aspects of the aviation industry, leading to overloading in various areas, from personnel such as air traffic controllers and pilots to infrastructure, including airports and airways. To accommodate this demand, flight frequencies on routes connecting major airports have risen, leading to congestion and greater requirements for accurate route planning.

The Ho Chi Minh City - Hanoi route is the most frequently operated domestic route in Vietnam. This connection between the key airports of Tan Son Nhat and Noi Bai regularly experiences congestion, resulting in delays and cancellations, which substantially affects the operational efficiency of both airports and the airlines that serve this route. The commonly used flight paths for this route include:

- **Route W1:** This is a bidirectional route that uses traditional navigation methods.

- **Routes Q1 and Q2:** These are one-way routes that utilize the RNAV5 area navigation method.

The Ho Chi Minh - Hanoi route is a major flight path with a high volume of flights each day. According to a report from OAG<sup>1</sup>, the UK-based

aviation research company, the Hanoi - Ho Chi Minh route had a total of 39,291 flights in 2018, ranking 6th in the world and 5th in the Asia-Pacific region for domestic flight traffic. On average, this route operated 108 flights per day.

In 2019 and 2022, the Hanoi - Ho Chi Minh route ranked 4th and 3rd, respectively, on this list. Statistics from AOG indicate that the route maintained high activity levels even during the challenging Covid-19 pandemic period. In 2019, the route saw 39,291 flights operated by three airlines. In 2020, the route offered 892,800 seats, surpassing the combined total of the top four U.S. routes.

In 2023, as the aviation industry recovers rapidly from the pandemic, the Hanoi - Ho Chi Minh route continues to be one of the busiest, ranking 4th in the world for flight traffic. The Civil Aviation Authority of Vietnam reported that in 2023, the Ho Chi Minh - Hanoi route was the most frequently operated route, with nearly 43,000 flights (about 60 round-trip flights per day). This figure represents 17.5% of the total domestic flights and 22% of domestic passenger traffic.

## 3. Overview of graph neural network (GNN) [1]

### 3.1. Introduction

The GNN is a type of machine learning model specifically designed to work with graph data. The primary goal of the GNN model is to learn embeddings that contain information about the neighborhood of a node. This embedding feature can solve various problems, including node labeling, node and edge prediction, etc.

A notable feature of GNN is its ability to integrate node characteristics with the graph structure, enabling it to learn complex models and represent intricate relationships between objects in the graph. GNN models can be applied to analyze data and optimize complex operations, such as civil aviation movements, by providing efficient optimization.

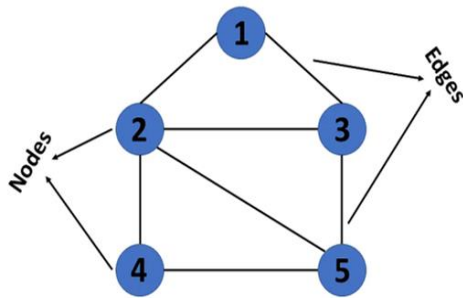
### 3.2. Structure of GNN Model

The most basic component of GNN is the Graph, which consists of two elements: nodes (vertices) and edges. If the edges are directional

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<sup>1</sup><https://www.oag.com/>

between the nodes, the graph is considered directed; otherwise, the edges are undirected.



**Figure 1:** Graph data structure

A graph represents the relationships between information within it, typically as:  $G = (V, E)$

Where:

+  $G$  is the constructed graph;

+  $V$  is the set of vertices/nodes of the graph;

+  $E$  is the set of edges connecting the vertices/nodes.

**Nodes (vertices):** The vertices are the fundamental units of the graph. Each vertex may or may not be labeled.

**Edges:** The edges are drawn to connect two nodes. Sometimes, edges are referred to as arcs. Each edge can also be labeled or unlabeled, similar to the nodes.

For a Directed Graph  $G = (V, E)$ , where:

+  $V$  is the non-empty set of vertices/nodes;

+  $E$  is the ordered set of edges connecting the vertices/nodes.

A Directed Graph represents relationships between points where each vertex pair has an order. In this ordered pair, the first vertex is called the start vertex, and the second is the end vertex. Many properties of directed graphs are independent of edge direction, and in many cases, it's more convenient to ignore the direction of edges.

### 3.3. GNN Model Evaluation

**Data Representation:** GNN explicitly model relationships between data points in the form of graph structures, making them well-suited for tasks involving structured data.

**Generalization Ability:** GNN can learn patterns and generalize to unseen cases with similar graph structures, even if specific node

features differ. This makes them robust to changes in individual data points while capturing underlying relationships.

**Scalability:** Modern GNN can efficiently handle large-scale graphs with millions or even billions of nodes and edges.

**Representational Ability:** GNN visually represent the structure of graphs, facilitating easier understanding and interpretation of graphs.

## 4. Application of GNN model on the Ho Chi Minh - Hanoi route

### 4.1. Influencing Factors

- *Weather*

According to regulations on flight planning for route operations, the aircraft operator must assess information regarding weather conditions, including seasonal meteorological effects or other adverse meteorological conditions that may impact the flight. This demonstrates that meteorology is a crucial factor in flight planning. Poor weather conditions can create adverse conditions that directly affect flight safety and impact air traffic control operations.

For Vietnam, a country with a tropical climate, meteorological factors that could affect flight routes and air traffic control operations include turbulence, storms, and wind.

- *Air Traffic Flow*

Additionally, the issue of flight volume on each route poses a significant challenge for Vietnamese aviation. When flight volume exceeds the route's capacity, air traffic congestion can occur, causing aircraft to queue for departure and further exacerbating delays.

- *Military Operations*

In Vietnam's airspace, air traffic services are managed by both civilian air traffic control facilities and military units. This dual management can result in situations where aircraft are required to change their routes due to military activities, such as:

- Conducting domestic and international military exercises.
- Performing special military missions like patrols or combat operations.
- Protecting and managing national airspace, which includes patrols and guarding airspace along border areas.
- *Emergency Situations*

In some emergency situations, the aircraft may not be able to follow its planned flight path and need to divert to the nearest alternate airport for handling. Examples include:

- Severe technical issues.
- Medical emergencies.
- Security requests.

In such situations, when the aircraft cannot adhere to the original route, airway, flight area, entry point, exit point, or cannot land at the designated airport or airfield as per the flight plan due to external reasons, the flight commander must promptly report to the air traffic service provider. This allows for assistance and guidance on alternative response measures and the quickest new flight route to effectively handle unexpected situations.

## 4.2. GNN model algorithm

### 4.2.1. Finding the Shortest Path

The goal is to find the shortest path from a vertex  $u$  (source vertex) to a vertex  $v$  (destination vertex) in a graph  $G = (V, E)$ , where the distance between two vertices  $u$  and  $v$  is defined as  $d(u, v)$ , calculated by summing the weights of the edges that the path traverses.

Weight Matrix  $W$ :

For a weighted graph  $G = (V, E)$ , where  $V = \{v_1, v_2, \dots, v_n\}$ , the weight matrix  $W = w_{ij}$  is defined as follows:

$$W_{ij} = \begin{cases} 0 & \text{when } i = j \\ w(v_i, v_j) & \text{when } v_i, v_j \in E \\ \infty & \text{when } v_i, v_j \notin E \end{cases} \quad (1)$$

### 4.2.2. Problem Definition

The overarching problem for a weighted graph  $G = (V, E)$  with positive weights is to determine the shortest path from vertex  $u$  to vertex  $v$  and to compute the distance  $d(v, u)$ . The solution involves the following steps:

#### Step 1: Base case

Let  $S$  be the set of vertices  $V$  of the graph. Iterate through the vertices and select up as the starting vertex. Set the initial distance  $L$  of up to 0, and the distances  $L(v)$  of all other vertices  $v \in S$  to infinity. If the starting vertex and the destination vertex are the same, their distance is set to 0. The symbol  $L$  is used to store the distances of the vertices, and each vertex is marked with  $(\infty, -)$ , where " $\infty$ " indicates the

distance to the current vertex being examined and "-" indicates the predecessor vertex:

- $i=0$ ;  $S = V \setminus \{u_0\}$ ,  $L\{u_0\}=0$ ,  $L(v) = \infty$ ,  $\forall v \in S$
- Mark vertex  $v$  with  $(\infty, -)$
- If  $n=1$ , then output  $d(u_0, u_0) = 0 = L(u_0)$

#### Step 2: Inductive step

For all vertices  $v \in S$  adjacent to  $u_i$ , consider the sum of the distance  $L(u_i)$  and the weight  $w(u_i, v)$  compared to  $L(v)$ . Choose the smaller value between  $L(v)$  and  $L(u_i) + w(u_i, v)$ . Once the minimum value is identified, denote it as  $k$ . Repeat these steps with vertex  $u_{i+1}$ , then remove  $u_{i+1}$  from consideration to continue the examination. If the vertex being examined is the target vertex  $v_j$ , output the value and mark  $v_j$  with  $(L(v_j); u_i)$ .

- Set  $L(v) = \min \{L(v), L(u_i) + w(u_i, v)\}$
- Identify  $k = \min \{L(v), v \in S\}$ .
- If  $k = L(v_j)$ , then output  $d(u_0, v_j) = k$  and mark  $v_j$  with  $(L(v_j); u_i)$ .
- $u_{i+1} = v_j$ ;  $S = S \setminus \{u_{i+1}\}$

#### Step 3: Distance Update

Increment  $i$  by 1. If  $i = n - 1$ , terminate the process; otherwise, return to Step 2.

#### Conclusion:

To use this algorithm for solving a shortest path problem, the following steps are performed:

**Base case:** Assign the shortest distance from the source to itself as 0, and the distance from the source to all other nodes as infinity. Insert these vertices into the initial queue.

**Inductive step:** In each iteration, select the vertex from the queue with the shortest distance to the source, then re-evaluate the distances to the source for its neighboring vertices.

**Distance Update:** If the distance from the source to a neighboring vertex through the current vertex is shorter than the existing distance, update that distance and insert it into the queue.

**Loop until all nodes are visited:** Continue the loop until all vertices have been visited, and the shortest distance from the source to all vertices has been determined.

### **4.3. Application of the GNN Model to identify the Shortest Flight Route from Ho Chi Minh to Noi Bai**

#### **4.3.1. Model Setup and Edge Weight Updates**

Identifying the shortest flight route involves numerous factors. To simplify the model, this study focuses on two primary considerations:

- The distance between flight segments connecting navigation points.
- The impact of weather conditions on specific navigation points.

Subsequently, we utilized data on the distances (in kilometers) between navigation points, gathered from the Aeronautical Information Publications of Vietnam, to update the weights for each edge in the diagram.

#### **4.3.2. Flowchart of the optimization model**

To develop an algorithm for determining the optimal flight path in terms of time, leveraging a GNN model and utilizing input data such as waypoints and distances between them, we construct a Python-based program. The algorithm is designed to find the shortest path for an aircraft traveling from Hochiminh to Hanoi while accounting for specific constraints. The model will be executed under two scenarios: (1) the ideal case, where no waypoints are restricted, and (2) a scenario where the waypoint PLK is unavailable due to external factors, such as weather conditions or equipment failure. Figures 2 and 3 illustrate the flowchart of the model.

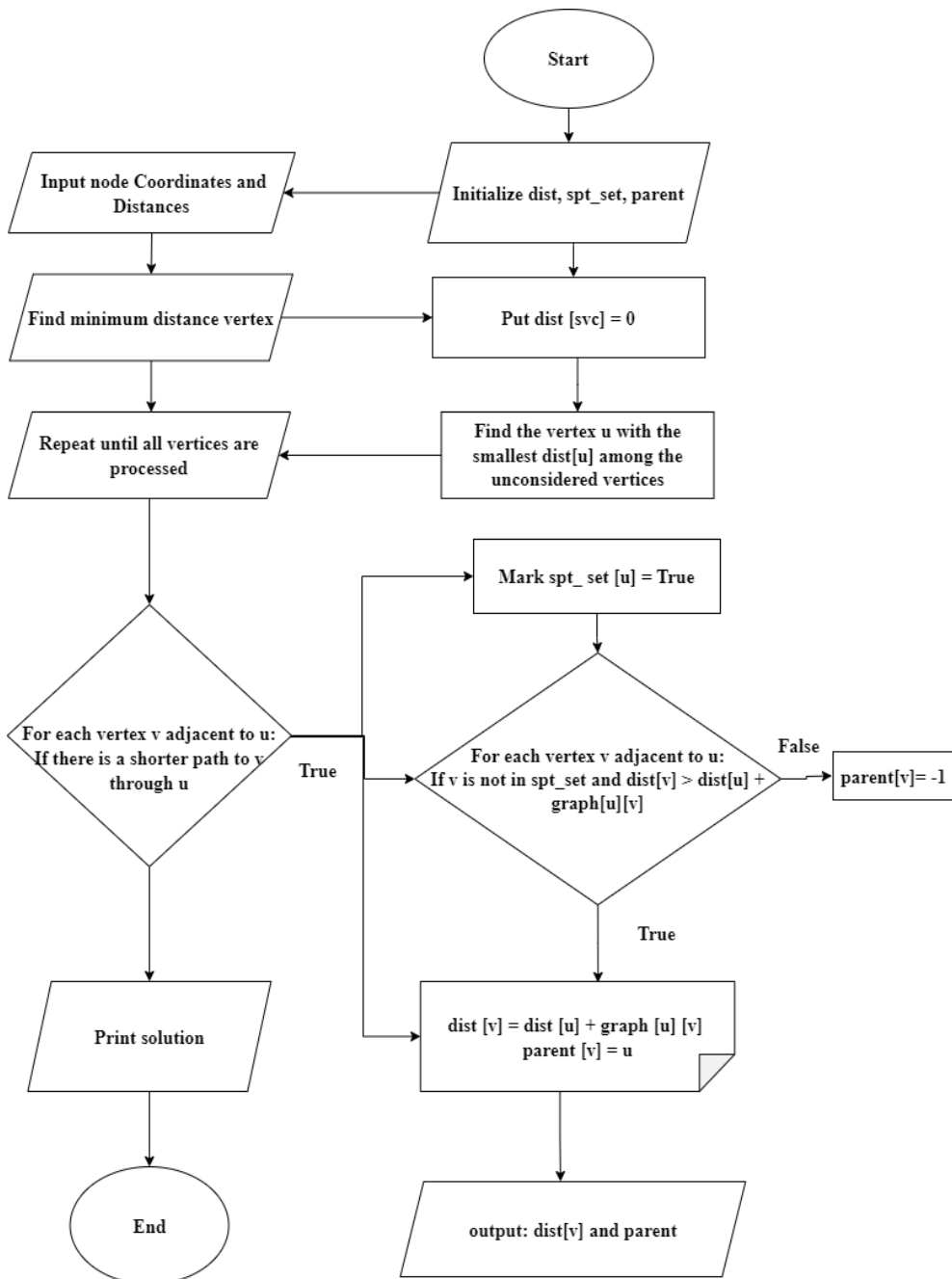


Figure 2: Overall process flowchart

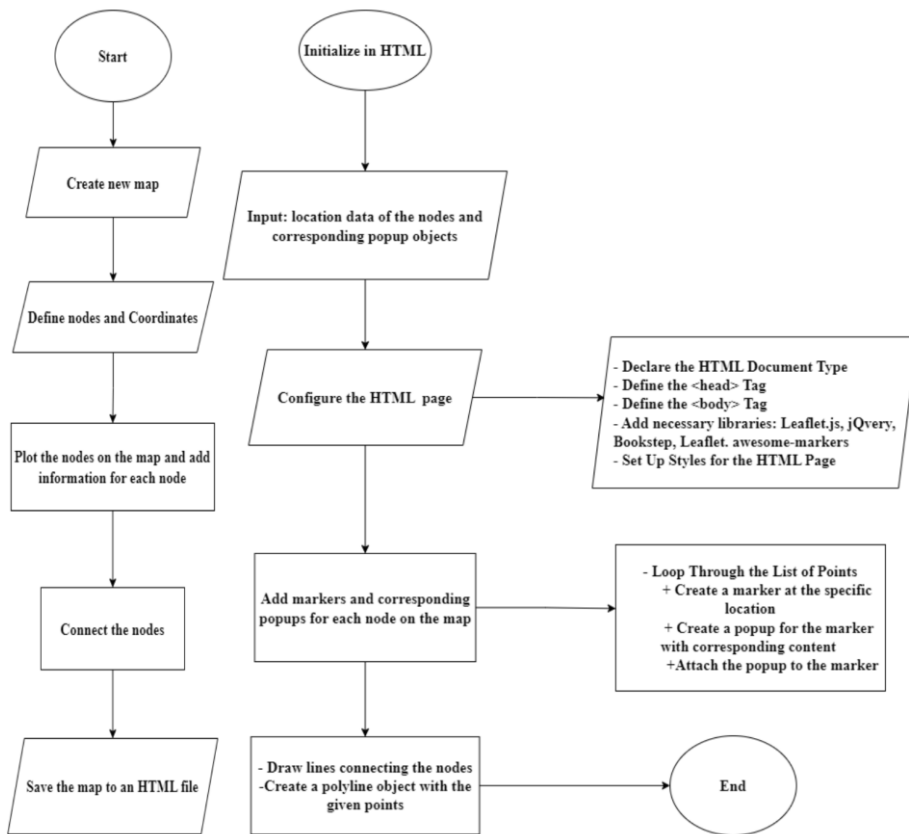


Figure 3: Setup map/nodes and Display as a path image

4.3.3. Modest result

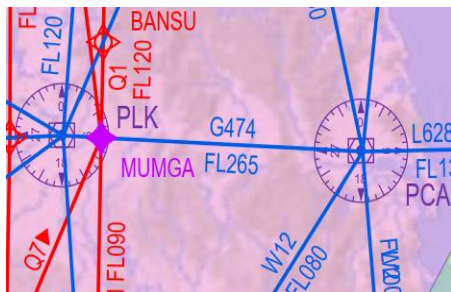


Figure 4: PCA and PLK waypoint

In practice, aircraft typically avoid making sharp 90 degree turns during flight. Therefore, the model will impose a constraint that limits changes in flight path direction to an angle of less than 75 degrees. For example, the aircraft will not be able to make a turn between two waypoints, such as PCA and PLK (as shown in Figure 4).

When the PLK waypoint becomes inaccessible, Air traffic Controller must select an alternative route to the ideal route (The ideal case has no constraints on the waypoints). However, in practice, aircraft may not be able to follow this new shortest route due to constraints such as cruising altitude, air traffic control regulations, and the aircraft's performance capabilities, etc. As a result, it becomes necessary to identify a second-best route when the primary alternative path is unavailable due to these factors.

Based on the above requirements, we executed the model and obtained results for the following three scenarios (see Table 1) with:

- Case 1: Identifying the Shortest Path with Fixed Navigation Points and Flight Segments.

- Case 2: Identifying the Shortest Path when the PLK waypoint is inaccessible due to external factors.
- Case 3: Identifying the Second Shortest Path when the Shortest Alternative Route is inaccessible due to external factors.

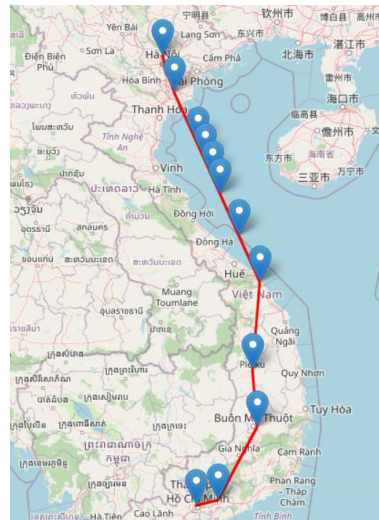
**Table 1: Model results**

Case	Flight path (route section changed)	Distance
1	TSH – AC – BMT – <b>PLK</b> – DAD	653 km
2	TSH – AC – <b>BMT</b> – <b>PCA</b> – <b>CQ</b> – DAD	705 km
3	TSH – AC – <b>LKH</b> – <b>CRA</b> – <b>PCA</b> – <b>CQ</b> – DAD	786 km

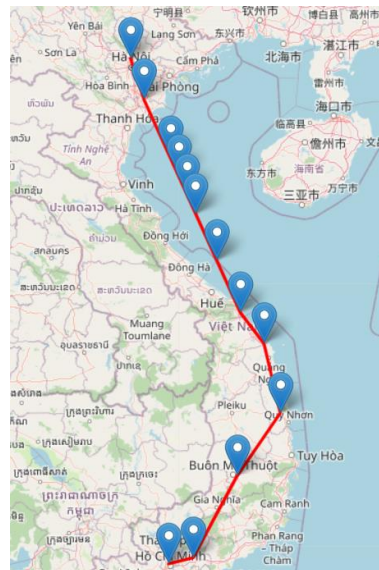
Upon reaching the DAD waypoint, since there are no constraints on the subsequent portion of the flight path, the flight will proceed along the predetermined waypoints towards Hanoi in all three scenarios. Specifically, the route follows: HAMIN – XONUS – HATIN – VIDAD – MAREL – NAH – NOB.

The final result is a map displaying the calculated routes, where each point is represented by a marker on the map, and the points are connected by a red line. The points are assigned coordinates and names so that users can easily identify them (figure 5, 6, 7).

In general, the model has been designed to closely simulate real-world conditions, enabling the algorithm to calculate the shortest alternative routes while accounting for influencing factors such as weather, air traffic, military activities, and emergencies.



**Figure 5: Graphic result of flight path in case 1**



**Figure 6: Graphic result of flight path in case 2**

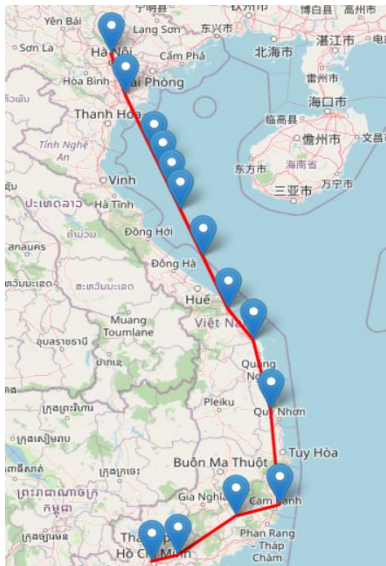
**4.3.4. Applicability of the Algorithm**

Firstly, this algorithm is well-suited for graphs with light, non-negative edge weights, and minimal time variables, making it ideal for designing small-scale flight routes, such as those within Vietnam airspace.

Secondly, during the early stages of the Northeast Monsoon, tropical

depressions or storms frequently occur in Vietnam's central provinces. This can result in the formation of cumulonimbus (CB) cloud walls, extending from Laos to Hainan Island, which pose significant safety risks to flight operations. Consequently, flights may need to be rerouted to bypass waypoints in the Central region.

Another real-world scenario arises when international flights over the sea are required to change routes due to satellite testing conducted by China in its maritime territory. Such events can impose flight restrictions over large sea areas, forcing international flights to divert to alternative routes.



**Figure 7:** Graphic result of flight path in case 3

## 5. Conclusion

To pave the way for the broader implementation of the model in the future, it is crucial to address and overcome the weaknesses of recognition algorithms, aiming to improve and minimize charting discrepancies, thereby ensuring the model's functionalities are leveraged effectively. Based on the framework of the model that has been researched and applied in the area of en-route air traffic control, the research team recognizes the potential of GNN to be

applied in long-haul airspace as entirely feasible.

The GNN model stands out as one of the most viable methods for optimizing flight routes, offering superior accuracy compared to other predictive models. This model is not only applicable in the aviation industry but also finds use in the field of road traffic management.

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