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"SOLUTION OF AIR-SPACE NETWORK BY DIJKSTRA'S ALGORITHM"

Poonam[1]
Ph.D. Research Scholar Dept. of Mathematics,
Maharishi School of Science,
MUIT University, Lucknow, U.P.

Dr. Chitamani Tiwari[2]
Professor, Research Guide,
Dept. of Mathematics,
Maharishi School of Science,
MUIT University, Lucknow, U.P.

ABSTRACT

This paper show us how can we develops a mapping approach to explore the relationship between different layers of a multilayer air transport network composed of airway, route, and flight network. By this paper we can calculate the shortest path in given air space network. In this paper a air space network stations are converted in node and route are converted in the edges and now we get the air space network as a weighted graph. A two-step methodology is adopted to investigate the hierarchical structure and mapping relationship of the integrated network. First, the relationship between airway and route network is characterized by a multisource multi-sink shortest path method based on a generalized incidence matrix. Second, the relationship between route and flight network is formulated by a two-dimension array. A study of an en route airspace in India air traffic control area in India verifies the feasibility of the proposed two-step methodology. The identification of demand-capacity imbalance is very important in Air Traffic Flow Management in determining the traffic situation in the near future; airspace optimization can be made in advance. When a military exercise or extreme weather occurs, capacity of relevant airways will drop or even be zero, which leads to flight delays on such airways. By mapping the relationship among the three networks, affected flights can be predicted. On this basis, the flight paths and departure times will be optimized in advance. To solve the problem that some flights do not fly the shortest path in reality due to the interruptions of the real-time weather, the research on the mapping between route network and airway network can be extended from static mapping to dynamic mapping.

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1. Introduction

Air Transport System (ATS) is composed of airspace and transport system. The former can be modeled by an airway network, and the latter can be modeled by both route and flight network. The interplay between the three single-layer networks makes the research on an integrated network to be interesting. In order to achieve effective operational control of an ATS, it is necessary to develop a multilayer integrated network consisting of all the three single-layer networks and establish a mapping relationship between different layers. This paper provides a method to manage the air transport operation control at the system level to predict and manage the air traffic flow.

Although the ATS in China has experienced rapid development [1], the lack of airspace and airport capacity in China causes system-wide flight delays, leading to disruptions to aircraft and crew routes [2]. Due to the interaction between various system elements of ATS, involving a wide range of space and time, flight delays are transmitted on transport network, which may lead to other elements (e.g., passenger travel) deviating from the initial plan. The airspace network determines total transportation capacity, while the route network reflects the scope of transportation market, and the flight network gives the specific transportation scheme. The control and optimization of ATS involves three-layer networks and the study of the mapping relationship between three networks is beneficial to understanding the interior more concisely and effectively and even further to realizing more effective control of it. This paper contributes to the literature by proposing a theoretical framework to map the relationship between the three layers of an integrated multilayer air transport network.

This paper is organized as follows. Section 2 introduces the structure and definition of airway network layer, route network layer, and flight network layer. Section 3 presents literature review to single network layer and between them. Section 4 uses graph theory and incidence matrix to illustrate the mapping relationship between flight network and route network and between route network and airway network. A case study with real dataset from Lanzhou control area is presented in Section 5. The conclusion and discussion of future research are drawn in Section 6.

2. Air Transportation System Framework

The controlled airspace in China is categorized into three/four parts: tower controlled airspace/ airport controlled ground, approach controlled airspace and en route controlled airspace, where the aircraft are, respectively, in the landing/take-off phase, the approach phase, and the cruise phase. The en route controlled airspace is further partitioned into area sectors, and controllers guide the aircraft in their assigned sectors along the specified air route according to its flight plan. Aircraft in en route airspace are all in the cruise phase, which takes up the longest part of most flights. Airway is the flying corridor for aircraft in the airspace that is set with navigation equipment. An aircraft is required to fly based on the predetermined airways that are specified in its flight plan. The airway network is composed of airways and nodes including crossing points, control handover points, and other important points, which is described by spatial geography and geometric parameters. Edges connecting those nodes are airways, which specify flying path for aircraft.

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Route network refers to a network system that consists of the routes, which shows the spatial distribution of air transportation. A route network consists of the nodes that represent airports and the edges that represent the flight routes which directly link two airports. Route network plays an important role in the operation efficiency and customer service quality of airlines, because it is a prerequisite for airline production plan such as flight plan and crew scheduling.

Flight network is the time-space network of flight plan, which refers to frequency, time, slot and aircraft type of scheduled flights. Flight plan is the basis and core of all production activities of airlines. Other production plans such as the passenger and cargo sales plan, aircraft maintenance plan, and crew scheduling plan are built on the basis of flight plan and, in turn, provide guarantee for smooth implementation of flight plan.

Time-space network contains two-dimensional coordinates of time and space in the flight network. Time is shown as the times of departure and arrival, and space is shown as the airports of departure and arrival. First, the discrete airports are labeled in the abscissa, and the times of departure and arrival are labeled in a vertical axis for each airport as the timeline (continuous), whose direction is from top to bottom. The starting point is the airport opening time, and the ending point is the airport curfew time. The corresponding nodes, which represent the arrival time or departure time of a flight on an airport, are given according to flight schedule. There may be more than one flight on each route.

There are three kinds of edges on flight network. The first, called flight edge, is from the time node at departure airport to the time node at arrival airport. The second, called parking edge, is from a certain time node that arrives at one airport to the next time node at the same airport. The orientation of this kind of edge is always omitted because the orientation is always pointing down. The third kind of edge, pointing to the first node from the last node at the same airport, is called overnight edge, whose orientation is upward. It indicates the aircraft stays overnight at this airport, which is ready to perform the flight schedule plan for the next day.

3. Literature Review

In the past few decades we have witnessed increased interest in developing airway network flow models and tools, which aims to identify and resolve demand-capacity imbalance through the prediction and optimization of air traffic. One of the most well-known models was proposed by Bertsimas and Patterson [3]. They illustrate how the model can be extended to account for airway network flow. In the following paper, they propose an airway network flow model in dynamic weather conditions [4]. More recently, the previous model is further explored by taking into account the dynamic capacity, which is effected by weather conditions, other flights, and equipment status, to facilitate the optimal operations in various scenarios [5, 6]. McCrea et al. [7] developed a novel severe weather-modeling paradigm to be applied within the context of a large-scale airspace planning and collaborative decision-making model in order to reroute flights. Sun et al. [8] analyzed two network layers: the air navigation route network and the airport network. The airports are as nodes of each layer in this paper, and the method can handle various situations including weather condition, reroute, airport, and airway capacity with the mapping relationship.

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In the optimization design of route network, the research work mainly focuses on the optimization model and optimization algorithm of the existing route network, especially the network design of the hub routes. Li et al. [9] proposed a new model for optimizing the allocation of additional routes in a liberalizing airline market, in which airport capacity constraints are explicitly considered. Xiong and Hansen [10] use a flight delay propagation tree to analyze the potential delay propagation on route network and compare the delay propagation characteristics of two networks, such as point-to-point network and hub-and-spoke network. They predict airline responses to Traffic Management Initiatives and reveal the underlying preference structures that shape these responses. Babic and Kalic [11] deal with the model used to select airline network structures for airlines operating in a competitive environment. Mohri et al. [12] present a new practical airline hub location model with hub capacity decision based on airport capacity envelope functions. Zanin et al. [13] analyze four of the most common ones, specifically related to the assessment of the scale-freeness of networks, the interpretation and comparison of topological metrics, the definition of a node ranking, and the analysis of the resilience against random failures and targeted attacks. Route network research mostly refers to the structure analysis and optimization design under airport capacity, partly about analysis combined with flight, and scarcely with airway.

In the aspect of flight network, the research on the recovery of disturbed flight network and the phased recovery method is the current mainstream. Eggenberg et al. [14] try to design an antidelay flight plan by considering the impact of airport congestion and flight delay during making a flight plan. They illustrate the concept by solving the Aircraft Recovery Problem with maintenance planning and give some insights into applying this model to the Passenger Recovery Problem. Clausen et al. [15] provide a thorough review of the current state-of-the-art research within airline disruption management of resources, including aircraft, crew, passenger, and integrated recovery. Pita et al. [16] present a mixed-integer linear optimization model, which is aimed at assisting airlines in making integrated flight scheduling and fleet assignment decisions that take aircraft and passenger delay costs explicitly into account. Zhang et al. [17] proposed a two-stage heuristic algorithm for the integrated recovery problem. Sternberg et al. [18] evaluate and quantify all attributes that may lead to delays according to Brazilian flight data and six research questions related to causes, moments, differences, and relationships between airports and airlines. It shows the main patterns and their chances of occurrence in the entire network of each airport and airline. Lin and Nguyen [19] focus on investigating network reliability in the airline industry and propose an algorithm of evaluating flight network reliability of a multistate flight network considering the time and the number of stopovers. An integration recovery problem in flight network usually is solved from airlines viewpoint, not from region or country. Flight network problem occasionally considers airway or route.

At present, the research on ATS only considers a single network or up to two networks about mechanism and improvement measures. The result of improvement is just local optimization rather than global optimization, which not only causes waste of resource, but also leads to conflict with global optimization. Although some studies consider the limitation of airway capacity and flight schedule at the same time and optimize the ground waiting or rerouting from a global perspective, there is not effective connection between airway capacity and flight scheduling so that application range is limited. ATS needs to be focused on solving the problem of airway, route, and flight fundamentally and systematically. We regard airway

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network, route network, and flight network as an integrated network to study ATS. Airway network is the first layer called physical layer, route network is the second layer called logic layer, and the last layer is flight network that is operation layer. Through the internal links of airway network, route network, and flight network, the spatial and temporal location of flights can be clarified on airway network, which is conducive to make full use of airspace resources, to improve the efficiency of the ATS, and to lay the foundation for the later study of flight delay.

4. Mathematical Formulation

4.1. The Mapping Relationship between Airway Network and Route Network

On route network, two nodes associated with one edge are source and sink of a certain path on airway network, with the departure airport of a route as the source and the destination airport as the sink. There may be several paths between the two airports of one route, which must have the shortest path between source and sink on airway network. If all airport nodes are marked out on airway network according to route network, the shortest path of all relevant routes can be found on airway network by using multisource multisink shortest path algorithm. A route maps into a path consists of airways, and route network consists of routes maps into airway network. That is to say, the shortest path is available to be expressed as a path by the collection of the airport node -edge - node - edge -- node - edge - the airport node, on airway network as shown in Figure 3

The classical shortest path problem is a single-source single-sink problem. Considering that route network is a multisource multisink network, the mathematical model of the classical shortest path problem is improved into multisource multisink shortest path problem described as follows: The problem is formulated in the form of an integer programming problem. O is the source node, which is the departure airport. D is the sink node, which is the arrival airport. The distance of the airway is defined. The decision variable is equal to unity if the airway is on the shortest path of route k and equal to zero otherwise. The objective function in (1) minimizes the distance of airways. Constraints in (2) ensure the flow balance for each node of route k. Constraints in (3) ensure balance between supply and demand; that is, total flow can not exceed capacity of the airway . is a connection matrix of airway network, which consists of three elements with . represents the correlation matrix of the shortest path with o as the source node and d as the sink node, which is composed of . Therefore, the mapping relationship between airway network and route network can be expressed as .

Fig-1, Air space network converted in the graph

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4.2. The Mapping Relationship between Route Network and Flight Network

Each airport node is added the time axis on flight network, and the time of arrival and departure of the flight is marked according to the flight schedule. The set of nodes - parking edge - node - parking edge -- node in an airport can only be represented a node on route network.

The matrix is used to represent the internal direct connectivity of route network. means departure airport and means arrival airport. consists of two elements . If airport *m* and airport *n* are connected so that a route exists between two airports, the parameter is unity and zero otherwise. is a two-dimension array that contains the departure time dimension and the arrival time dimension, representing the departure time and arrival time of flight *p* on OD route. Therefore, the mapping relationship between route network and flight network can be expressed as .

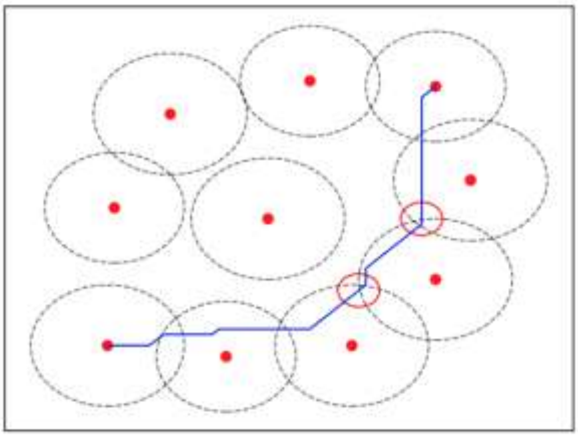

Fig-2, Air space network designed in the graph

4.3. Model Formulation

According to the mapping relationship between flight and route and route and airway summarized above, we derive a mapping relationship of flows between three networks and use 0-1 representation operator to express the existence or not of mapping relationship between networks. The total traffic flow of route *k* for a day is calculated in terms of the number of all flights that are on route *k*. The total traffic flow of airway for a day is calculated in terms of the number of all flights on the airway .Flight *l* has four parameters: departure airport *m*, arrival airport *n*, departure time , and arrival time . To calculate the real-time traffic flow of airway network, we have to determine which airway the flight is on at a certain time. The total traffic flow of route *k* at time *t* is calculated in terms of the number of all flights that on the route *k* at time *t*. The total traffic flow of airway at time *t* is calculated in terms of the number of all flights that are on the airway at time *t*. While most 0-1 representation operators are known according to existing information such as flight schedules, correlation matrix of the shortest path, , needs to be judged by the real-time flight path of the aircraft.

According to the predefined set of trajectory segments, we can determine the value of based on the relationship between flight time and flight horizontal distance.

It should be noted that when , and must also be equal to 1; that is, and are bound to hold.

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5. DATA DESCRIPTION

Since there are tens of thousands of domestic flights a day, data is numerous and complicated. In order to simplify the data and ensure the validity of the calculation examples at the same time, we first make a statistical analysis on radar data in history. Selecting all flights passing through Lanzhou control area in November 26, 2014 (including all flights that take any airport in Lanzhou control area as take-off or landing airport (385 sorties) and all flights that flying over Lanzhou control area (190 sorties)), the change of flow rate of space section with time dimension of main airway points on Lanzhou control area is obtained.

Figure 6 is a time distribution line chart of the flow of main airway points on Lanzhou control area obtained from historical radar data. It can be seen from the figure that the traffic peak hours of Lanzhou control area are mainly distributed at 10:00-14:00 and 17:00-21:00. This example relates to predicting the flow distribution at the peak time 12:00; therefore we select all flights with departure time before 12:00 and landing time after 12:00 of all flights passing through Lanzhou control area as the data samples. A total of 93 flights on 53 routes meet the requirements (see Appendix). Among them, 11 flights take off from the airport in Lanzhou control area, 37 flights land at the airport in Lanzhou control area, and 6 flights take off from the airport and land at the airport both in Lanzhou control area. There are also 51 flights flying over Lanzhou control area.

Considering that although air traffic controllers can be aware of the current flow distribution through real-time radar data, they can only accomplish a real-time adjustment of flight path of subsequent flights and achieve local optimization at best. In this paper, we use an advanced aircraft performance model from Base of Aircraft Data (BADA) developed and maintained by EUROCONTROL, to simulate the 4D trajectory of the aircraft to verify the value of , so that flight path can be optimized globally before taking off according to the mapping relationship between three networks.

The process of specific aircraft model instance generation aims to identify coefficients of mathematical models with the objective to achieve the best fit between calculated and reference aircraft performance parameters. As a result, the set of aircraft coefficients is identified to describe a specific aircraft type. BADA 3 defines the following flight phases: take-off, initial climb, climb, cruise, descent, approach, and landing. For each phase a typical aerodynamic configuration is assigned in terms of high lift device and landing gear positions.

On the basis of Section 3, the shortest path of 53 routes on airway network is obtained by using the multisource multisink shortest path algorithm. Again according to the mapping relationship between three networks, combined with BADA model to judge the value of , air traffic flow on airway network can be forecasted. According to historical data, the average taxi time before actual departure is approximately 15 minutes. The actual departure time of all flights is postponed for 15 minutes to recalculate the flight traffic distribution. The method is feasible because the location of the flight route calculated by BADA is basically correct compared with the real radar data in Figure 7. The black line segment indicates that there is no aircraft on the airway at that time. The deeper the online color is, the more the aircraft are on the airway. Although some flights do not fly the shortest path in the actual situation because of actual weather factors, the accuracy of the prediction is up to 87%. To improve the accuracy, the approximate actual taxi time replaces the average taxi time, which makes it hard to collect the datum at present.

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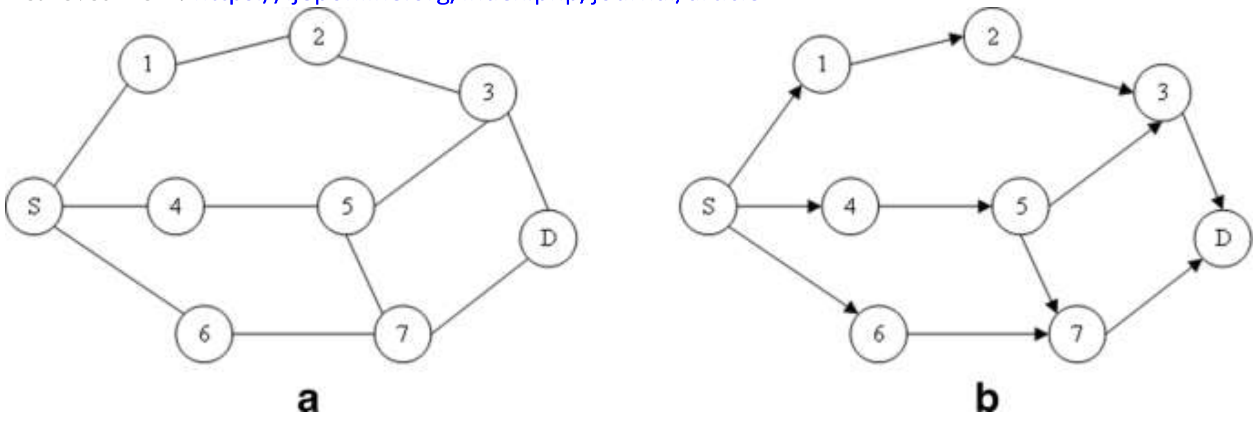

Fig-3, Airport are converted in the Node.

The illustrative example can prove the mapping relationship between flight network, route network, and airway network, which lays a foundation for further research on the relationship between flight delay and airway choice in abnormal state.

APPLICATIONS OF DIJKSTRA'S SHORTEST PATH ALGORITHM

Dijkstra's algorithm is one of the most popular algorithms for solving many single-source shortest path problems having non-negative edge weight in the graphs i.e., it is to find the shortest distance between two vertices on a graph. It was conceived by computer scientist **Edsger W. Dijkstra** in 1956 and published three years later.

Dijkstra's Algorithm has several real-world use cases, some of which are as follows:

1. **Digital Mapping Services in Google Maps:** Many times we have tried to find the distance in G-Maps, from one city to another, or from your location to the nearest desired location. There encounters the Shortest Path Algorithm, as there are various routes/paths connecting them but it has to show the minimum distance, so Dijkstra's Algorithm is used to find the minimum distance between two locations along the path. Consider India as a graph and represent a city/place with a vertex and the route between two cities/places as an edge, then by using this algorithm, the shortest routes between any two cities/places or from one city/place to another city/place can be calculated.
2. **Social Networking Applications:** In many applications you might have seen the app suggests the list of friends that a particular user may know. How do you think many social media companies implement this feature efficiently, especially when the system has over a billion users. The standard Dijkstra algorithm can be applied using the shortest path between users measured through handshakes or connections among them. When the social networking graph is very small, it uses standard Dijkstra's algorithm along with some other features to find the shortest paths, and however, when the graph is becoming bigger and bigger, the standard algorithm takes a few several seconds to count and alternate advanced algorithms are used.
3. **Telephone Network:** As we know, in a telephone network, each line has a bandwidth, 'b'. The bandwidth of the transmission line is the highest frequency that that line can support. Generally, if the frequency of the signal is higher in a certain line, the signal is reduced by that line. Bandwidth represents the amount of information that can be transmitted by the line. If we imagine a city to be a graph, the vertices represent the switching stations, and the edges represent the transmission lines and the weight of the

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edges represents 'b'. So as you can see it can fall into the category of shortest distance problem, for which the Dijkstra is can be used.

4. **IP routing to find Open shortest Path First:** Open Shortest Path First (OSPF) is a link-state routing protocol that is used to find the best path between the source and the destination router using its own Shortest Path First. Dijkstra's algorithm is widely used in the routing protocols required by the routers to update their forwarding table. The algorithm provides the shortest cost path from the source router to other routers in the network.
5. **Flighting Agenda:** For example, If a person needs software for making an agenda of flights for customers. The agent has access to a database with all airports and flights. Besides the flight number, origin airport, and destination, the flights have departure and arrival time. Specifically, the agent wants to determine the earliest arrival time for the destination given an origin airport and start time. There this algorithm comes into use.
6. **Designate file server:** To designate a file server in a LAN(local area network), Dijkstra's algorithm can be used. Consider that an infinite amount of time is required for transmitting files from one computer to another computer. Therefore to minimize the number of "hops" from the file server to every other computer on the network the idea is to use Dijkstra's algorithm to minimize the shortest path between the networks resulting in the minimum number of hops.
7. **Robotic Path:** Nowadays, drones and robots have come into existence, some of which are manual, some automated. The drones/robots which are automated and are used to deliver the packages to a specific location or used for a task are loaded with this algorithm module so that when the source and destination is known, the robot/drone moves in the ordered direction by following the shortest path to keep delivering the package in a minimum amount of time.

6. CONCLUSION AND FUTURE SCOPE

In this paper, we propose a mapping approach to characterize the relationship of different layers in a multilayer air transport network consisting of airway, route, and flight network. We use a multisource multi-sink shortest path method based on a generalized incidence matrix to illustrate the mapping relationship between airway network and route network, while the time-space network problem with two-dimension array between route network and flight network. The routes that share the same airway and flights determine traffic flow of airways. The number of incoming and outgoing flights in an airport on flight network determines incoming and outgoing flow of each node on route network. The density distribution of traffic flow of each airway on airway network can be obtained by the prediction in advance. In practice, controllers adjust the whole subsequent flight according to the current flow distribution through real-time radar data to achieve local optimization. However, the mapping relationship among three networks proposed in this paper can optimize flight paths selection, and local real-time optimization can be carried out in case of emergency. The actual time data of historical flights forecast the traffic flow on airway network on Lanzhou control area and verify the feasibility of the method with the real-time radar data.

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7. DATA AVAILABILITY

The flight schedule for related flights data used to support the findings of this study is included within the article. The radar data in history used to support the findings of this study are restricted by the Civil Aviation Administration of China in order to protect flying safety. Data are available from Civil Aviation Administration for researchers who meet the criteria for access to confidential data.

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