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Modeling Inter-sector Air Traffic Flow and Congestion Degree Prediction

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The demand for air transportation is expected to grow significantly around the world. Accordingly, the number of air transportation passengers is increasing in both developed countries and developing countries. By this reason, new optimization techniques and efficient control have been demanded to predict and resolve demand-capacity imbalances in the airspace. In Japan, the number of passengers is also increasing. In 2015, the Ministry of Land, Infrastructure and Transportation (MLIT) established Collaborative Actions for Renovation of Air Traffic Systems (CARATS), which is a long-term vision for the future air traffic system and specific policies for the transformation of the air traffic system. Additionally, they have started to provide information on aircraft flying over Japan, called CARATS Open Data, and conducted research on aviation systems actively.

Airspace is divided into sectors, which are used for limiting air traffic to control safely and efficiently by human controllers. Sectors over Japan are controlled in 5 airspace areas, Fukuoka, Tokyo, Sapporo, Naha, and Air Traffic Management Center which is Japanese airspace over the Pacific Ocean. If the shape of a sector is not appropriate, air-traffic control operation becomes inefficient and prevents smooth operating control. Also, if the size of a sector is too large, it exceeds the amount of traffic that can be handled by human traffic controllers. Each sector is designed to control safely and to minimize the delay in handling aviation traffic without any problem by human control.

The control of air traffic flow relies on the skills of air traffic controllers. One of the modeling methods for air traffic flow is Linear Dynamic System Models (LDSM). LDSM is used for predicting the number of aircraft in each sector. Air traffic may vary with the seasons, day of the week, and weather, multiple aggregate models can be built to represent different situations. By using this characteristic, Aggregate Sector Flow Model for predicting sector congestion degree has been proposed by selecting the most appropriate model depending on air traffic conditions. However, the method does not have clear guidelines in detail such as the number of models and switching conditions. Moreover, the experiment conducted only for small-scale data.

In this paper, we aim to build models by applying clustering analysis to state transition matrices generated from CARATS Open Data, which is a large amount of trajectory data in airspace. In addition, we propose a congestion prediction method that selects the most appropriate model from representative models of clusters according to the current traffic condition in airspace. The air traffic flow can be represented by a state transition matrix. Each model is considered to be an estimation of the characteristic feature the cluster of state transition matrices has.

Firstly, we generated state transition matrices by Sector flow model. CARATS Open Data provides each flight’s time, flight number, longitude, latitude, altitude, and aircraft type data. With the location data, it can be identified the sector of the aircraft in each time. Sector flow model can be used for predicting the sector demand, which is the number of aircraft in a sector. It follows the center flow model which is expressed in the standard state equation in control theory. Matrices represent the aircraft transitions between sectors. In order to evaluate the accuracy of congestion prediction with various time intervals, we prepared matrices constructed for time intervals of 15 minutes, 30 minutes, 1 hour, and 2 hours. Secondly, we analyzed state transition matrices expressed air traffic flow characteristics and applied *k*-means clustering to the matrices. Clustering shows that the state transition matrix is not greatly affected by the seasons, day of the week and weather. As a result, these matrices were classified into two major classes, one for the times when the number of flights was large and the other for the times when the number of flights was small. After preparing multi models represented as state transition matrices, we predicted sector congestion degree at each time step by selecting the appropriate model for the traffic situation. This was conducted for each predicting interval and each center.

In order to evaluate the effectiveness of model switching, we compared the accuracy of congestion prediction using a single model with that using switching multiple models. Multiple models prediction showed higher accuracy than that of the single model. Furthermore, multiple models achieved high accuracy in the time period with large number of flights, which is most necessary for controlling air traffic flow like daytime. The prediction accuracy was low in the early morning and late evening hours at the Sapporo center. When the characteristics of the flight do not appear significantly in the state transition matrix, such as the number of each sector's flight is small or the time like early morning or late evening periods, it is difficult to form a model that captures the characteristics. In those cases, the method is not effective. However, during the time of day when the volume of air traffic is low, or when the number of sectors in the center is small and each sector is large, it is easy to control and predict air traffic so the method may work in practical use.

As a result of this approach, we construct a congestion degree prediction system. It has sufficiently accurate by representing the past air traffic flow as a state transition matrix, constructing multiple models, and then switching the model to optimal one in each time step. We assume that the system can be operated in practical use especially in the high demand time. However, since we build models for multiple conditions in each center, we were not able to build and test a model that covers all irregular traffic patterns that exist at a particular time or in a particular case. In addition, previous studies have constructed multiple models by using season and weather conditions but the clustering into state transition matrix groups did not show those characteristics in the classification results. The proposed method shows the usefulness to predict congestion degree by analyzing and modeling the characteristics of past flight data and switching the model to the most appropriate one for the air traffic flow at each time step. New data is added to the CARATS open data every year. Therefore, the model can be further improved by adding additional trajectory data and the model will enable more flexible congestion prediction. Consequently, it can help human air traffic controllers to make better decisions.

In this study, we generated models by using only state transition matrices, and it performed the congestion degree with good accuracy. The LDSM model can be built considering additional attributes such as weather and season, which is not used in the proposed approach. We expect this will improve accuracy of prediction for high demand centers.