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Estimating the mean waiting time in airports through cooperative disaster response operations

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ABSTRACT

Airport use rises in response to the need to transport people and deliver aid following a disaster episode. However, owing to unexpected demand and the availability of multiple aircraft operators and organizations, the fluctuating waiting time in airports has become an operational bottleneck. This requires airports to carry out cooperative disaster response operations in the region to relieve congestion and reduce response time. This study develops a model to estimate the mean waiting time in airports through cooperative disaster response operations, using an open Jackson network model. It presents a numerical example to understand the different operational schemes. The result shows that assignment by adjusting the transition probability to meet the airport's service rate is the optimal case through cooperative operations. The policy implication for airport operators is that airports must be prepared to handle a balanced role assignment during disaster responses.

1. Introduction

In air transport networks, effective disaster preparedness and response planning can decrease the impact of large-scale emergencies. The management of these catastrophes typically requires the involvement of multiple airports as well as different operators, agencies, and international and local humanitarian aid organizations,[1] and this can lead to bottlenecks in airports since aircraft are operated by different organizations, different operators are not prioritized, and location assignment is also difficult (Hanaoka et al., 2013). Cooperation among airports and aircraft operators is thus essential to achieve an effective disaster response because one entity cannot manage it solely within its own capacity (Sampey, 2013).

In addition, excessive demand on an air transport network provides additional scope for bottlenecks in airport operation. This congestion in airports raises the waiting time incurred when transporting people and goods. Indeed, the unassigned priorities of aircraft operators raise the waiting time for aircraft operators involved in saving lives to unacceptable levels (Hanaoka et al., 2013). Therefore, airport managers are often the ones to decide which types of aircraft can land at the airport during an immediate disaster response.

Regarding the prioritization of aircraft operators, Choi and Hanaoka (2016) confirmed the effect of changing queuing discipline and the significance of the runway service rate for reducing waiting time in an airport. They asserted that airport disaster response operations in the region play a vital role in reducing waiting time in airports. However, the need for cooperation (i.e., helping each other and overcoming problems jointly) among airports is also hampered, especially during emergency responses when assigning disaster response roles. This assignment of disaster response role can refer to accepting which kind of aircraft operator and type that airports should handle preponderantly.

Planning for cooperative disaster response operations in airports is therefore worthy of study. The present study is motivated by this issue, and it thus introduces assigning the main disaster response roles in an airport based on the network as well as serving other response roles through cooperative disaster response operations. We investigate how to enhance operations through cooperation among multiple airports in order to relieve operational

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[1] Examples include the Great East Japan Earthquake in 2011 and Haiti Earthquake in 2010.

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bottlenecks during disaster responses. In this regard, this study develops a model that can estimate the mean waiting time in airports through cooperative disaster response operations by using an open Jackson network.

The remainder of the paper is organized as follows. The next section summarizes the relevant literature on airport cooperation during disasters and the open Jackson network model. Section 3 presents the proposed research method and Section 4 describes the numerical experiments and their results. Finally, Section 5 provides the conclusions from the research as well as the limitations of the study and future research directions.

2. Literature review

2.1. Airport cooperation during a disaster response

Airports cooperate closely with local emergency management agencies throughout the preparedness, response, and recovery phases of an emergency. Smith (2007, 2010) first discussed the cooperation, coordination, and communication roles of regional airports during disasters. He investigated the actual response activities and measures undertaken during previous disasters based on case studies to discover the essential elements of airports' collaborative practices (see also Smith, 2014). Likewise, a number of studies have examined various aspects of cooperative emergency management at airports (Barich et al., 2013; Smith, 2012a, 2012b; IEM Inc et al 2012).

Airport guidelines for preparing for emergencies and mutual aid agreements among nearby regional airports have been proposed in the United States (TRB, 2012). In particular, as part of disaster management planning, the Airport-to-Airport Mutual Aid Program, which was initiated with the voluntary assistance of airports in the aftermath of major natural disasters in the United States, was reviewed for this study. This program was developed to assist and provide aid during large-scale disasters and emergencies (TRB, 2012).

In one real-life example, Minato and Morimoto (2012) confirmed that regional airports in the Tohoku region were highly utilized in the wake of the Great East Japan Earthquake of 2011 compared with normal operations. Airports in the region responded by offering logistics services, transporting personnel and evacuees, collecting information, refueling helicopters, and providing immediate medical care. The aircraft operators involved included the fire department, disaster management agencies, medical helicopters, the Japan Self-Defense Forces, the Japan Coast Guard, and the Ministry of Land, Infrastructure and Transport in Japan (Hanaoka et al., 2013).

Table 1 summarizes the aircraft takeoff frequencies following the Great East Japan Earthquake as well as the disaster response purposes and operators. This table shows the responses of the three major airports (Hanamaki Airport, Yamagata Airport, and Fukushima Airport) from March 11 to 14, 2011. For example, Hanamaki Airport's landing frequency was 124 and departing frequency was 94 on March 12, 2011, more than 10 times usual airport operations (Aratani et al., 2013).

Cooperation among airport organizations as well as among organizations that operate aircraft is recommended (Hanaoka et al., 2013). Yamagata Airport and Hanamaki Airport assigned major disaster response roles such as ambulance transport and rescue operations as high priorities among the different roles. However, Fukushima Airport only accepted the task of providing a landing point for the helicopters used by the media and the collection of that information thus focused on this airport. This balancing of the disaster response roles among airports in a real-life example of cooperative operation among airports in the immediate disaster response examined in the present study. Hanamaki Airport suffered few difficulties compared with the other two airports since it had previously cooperated with various aircraft operators in the response to the 2008 Iwate-Miyagi Nairiku Earthquake (Aratani et al., 2013).

2.2. Queuing theory and the open Jackson network model

Airports are often modeled by using queuing theory. Airport departure modeling and the queuing approach was first developed by Balakrishnan and Chandran (2007). This approach identified the runway system as the primary bottleneck in the departure process, primarily because of the different constraints imposed on runway operations (Idris et al., 1998). The terminal area is a dynamic and uncertain environment, with constant updates to aircraft obtained from surveillance systems and airline reports (Atkins and Brinton, 2002).

Another model was developed by Carr et al. (2002) to model airport queuing dynamics by considering spatial and temporal restrictions. Once an (unrestricted) aircraft completes its stochastic nominal taxi-out time, it enters a first-come-first-served (FCFS) queue, which leads to the departure queues typically observed near airport runways (Idris et al., 2001). Here, the runway service rate is estimated as a high departure congestion service when the runway operates at its maximum throughput. Hence, queuing model dynamics consider not only the flow of taxiways but also runways as servers.

The queuing network is a connected series of queuing systems. Servers are connected as in the network and modeled according to their conditions. Among queuing theory, Jackson (1963) developed a queuing network model called the open Jackson network showing such queuing characteristics as Poisson arrivals, FCFS service disciplines, exponential service times, probabilistic routing, the steady-state joint probability, and a product-form solution. This model is used in the present study.

3. Problem formulation

3.1. Study focus

As mentioned above, multiple airports cooperate with each other to mitigate the impact of a disaster in a region. The roles and operators of aircraft in each airport naturally differ, however. Although there are numerous ways for airports to cooperate, this study provides cooperative operational schemes that have not thus far been suggested in the literature. Such schemes aim to balance operations at airports assigned responsibility to conduct specific disaster response roles. An example of this operation, as the initial stage in humanitarian logistics in a disaster response scenario, is modeled in Fig. 1. The stage presented in this figure is the initial flow from aircraft departing to their stay in airports until the next flight mission. Since airports are the points of entry to many nations, bottlenecks always hinder the effective operation of the whole humanitarian logistics network. Therefore, we highlight the importance of cooperative airport operations in the initial stage.

Our proposed cooperative operation scheme considers the following:

- Roles include the transport of personnel and transport of aid
- The main disaster response airport is the closest one to the disaster
- The supporting disaster response airport is determined based on the service rate
- The transition probability of all arriving aircraft in the region is adjusted according to the airport's operational capability