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A hybrid fuzzy MCDM approach for mitigating airport congestion: A case in Ninoy Aquino International Airport

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ABSTRACT

In this paper, we introduce the application of an integrated fuzzy multi-criteria decision-making (MCDM) model to mitigate airport congestion which affects the on-time performance of airlines, operational reputation of airports, and air travel experience of passengers. In a classical approach, when congestion occurs at the destination airport while the aircraft is en-route, an air traffic flow management action is prompted for implementation. In selecting the most suitable action in the event of airport congestion, the decision must reflect the multiple criteria nature of the problem as well as the uncertainty and vagueness associated with the decision-making process; thus, an integrated fuzzy MCDM is adopted. The applicability of the proposed approach is demonstrated in a case study at Ninoy Aquino International Airport. It is found that stakeholders of the commercial aviation industry favored to apply rerouting, among other actions, as this satisfies aviation safety as the most prioritized criterion.

1. Introduction

In as early as 1970s, the Philippines has long faced the issue on flight delays along with the increase in demand for air travel at a rate of 11% annually (Manila International Airport Authority, 2016). The country's major airports are prompted to address such issue considering that the entire air transportation system is at stake as well as other economic sectors which largely depend on air transport such as tourism and manufacturing, among others. Three major entities in the commercial aviation industry, namely airport management, airlines industry, and air traffic service (ATS) providers, are the most concerned and affected stakeholders with the occurrence of flight delays. Aside from credit obligations and huge profit losses, performance metrics represented by on-time schedule reliability, operational reputation, and quality of customer service, are likewise undesirably affected (Bongo and Ocampo, 2016).

It has been well established in current literature that both adverse weather and air traffic congestion mainly caused flight delays (Hongjun and Junga, 2012). This is highly consistent with the local condition in the Philippines where air traffic congestion is considered as the main cause of flight delays which accounts for 40% of flight delays annually (Ninoy Aquino International Airport, 2014). The Aeronautical Information Service under the Philippine Department of Transportation and Communications and Civil Aviation Authority of the Philippines (DOTC-CAAP), government agencies which are specifically sanctioned for air transportation services and regulations, issued a memorandum circular in 2012 to address air traffic congestion in Ninoy Aquino International Airport (NAIA), the leading airport hub in the Philippines. The memorandum directs the implementation of an air traffic flow management (ATFM) action, i.e., ground holding, airborne holding, rerouting, and speed controlling, at a given air traffic condition. These ATFM actions are highly regarded in current literature as effective approaches in addressing flight delays, being a direct result of air traffic congestion, in various respective scenarios and considerations (Ball et al., 2011; Bertsimas et al., 2011; Reynolds, 2014; Lulli et al., 2015).

NAIA, located in Manila, is considered as the country's major gateway to both international and domestic air travel. It accommodates various types of aircrafts ranging from long-haul international jets to domestic planes, including those for general aviation and military flights. In terms of its physical infrastructure, it has two runways that intersect at a point which also contributes to congestion and difficult air traffic control. Despite of being the leading airport in the Philippines, NAIA is recently ranked as the

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fifth worst airport in Asia as pointed out by a renowned website survey (Worst Airports for Overall Experience, 2016) with a major complaint on insufficient seating, among others, which is directly related to airport congestion. Along with the airport management, two other key stakeholders – airlines industry and ATS providers – communicate with one another to provide an efficient flow of air traffic. The communication culminates with the implementation of an agreed ATFM action.

In relation to how an ATFM action should be implemented, a number of optimization models and learning algorithms were developed in domain literature. For instance, Bertsimas et al. (2011) presented an integer programming model for large-scale instances of ATFM problems. The model covered all phases of flight and solved for an optimal combination of flow management actions, including ground holding, airborne holding, rerouting, and speed controlling, on a flight-by-flight basis. Clare and Richards (2012) contested the model developed because some elements of the demand-capacity balance problem are subject to uncertain variations. Therefore, the deterministic solution generated may be sub-optimal and even infeasible. As an extension to this model, Clare and Richards (2012) developed a deterministic, discrete-decision mixed-integer linear programming (MILP) optimization model. This augments constraints on the chance of sector capacity violations occurring given probabilistic information about the future capacity states. The challenge in implementing this type of scheme lies in defining which sectors should be considered linked.

A recent model is developed by Barnhart et al. (2012) to address a scenario when air traffic demand is projected to exceed airport capacity. It comprises two integer programming approaches for coordinating air traffic flow programs that balance the tradeoff between equity (measured by fairness metric according to current industry standards) and efficiency (measured by aggregate system delay). Early model formulation made by Bertsimas and Stock Patterson (1998) served as a foundation from which Barnhart et al. (2012) described the components of the deterministic, multi-resource air traffic flow formulation in their model. The results suggest that this approach could lead to system-wide savings as much as $50 million per year.

These optimization models and algorithms consider only a single criterion, e.g., cost minimization, in addressing air traffic congestion. However, in real-life conditions, selection of a specific ATFM action requires multiple criteria of interest to one or more of the stakeholders that have a substantial impact to the general operation of the air transportation system. Bongo and Ocampo (2016) listed down a number of important criteria in choosing an ATFM action: cost of using flight routes, landing/take-off fee, fuel cost, extra crew cost, passenger cost, customer goodwill, safety, equitable treatment of competing air carriers, utilization of runway and terminal, environmental value, economic value, and social value. Limiting the decision-making process to the traditional cost consideration may be counterintuitive and may not promote the system and individual utilities of all stakeholders. Thus, treating an ATFM action selection as a multiple criteria decision-making problem is crucial in making holistic decisions which would address the interests of different stakeholders. Aside from considering the ATFM action selection in a multiple criteria perspective, its complexity is further increased by the inherent interrelationships which exist among various criteria. With multi-criteria decision-making (MCDM) approach, the ATFM action selection could be better illustrated (Kuo, 2011).

In air transport literature and related domains, the use of MCDM methods is an emerging agenda. For instance, Janic (2015) adopted simple additive weighting (SAW) and technique for order of preference by similarity to ideal solution (TOPSIS) in selecting the preferred alternative/candidate airport for building a new runway as a solution for matching runway airside system capacity in Europe. Chang et al. (2002) utilized fuzzy set theory in evaluating airline service quality and improving such quality was demonstrated by Kuo (2011). Kuo and Liang (2011) combined VIKOR (The Serbian name, *VlseKriterijumska Optimizacija I Kompromisno Resenje*) and grey relation analysis (GRA) techniques in evaluating airports service quality under fuzzy environment. Lastly, Vanderschuren and Zietsman (2014) performed analytic hierarchy process (AHP) assessment for potential multi-airport systems in Africa.

While the use of several MCDM approaches have proven its viability in domain literature, to the best of our knowledge, air traffic congestion in a multiple criteria perspective has been addressed only recently by Bongo and Ocampo (2016). They attempted to extract the preference of air traffic service providers in relation to the most suitable ATFM action to be applied in the event of a destination airport congestion. However, Bongo and Ocampo (2016) were not able to cover the possibility that an aircraft may already be airborne when the information of destination airport congestion is made known. This condition is highly prevalent in current scenarios, particularly in the case of NAIA, where airport congestion is made known only after the aircraft is already airborne. When this happens, the result of their study involving the application of ground holding may not at all conditions be applicable despite its favorability in terms of cost-efficiency, safety, and environmental considerations (Ball et al., 2011; Reynolds, 2014; Babić and Simić, 2014). While there are outstanding literature (Andreatta et al., 2014; Reynolds, 2014; Cavca and Ozgur, 2014) that firmly support that the underlying principle of ground holding to primarily instigate departure delays on the ground (Ivanov et al., 2017) remains the main solution method for air traffic flow management problem, these can no longer hold true when an aircraft has already taken-off or is en-route.

To address the significant limitation of Bongo and Ocampo (2016), this paper aims to develop a multi-criteria decision support system using MCDM methods which identifies an ATFM action to be implemented during destination airport congestion, sensitive to the general time horizon when air traffic congestion is known. Therefore, the gap that is advanced in this paper is the application of MCDM approach when destination airport is congested and is known after the take-off of an aircraft. This is in the context of an ATFM action selection. Lastly, the contribution of this paper in the body of knowledge lies on its attempt to address destination airport congestion through ATFM action selection using hybrid fuzzy MCDM methods while taking into account the preferences of stakeholders in the commercial aviation industry. Furthermore, since the criteria that are integrated in this hybrid fuzzy MCDM approach are laid in parallel to the stakeholders' individual auxiliary goals, it is expected that the results obtained from this approach is apparently convergent to a satisficing decision; thus, addressing the interests of the stakeholders involved, i.e., airport management, airlines industry, and ATS providers, is achieved. This makes the problem highly relevant and crucial in air transport management.

2. Proposed hybrid fuzzy MCDM approach

In mitigating airport congestion, multiple criteria need to be considered by stakeholders. It is believed that there exist inherent relationships among criteria, therefore the use of DEMATEL in the context of this paper is deemed necessary. While DEMATEL can clearly extract the relationships among criteria, ANP can provide