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Carbon emission allowance allocation with cap and trade mechanism in air passenger transport

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ABSTRACT

With the rapid development of the aviation industry over the last decade, carbon emissions in air passenger transport have become an increasing concern. By combining the equilibrium strategy with a cap and trade mechanism, this paper proposes a bi-level multi-objective model for carbon emission allowance allocations in air passenger transport, in which a government and airlines are considered as the leader and follower decision makers respectively. Compared with previous studies, this model has the ability to describe the interactions of multiple stakeholders and balance their conflicts. To solve the proposed model, a solution method which integrates an interactive evolutionary mechanism and a fuzzy logic controlled genetic algorithm is developed. Then a numerical example is provided to demonstrate the practical applicability and effectiveness of the method for carbon emission mitigation. Results show that the cap and trade mechanism plays a vital role in mitigating air passenger transport carbon emissions and thus it should be effectively applied to air passenger transport. Results of carbon emission allowance allocations also indicate that the proposed method can provide efficient ways of mitigating carbon emissions for air passenger transport, and therefore assisting decision makers in formulating relevant strategies under multiple scenarios.

1. Introduction

As one of the largest contributors to the rising temperatures and changing weather patterns that are threatening human well-being, carbon emissions have been increasingly paid attention (Peters et al., 2013; Hu et al., 2015a,b). With the increasing march of globalization, the aircraft is rapidly becoming the most important means of transportation, which has resulted in carbon emissions in aviation industry becoming a major obstacle to achieving the collective medium term goal of restricting the global carbon emissions at the same level from 2020 (Chao, 2014). Currently, carbon emissions in air passenger transport have become the main contributors to carbon emissions in aviation industry (Sgouridis et al., 2011), so controlling these emissions in air passenger transport is crucial to the goal of restraining overall global carbon emissions. The International Civil Aviation Organization (ICAO) Committee on Aviation Environmental Protection estimates that as the aviation industry grows, by 2040 carbon emissions are projected to increase by 2.8–3.9 times compared to the 2010 level (ICAO, 2013). Accordingly, the carbon emission mitigation of air passenger transport is now facing increasing threats.

Fortunately, there have been worldwide multilateral efforts to mitigate carbon emissions. Many laws and policies have been developed, such as the United Nations Framework Convention on Climate Change and the European Union Emissions Trading Scheme (EUETS). However, there are presently no global binding laws or policies aimed at emission mitigation, meaning that there is often a lack of flexibility in different areas and different conditions. Therefore, it is often hard to determine the precise constraints for specific airlines in different regions. Many studies have focused on

Abbreviationlist: ICAO, International Civil Aviation Organization; EUETS, European Union Emissions Trading Scheme; CEAAP, carbon emission allowance allocation problem; RPK, Revenue Passenger Kilometers; ASK, Available Seat Kilometers; IPCC, Intergovernmental Panel on Climate Change; EEA, European Environment Agency; LTO, Landing and Take Off cycle; CCD, Climb, Cruise and Descent cycle; NP-hard, non-deterministic polynomial-time hard; GA, genetic algorithm; FLCs, fuzzy logic controllers; IFLC-GA, interactive fuzzy logic controlled genetic algorithm; MATLAB, Matrix Laboratory.

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these problems based on the cap and trade mechanism. Chin and Zhang (2013) proposed an alternative permit allocation method to simulate the aviation sector with an emissions trading scheme and offered great incentives to increase the efficiency of aircraft operators. Steven and Merklein (2013) analyzed the effects of a strategic alliance membership on the carbon intensity determinants for passenger transportation with an emissions trading scheme and found that European airlines had lower carbon intensity than others in the given time period. Li et al. (2015) proposed an equilibrium model for a personal carbon trading scheme and investigated consumer welfare changes. This research found that the personal carbon trading scheme was progressive and could provide a buffer between the energy and allowance prices. These works have contributed to improvements of viable solutions to the carbon emission allowance allocation problem (CEAAP) for mitigating the carbon emissions in air passenger transport and have already got some achievements. Nevertheless, the conflict between the goals of the government and the airlines has still not been fully resolved and further development is necessary.

The key factor in resolving the conflict between air transport demand and emissions reduction is to develop and implement rules and planning for the air transportation to prevent excessive carbon emissions with the full consideration of both economic development and social stability. In another word, methods that promote air passenger transport and environmental protection equilibrium are critical in solving such conflict. Equilibrium strategy has been found to be a powerful tool in solving such problems and has already been used with remarkable results to resolve conflicts in other fields. Küçükaydin et al. (2011) presented an equilibrium theory based bi-level programming model to deal with a competitive facility location problem which served as a valuable guide for subsequent research. Angulo et al. (2014) developed a kind of equilibrium method to resolve conflicts between the environmental, economic, social factors in the transportation network expansion problem and effectively assisted macroscopic highway design from a global view using this method. Recently, Xu et al. (2015a) proposed a multi-coal seam mining based bi-level programming model to solve a "coal-water" conflict in a large scale coal field and demonstrated the effectiveness of the model in reducing this conflict. In this paper, this innovative research has inspired the establishment of an equilibrium strategy-based method to solve the conflict between air transport demand and emissions reduction to ensure the sustainable development of air passenger transport.

Several barriers need to be overcome when seeking to use an equilibrium method to solve the conflict between air transport demand and emissions reduction. First, all stakeholders' rights need be fully considered and in many cases these stakeholders compete with each other. Therefore, a bi-level programming model is adopted to adequately describe the trade-offs between the stakeholders in this paper. Further, as the cap and trade mechanism significantly impacts air passenger transport activities, this must be integrated with the equilibrium strategy to solve the conflict between air transport demand and emissions reduction. In addition, the uncertainties are inherent in almost all air passenger transport activities and the carbon emission environmental impacts are difficult to measure exactly, which means that traditional programming methods are unsuitable for these problems. Therefore, uncertainty theory must be considered as part of the bi-level programming model. From the above discussion, to explore the sustainable development of air passenger transport, a bi-level programming method with an equilibrium strategy under an uncertain environment is proposed to resolve the conflict between air transport demand and emissions reduction. Compared with previous studies, the method proposed in this paper, which integrates a bi-level programming model, a cap and trade mechanism and uncertainty theory, has the ability to simultaneously deal with the trade-offs between stakeholders, the conflict between air transport demand and emissions reduction, and the uncertainties.

2. Key problem statement

The aviation industry CEAAP is a complex system between the government and the airlines based on a carbon trading market. Carbon trading originally stemmed from the idea of a pollution right exchange (Coase, 1960). A carbon emission allowance exchange refers to a situation in which total carbon emissions are controlled through the government allocation of carbon emission allowances to emitting entities, which incur a penalty if they surpass these allowances (free and non-free). Carbon emission allowances, however, can be exchanged freely within the market. The initial carbon emission allowance allocation is the most important component of the carbon emission exchange, and has been the focus of most carbon emission allowance exchange research (Liao et al., 2015). As unsuitable allowance allocations may not only fail to accomplish carbon emission mitigation targets, but may also lead to airline passenger seat supply shortages or even aviation industry downturns, efficient allocation policies are crucial.

Unless aviation carbon emissions reductions can be achieved, the growth in global aviation demand potentially conflicts with national and international emission goals (Dray, 2013). However, when dealing with carbon emissions allowances, there is a gap between the theoretically competitive neutral government implementation and the major competitive disadvantages airlines (Albers et al., 2009). The government seeks to control carbon emissions by limiting allowances, but the airlines desire greater allowances to meet demand and expand their businesses. The carbon emission allowance allocation by the government is expected to control carbon intensity and improve the allocation satisfaction degree, while the airlines determine the aircrafts that can maximize air passenger transport benefit under the government allocated carbon emission allowances. However, increased air passenger revenue results in increased actual emissions, which in turn, increases the carbon trading volume and the trading price in the market, thereby decreasing the air passenger transport benefit, and vice versa. Therefore, it is difficult to overcome the conflict between the achievement of the goals for both the government and the airlines.

With a competitive air transport market and more stringent environmental measures being applied at airports, for sustainable growth, airlines are seeking a balance between the costs, fares and demand (Lu, 2009). The airlines share the free carbon emission allowances and exchange non-free allowances in the carbon trading market. As they are independent decision makers and wish to obtain a greater proportion of free allowances, they seek to gain greater economic benefit by better aircraft selections. Meanwhile, they can also buy additional allowances or sell excess allowances on the market. Therefore, there is a "leader-follower" relationship between the government and the airlines with Cournot competition, which is actually a Stackelberg game, then the conflict between the government and the airlines can eventually arrive at a Stackelberg-Nash-Cournot equilibrium (Hansif et al., 1983).

In real conditions, the carbon emission allowance allocation decision is usually made before any air passenger transport activity, so the values of some parameters can not be determined in advance, meaning that uncertainty needs to be considered in air passenger transport programming problems. The CEAAP for air passenger transport is considered here, which is subject to uncertainty because of incomplete or uncertain information. In this study, airfares, operating costs, and each aircraft type's fuel