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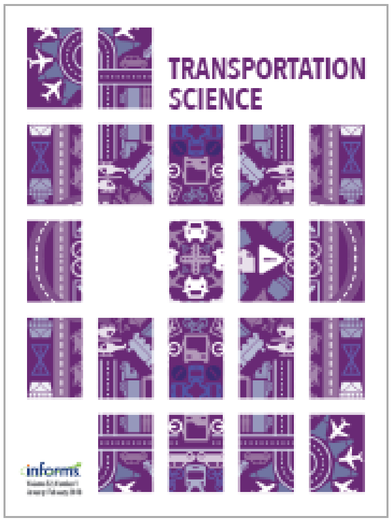

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Introduction to the Special Section: Air Transportation Systems Planning and Operations Under Uncertainty

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The air transportation industry operates under pervasive long- and short-term uncertainty. The U.S. Department of Transportation's (DOT) Bureau of Transportation Statistics (BTS) reported recently that, in 2019, 18.72% of the passenger flights in the United States were delayed by more than 15 minutes (relative to a schedule that already includes an allowance for estimated delays), and more than 2.0% were either cancelled or diverted. This is equivalent, on average, to more than 8,000 delayed flights per day and more than 900 flights cancelled or diverted. These figures illustrate the high level of flexibility and preparedness required of airlines, airports, and air navigation service providers (ANSPs) if they are to operate their respective systems at acceptable levels of service, efficiency, and cost. In addition, stakeholders must plan their operations for the long-term, under highly uncertain assumptions regarding the evolution of demand over time, competitive behaviors, and future economic and technological developments.

The growing interest in explicitly considering uncertainty when developing planning and optimizing solutions for air transport operations is now reflected in the recent academic literature. In general, such studies pursue two complementary research goals—development of models that capture the underlying stochasticity and efficient computation of proposed solutions that increase the resilience/robustness of systems and operations. The ultimate goal is to mitigate the negative impacts of uncertainty. This special issue aims to provide a selected sample of the current state-of-the-art in this respect. Of the 18 papers that were submitted and reviewed by more than 40 referees in several review rounds, eight papers were eventually accepted for publication. Their coverage spans all three main stakeholders of the air transport system, namely airlines, airports, and ANSPs. Five of the papers are concerned with issues pertaining to airports or to air traffic management (ATM) or to both, and three are focused on airlines.

They address a variety of problems, including the following:

- allocating airport slots to airline flight requests;
- developing ground-handling policies;
- optimizing airport surface operations;
- allocating tasks and staff to turn around operations between flights;
- planning air traffic control capacity; and
- managing airline disruptions.

The papers also adopt a range of methodological approaches. In several cases, the authors formulate stochastic multistage integer programming models, proposing efficient relaxation, decomposition, or approximation methods that exploit the problem's structure. Queuing models are also used, in a few of the papers, to capture details of the operations, especially the *network effects* of capacity limitations across multiple elements of the air transportation system. One paper describes the use of a machine learning technique to address a complex resource allocation problem.

The following are capsule outlines of the papers, beginning with those on airports/ATM and continuing with those on airlines:

The paper *Quantity-Contingent Auctions and Allocation of Airport Slots* (Ball et al. 2020), by Michael O. Ball, Alexander S. Estes, Mark Hansen, and Yulin Liu, contributes to the fast-expanding literature on airport slot allocation, specifically on slot allocations performed through *market-based* mechanisms, unlike the current purely administrative procedures. In particular, this paper presents and argues for the conceptual and theoretical viability of a quantity-contingent auction (QCA) mechanism. Such a mechanism not only determines the winning bids but also optimizes the number of slots offered or the number of permits assigned to bidders, assuming that each slot holder submits bids for a package of slots. The authors consider the allocation of both arrival and departure slots while also enforcing constraints limiting airline market power. A continuous optimization model and an integer programming model are proposed to formulate the associated winner-determination problem. Using these models, the authors demonstrate that the QCA mechanism increases overall welfare if no market power constraints are considered. However, when constraints on market power are enforced, the QCA may result in minor or even negative social welfare improvements. Nevertheless, this pioneer study opens the door to much exciting follow-up research. Examples of topics suggested by the authors include the setting of the appropriate constraints on market power and the extension of the current procedure to also consider slot exchanges between airlines.

Capacity planning for ATM systems is addressed in *Air Traffic Control Capacity Planning Under Demand and Capacity Provision Uncertainty*, by Stefano Starita, Arne K. Strauss, Xin Fei, Radosav Jovanović, Nikola Ivanov, Goran Pavlović, and Frank Fichert (Starita et al. 2020). This paper deals with a critical problem for ANSPs. Staffing decisions for en route air traffic control centers must typically be made many months in advance based on historical statistics and on traffic projections that are often subject to significant uncertainty. Staffing, of course, has a direct impact on en route capacity, thus affecting the overall performance of the air traffic system. The tradeoff here is between, on the one hand, capacity costs as influenced by staffing choices and, on the other, level of service to airspace users as reflected in the risk and costs of rerouting and of inducing flight delays. The authors of the paper focus, in particular, on the uncertainties introduced by nonscheduled flights. To tackle this problem, a scalable decomposition approach is proposed, inspired by the two-stage newsvendor problem. The authors present a set of numerical case studies with real-world data, analyzing the implications of several alternative planning policies.

The next three papers deal with more *tactical* aspects of airport and ATM operations. *Two-Stage Stochastic Mixed-Integer Programming with Chance Constraints for Extended Aircraft Arrival Management*, by Ahmed Khassiba, Fabian Bastin, Sonia Cafieri, Bernard Gendron and Marcel Mongeau (Khassiba et al. 2020), addresses the problem of prescheduling aircraft arrivals a few hours before their expected arrival times for an extended arrival management system (XMAN). The authors propose a two-stage stochastic programming approach with recourse, in which the first stage determines the aircraft sequence and target times and the second determines the landing times. A Benders decomposition approach is implemented to solve the stochastic integer program. It is assumed that the second-stage problem will be solved shortly before the landings, when the actual initial approach times will be revealed.

A queuing network model to support the optimization of airport surface operations is presented in *Impact of Off-Block Time Uncertainty on the Control of Airport Surface Operations*, by Sandeep Badrinath, Hamsa Balakrishnan, Emily Joback, and Tom G. Reynolds (Badrinath et al. 2020). According to the authors, this model can be easily adapted to different operating conditions and airport layouts. The paper addresses, in particular, the control of the pushback of aircraft from gates at congested airports. The best pushback time for each flight is determined based on predictions of the time the aircraft will be ready for pushback (also called earliest off-block timer (EOBT)). The authors validate their approach by developing queuing models for three major U.S. airports and by implementing and comparing the performance of several departure control policies there. Their analyses suggest that uncertainty in the EOBT may greatly reduce the benefits that can be obtained from airport surface control policies that were derived under perfect information assumptions. This underscores the potential value of queuing network models that account for uncertainty.

The paper *Equity and Strength in Stochastic Integer Programming Models for the Dynamic Single Airport Ground-Holding Problem*, by Alexander S. Estes and Michael O. Ball, is of a more technical nature (Estes and Ball 2020). It considers the well-known problem of designing a stochastic ground delay program (GDP), that is, a strategy for transferring delays from the air to the ground, for the case of a single impacted airport with equity/fairness requirements. The authors propose a new dynamic integer programming approach that scales better than previous models as the number of flights considered increases. This motivates an investigation of some properties of stochastic GDPs, thus providing a theoretical background for explaining the good computational performance of their model. The paper also proposes interesting extensions for future research.

The next three papers are related to airlines. *Shift Planning Under Delay Uncertainty at AirFrance: A Vehicle-Scheduling Problem with Outsourcing*, by Julie Poullet and Axel Parmentier, examines a stochastic version of the shift planning problem that considers outsourcing certain costs (Poullet and Parmentier 2020). The goal is to build efficient schedules for ground-handling staff (e.g., passenger check-in, aircraft turnaround personnel) and determine the sequence of jobs they have to perform. For this purpose, the authors propose a stochastic generalization of a vehicle scheduling problem. A column generation approach is presented in which the pricing problem is formulated as a stochastic resource constrained shortest path problem. Instances with up to 400 jobs can be solved to near optimality. Numerical experiments on examples drawn from AirFrance's operations indicate that using the proposed stochastic version of the problem can reduce expected total costs by 3.5%–4.8% on instances with more than 200 jobs compared with solving a deterministic version of the problem.

To help airlines manage daily disruptions caused by uncertainty in airport operating conditions, the paper *Dynamic Disruption Management in Airline Networks Under Airport Operating Uncertainty*, by Jane Lee, Lavanya Marla, and Alexandre Jacquillat (Lee, Marla, and Jacquillat 2020) proposes an approach that is not only reactive but also, for the first time, proactive. The central idea is to recover flight schedules in reaction to observed disruptions in a manner that also tries to anticipate, in a probabilistic sense, potential future systemic delays at hub airports. A dynamic stochastic integer programming framework is used to formulate the problem, with its components being a stochastic queuing model to capture airport congestion, a flight planning tool from Boeing/Jeppesen, and an integer programming model to compute solutions for disruption discovery that minimize networkwide expected recovery costs. The overall problem is solved using approximation techniques that enable obtaining solutions with reasonable computation times. Experimental results suggest that the consideration of future hub airport delays can reduce expected recovery costs by 1%–2%. These results motivate future work to improve recovery strategies by including dynamic delay predictions when solving airline disruption management problems.

Finally, the paper *Dynamic Optimization for Airline Maintenance Operations*, by Carlos Lagos, Felipe Delgado, and Mathias A. Klapp (Lagos, Delgado, and Klapp 2020), discusses the (currently hot) problem of dynamically determining which aircraft to maintain and the set of unscheduled tasks to be performed on those aircraft. The authors subdivide the tasks into critical and noncritical ones and allow for the possibility of swapping flight lines between aircraft to facilitate the allocation of a given aircraft to turnaround times that would allow the execution of maintenance, avoiding the cancellation of flights, whenever possible. The problem is approached from a Markov decision process perspective, and approximate dynamic programming techniques (including a value function approximation and rolling horizon) are used to design optimal policies. Numerical experiments with a case study drawn from LATAM Airlines demonstrates that the resulting maintenance policies are compatible with the airline's daily operations and that these policies outperform the simulated current policy of the airline, which is based on a set of nondynamic decision rules.

We believe that this special issue provides a good sample of the state-of-the-art of current high-quality research in the air transportation domain that considers uncertainty explicitly. Furthermore, we hope that this special issue will encourage further interest in this area by the operations research/management science community.

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