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A novel passenger recovery approach for the integrated airline recovery problem

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ABSTRACT

Schedule disruptions require airlines to intervene through the process of recovery; this involves modifications to the planned schedule, aircraft routings, crew pairings and passenger itineraries. Passenger recovery is generally considered as the final stage in this process, and hence passengers experience unnecessarily large impacts resulting from flight delays and cancellations. Most recovery approaches considering passengers involve a separately defined module within the problem formulation. However, this approach may be overly complex for recovery in many aviation and general transportation applications. This paper presents a unique description of the cancellation variables that models passenger recovery by prescribing the alternative travel arrangements for passengers in the event of flight cancellations. The results will demonstrate that this simple, but effective, passenger recovery approach significantly reduces the operational costs of the airline and increases passenger flow through the network. The integrated airline recovery problem with passenger reallocation is solved using column-and-row generation to achieve high quality solutions in short runtimes. An analysis of the column-and-row generation solution approach is performed, identifying a number of enhancement techniques to further improve the solution runtimes.

1. Introduction

The efficient flow of passengers is critical to all transportation fields, especially when regular operations are affected by disruptions. The response to such a disruption is termed *recovery*, which involves strategies such as delaying and cancelling services in an effort to return to the originally planned state. Since transportation applications involve a number of interrelated resources, for example crew and aircraft in the airline context, each of these must be considered in recovery. Passenger are also of high importance, but their direct costs are not easily quantified. Consequently, passengers are not usually considered until the final stages of recovery processes. Hence, it is common for passengers to be significantly affected by any disruption in transportation applications.

The complete airline recovery process is a very large and complex problem that is commonly broken into a number of sequential stages. In practice, the sequential stages that form the airline recovery process are, the schedule, aircraft, crew and passenger recovery problems; however, it is common for the schedule and aircraft recovery to be performed simultaneously. Solving the airline recovery problem as a series of discrete but related stages greatly reduces the problem complexity. These four stages are fundamental in the airline recovery process and provide the major focus areas of research. A very good recent review of the current airline recovery literature can be found in Clausen et al. [13].

The sequential solution approach for airline recovery involves solving each stage in isolation using the results from previous stages as input. Fixing the solution at each stage has the unfortunate effect of providing less flexibility to the problems solved later in this process. Consequently, it is common for the solutions to later stages to be suboptimal or even infeasible. The integration of multiple recovery stages is proposed as a method to address the possible suboptimality and infeasibility. The focus of this paper is an airline recovery problem that integrates schedule, aircraft, crew and passenger recovery. A major contribution of this paper is the modelling approach employed to consider passengers in the recovery process.

Airline planning and recovery processes and the flow of passengers is greatly affected by the network structure that is employed. There are two common types of airline networks, which are labelled as *hub-and-spoke* and *point-to-point* networks. The hub-and-spoke network identifies a number of key major airports (hubs) with a large proportion of all flights scheduled between these and outlying

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airports (spokes) and very few flights occurring between the spokes. This network is characterised by passenger itineraries, a set of flights booked to travel between an origin and destination, generally involving a transit through at least one hub. Alternatively, the point-to-point network is characterised by direct flights between most airports. As such, it is not common for passenger itineraries to involve more than one flight. The difference between these network types greatly affects the treatment of passengers during recovery. The attention towards point-to-point carriers in this paper is in response to the growing number of low-cost carriers providing this network structure and its relationship with other transportation applications, such as railway operations.

1.1. Airline recovery

The practicality of the sequential airline recovery process has driven the attention of researchers to review and develop individual recovery stages. Examples of the aircraft recovery problem, including schedule recovery decisions, are presented by Jarrah et al. [17], Cao and Kanafani [11,12], Bard et al. [6], Eggenberg et al. [15] and Rosenberger et al. [23]. The crew recovery problem has not received as much research attention compared to the aircraft problem, but many advancements have been made. Key examples of the crew recovery problem are presented by Wei et al. [28], Stojković et al. [26], Lettovsky et al. [19] and Abdelghaney et al. [2]. While the developments in each of the recovery stages have improved the overall recovery process, the issues of suboptimality and infeasibility still remain. These issues are only adequately addressed through the development of an airline recovery problem that integrates two or more of the sequential stages.

The development of the integrated airline recovery problem has been limited due to the problem complexity and difficulty in achieving fast solution runtimes. However, improvement in solution approaches and computing capabilities has prompted a recent surge of interest in this problem. An early proposal for solving the integrated recovery problem is provided by Lettovsky [18], which is based upon a Benders' decomposition framework. Lettovsky [18] presents a model that integrates the complete airline recovery problem; however, only the crew recovery problem has been implemented [19]. The modelling approach for the complete integrated recovery problem using Benders' decomposition is further explored by Petersen et al. [22]. In [22] a set of experiments for this approach are presented that achieve optimality within 30 min. An alternative, novel approach for the integrated recovery problem is presented by Abdelghany et al. [3] as an extension to the crew recovery problem of Abdelghany et al. [2]. This approach integrates aircraft, pilots and flight attendants with fast solution runtimes achieved by partitioning the schedule into sets of resource independent flights. While this partitioning process improves solution runtimes, a trade-off with the solution quality is observed through the overestimation of the optimal recovery costs. Finally, Maher [20] presents an airline recovery problem, integrating schedule, aircraft and crew. The focus of [20] is to improve the solution runtimes while maintaining a high solution quality using an exact solution approach. This is achieved with the application of a column-and-row generation framework that is developed in [20].

1.2. Passenger recovery

The vast majority of literature related to passenger recovery focuses on airlines operating a hub-and-spoke network. As such, the passenger recovery process must reconstruct all disrupted itineraries, which may consist of multiple flight legs. This is a very complex and difficult task, since the number of possible itineraries is potentially much larger than the number of flights in the network. Additionally, this approach may be overly complex for airlines operating on a point-to-point network, where itineraries most commonly contain a single flight. The work presented in this paper introduces an alternative passenger recovery approach with a specific focus on airlines operating point-to-point networks. The modelling approach developed in this paper is a contribution to the airline passenger recovery literature and can be employed for alternative transportation applications, such as railway operations recovery.

One of the first models dedicated to the recovery of passenger itineraries is presented by Bratu and Barnhart [10]. In [10], two different optimisation models are described, analysing the trade-off between operating and passenger recovery costs, while also considering aircraft rerouting and the use of reserve crew. McCarty [21] presents an alternative passenger recovery approach that fits within the sequential recovery framework. The approach by [21] attempts to identify recovered itineraries for passengers in the event of a delay on one or many flights. The integration of the passenger and aircraft recovery problems is presented by Jafari and Zegordi [16]. The recovery problem in [16] uses the modelling approach of Abdelghany et al. [2] and Abdelghany et al. [3], where the recovery horizon is partitioned into sets of resource independent flights. The integrated aircraft and passenger recovery problem was also the focus of the 2009 ROADEF Challenge [1] that resulted in the development of many exact and heuristic solution approaches. The winning solution for this challenge is given by Bisaillon et al. [9], implementing a large neighbourhood search heuristic that identifies high quality solutions in short runtimes. Finally, the integrated airline recovery approaches of Lettovsky [18] and Petersen et al. [22] both consider the recovery of passenger itineraries as a dedicated subproblem in the Benders' decomposition framework.

The alternative passenger recovery approach presented in this paper attempts to directly provide passengers with alternative travel arrangements following flight cancellations. This involves redistributing passengers from cancelled flights to alternative operating flights, which may have been delayed, to ensure passengers arrive at their desired destination. This is achieved by introducing variables that describe both flight cancellations and the optimal redistribution of passengers. Such passenger reallocation methods are applicable to many transportation applications where passengers book single segment journeys, which is observed with low-cost airlines and railway operations. To the best of the author's knowledge, the modelling of the cancellation variables to describe passenger reallocation options has not been previously considered. A contribution of this paper is the development of a simple approach that efficiently recovers passengers while significantly reducing the expected recovery costs.

1.3. Solution approaches

Solution runtimes are a critical consideration of airline recovery problems, with reductions achieved through various approximation and decomposition approaches. Such approximation approaches include the selection of specific recovery policies [17,28,26], approximating flight arrival and departure times [6,15] and the selection of affected aircraft [23] or crew [19,2]. In addition, decomposition techniques, such as column generation [24–26,15] and Benders' decomposition [18,22], have also been employed to improve the solution runtimes. Finally, a heuristic approach is employed to solve the integrated airline recovery problem presented by Bisaillon et al. [9]. While these approaches successfully reduce the runtimes of the recovery problems, the heuristic approaches and techniques such as Benders' decomposition do not guarantee integer optimality.

An investigation into an exact solution approach to solve the integrated airline recovery problem is presented by Maher [20]. In [20], a general framework for column-and-row generation is