Problem Statement

Airlines daily face the problem of how to recover when a crew’s schedule is disrupted by unplanned events such as maintenance problems or severe weather conditions. These problems create a domino effect and several flights may be delayed or canceled, and aircraft and crews may miss the rest of their assigned flights. Airline coordinators then have to find a minimal cost reassignment of aircraft and crews that satisfies all required safety rules, has minimum impact on passengers, and minimizes operational difficulties for the airline.

Problem Description

The airline crew rescheduling problem finds a minimum cost reassignment of crews to a disrupted flight schedule while taking into account monthly flown hours of the crews, current partially flown pairings, and future assignments. The authors assume that a crew is unsplittable for the length of a pairing. Reserve crews are considered explicitly as crews with an empty pairing assigned. An entire crew is considered to have only as much time available as its most constrained member. Crews are trained for specific aircraft types, so the flight schedule includes only flight legs assigned to a single aircraft type.

The problem can be modeled as a set covering problem. A row in the model represents a flight segment (i.e. one or more connecting flights that need to be covered). A column is a sequence of segments, called a pairing, flown by a particular crew and subject to Federal Aviation Administration (FAA) regulations and union contract requirements. If a pairing contains more than eight hours of flying time in any twenty-four hour period, FAA regulations and contractual restrictions require a longer compensatory rest.

A pairing must start and end at the same airport, called the crew base. On United States domestic routes, a typical pairing consists of up to five duties (a sequence of flight legs followed by an overnight rest), and lasts up to seven days. In some cases, a pairing includes deadheads, which are flight legs in which the crew flies as passengers. Deadheads are typically used to relocate crews to a city where they are needed to cover a flight leg, or to enable a stranded crew to return to its crew base. A reserve crew is an on-call crew that stays at home and is ready to work if required. A reserve crew has minimum guaranteed hours paid even if no duty is performed, making it an expensive and limited resource that is called upon only when no other solution can be found.

The cost of a pairing is measured in hours, i.e. a crew will be paid a specified number of hours for flying some pairing. The actual cost of a pairing is the maximum of a fraction of elapsed time, actual flying time, and minimum guaranteed hours paid. Pay-and-credit is usually expressed as a percentage between the pairing hours paid and the actual time flown. The main causes of pay-and-credit are pairings that include long or frequent sits within a duty period, long overnight rests between duty periods, deadheading, and use of reserve crews. In some months, actual pay-and-credit can be as high as 7%, which costs the airlines millions of dollars. The authors’ objective is to decrease actual pay-and-credit by providing better recovery solutions.
Solution Methodology

This paper presents an optimization-based solution approach for solving crew recovery that provides a “real time” recovery plan for reassigning crews that restores disrupted crew schedules while protecting future crew assignments.

The solution framework involves first using a heuristic to reduce the size of the crew recovery problem. It is not possible to provide real time solutions to the problem by enumerating all possible crew pairings, so preprocessing techniques are used to reduce the problem to only those crews (and their pairings) that are most likely to participate in crew swaps. These pairings are stored in a tree where each node is a duty and any path from the root node to a leaf represents a legal pairing that starts and ends at the crew’s base. All leaf nodes with pairings not ending at the crew’s base are discarded. Whenever a new duty is added to the pairing, the next minimum compulsory rest defined by the 8-in-24 rule is updated. Duties departing before completing compulsory rest are then skipped.

Once preprocessing is complete, a set covering problem is generated and solved to help choose the minimum cost set of pairings that cover as many flight legs as possible with limited impact on passengers when cancellations and delays cannot be avoided. This Crew Recovery Model (CRM) is formulated as an integer program for small to medium size disruptions (see Appendix A). The authors use the primal-dual subproblem simplex method for solving the LP relaxation of the CRM.

If an optimal solution to the LP relaxation is integral, then it is an optimal solution to the CRM. If not, the authors use branch-and-bound to find a good integral solution. The authors developed a three-stage branching strategy that was customized for the CRM set covering problem. The goal of this branching strategy is to quickly find a good upper bound that helps prune the search tree and to provide a feasible integer solution as early as possible in case a solution is needed and the algorithm has to be stopped before it finds an optimal solution.

Applicability

I have witnessed first-hand the ineffectiveness of current crew recovery systems in action. One month ago, I had a flight returning to Austin delayed because the pilot did not show up. The airline called a reserve crew, but the schedule was incorrect so the crew was not actually available to fly the plane. After two hours, the airline worked out a solution where they cancelled a flight to El Paso and transferred that crew to our plane while reassigning the passengers of the partially filled El Paso flight to other flights. In all, my flight’s departure was delayed four hours. If the airline had been able to more quickly generate crew recovery solutions, they might have reduced their costs and reduced the frustration felt by the passengers on both the Austin and El Paso flights.

There has been much research into crew scheduling, but very little research on dynamic crew rescheduling for irregular operations. This paper presented a new optimization-based solution approach for the crew recovery problem. The authors tested their solution framework on three scenarios provided by Northwest Airlines that represented small, medium, and large disruptions. The solution framework handled the small and medium problems within an acceptable running time. For large disruption problems (the third test scenario involved a moving snowstorm that hit three airports), however, the solution framework does not provide solutions in an acceptable running time (i.e. better than the existing decision-making system). Therefore, the solution framework presented in this paper might have helped in my situation, but it is not the best solution for the full range of flight crew disruption problems.
APPENDIX A (Crew Recovery Model)

The following represents the Crew Recovery Model for a given equipment type \( e \) (IP\(_{CRM}\)):\(^1\)

\[
\begin{align*}
\text{Minimize} & \quad \sum_{k \in K_e} \sum_{p \in P_k} c_p x_p + \sum_{l \in L_e} f_l \kappa_l + \sum_{l \in L_e} d_l s_l + \sum_{k \in K_e} q_k v_k \\
\text{s.t.} & \quad \sum_{k \in K_e} \beta_{pl} x_p + \kappa_l - s_l = 1 \quad \forall \ l \in L_e \\
& \quad \sum_{p \in P_k} x_p + v_k = 1 \quad \forall \ k \in K_e \\
& \quad 0 \leq s_l \leq \max_l \quad \forall \ l \in L_e
\end{align*}
\]

\( P_{CRM} \) is the LP relaxation of IP\(_{CRM} \). The dual of \( P_{CRM} \) is:

\[
\begin{align*}
\text{Maximize} & \quad \sum_{l \in L_e} \pi_l + \sum_{k \in K_e} \pi_k \\
\text{s.t.} & \quad \sum_{l \in L_e} \beta_{pl} \pi_l + \pi_k \leq c_p \quad \forall \ k \in K_e, \quad \forall \ p \in P_k \\
& \quad -d_l \leq \pi_l \leq f_l \quad \forall \ l \in L_e \\
& \quad \pi_k \leq q_k \quad \forall \ k \in K_e
\end{align*}
\]

where

- \( e \) = a chosen equipment type (may represent several aircraft types if crew compatible)
- \( L_e \) = set of flight segments covered by crews of equipment type \( e \), where a segment can be one or more connecting flight legs
- \( K_e \) = set of crews available (disrupted, involved, and reserve crews) of equipment type \( e \)
- \( P_k \) = set of pairings that can be flown by crew \( k \in K_e \)
- \( c_p \) = cost of assigning pairing \( p \)
- \( d_l \) = displacement cost of using flight segment \( l \) for deadheading
- \( q_k \) = cost estimate of returning the crew to its domicile
- \( f_l \) = cost estimate of canceling flight segment \( l \)
- \( \beta_{pl} = \begin{cases} 1 & \text{if flight segment } l \text{ is included in pairing } p \\ 0 & \text{otherwise} \end{cases} \)
- \( s_l \) = number of crews deadheading on flight segment \( l \)
- \( x_p = \begin{cases} 1 & \text{if pairing } p \text{ is assigned to its crew} \\ 0 & \text{otherwise} \end{cases} \)
- \( v_k = \begin{cases} 1 & \text{if crew } k \text{ has no pairing assigned} \\ 0 & \text{otherwise} \end{cases} \)
- \( \kappa_l = \begin{cases} 1 & \text{if flight segment } l \text{ is canceled} \\ 0 & \text{otherwise} \end{cases} \)