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# A multi-criteria repair/recovery framework for the tail assignment problem in airlines

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ABSTRACT

Given a list of flights to be operated, the tail assignment problem aims at assigning each flight to a single airplane. When dealing with tail assignment problems, airline companies are willing to define assignments which minimize not only operation costs, but also robust solutions which are able to "resist" perturbations. Even with robust solutions, unexpected events can occur requiring to reconsider the plan under execution. This paper presents a general methodology for repair/recovery in tail assignment problems. When considering repair/recovery solutions for the initial plan under implementation, the decision maker may want to minimize operating costs, but also limit the changes with respect to the initial plan, minimize flights cancellations etc. Hence, we formulate the repair/recovery problem as a multiobjective integer linear programming problem minimizing specified functions for various repair criteria. The choice among the efficient solutions of this multiobjective program is supported by a multi-criteria model based on an additive value function elicited indirectly from past repair/recovery instances. The proposed repair framework applies to tail assignment, and is sufficiently generic to apply to any operations management problem formulated as a compact integer linear program.

## 1. Introduction

A wide variety of operations management problems, such as those arising in airline companies, have been formulated and solved as large scale discrete optimization problems. For an overview of the most significant optimization models, we refer to the survey papers by (Gopalan and Talluri, 1998; Barnhart et al., 2003; Barnhart and Smith, 2012). So far these models have been mostly developed and used under the assumption that the input data and parameters defining them are perfectly known in advance and not subject to unexpected changes, nor impacted by any kind of uncertainty. However, in recent years, the need for improved models providing efficient tools for quickly and optimally reacting to the occurrence of unexpected events (disruptions) has become a more and more important issue. The subject of the present paper is to investigate a general methodology and associated computational tools for reactive handling of disruptions, with special focus on the well-known 'Tail Assignment' problem, one of the few major problems arising in airline operations management.

The whole airline planning process is usually decomposed into several steps which are most often addressed and solved sequentially. The first step is the *timetable construction* based on traffic forecast between cities and airports. The second step is *fleet assignment*. It consists in deciding which fleet (i.e. aircraft type) is going to operate each flight in the timetable. The objective is to maximize total profit or minimize total cost under various constraints (such as aircraft capacities, maintenance requirements etc.). The third step is *crew planning* (or: rostering). Its goal is to assign crew personnel (pilots and cabin crew) to the individual flights. Like the fleet assignment problem, the crew planning problem aims at minimizing the total costs under much more sophisticated constraints including various crew management rules, human preferences to take a specific flight etc... The next step is *tail assignment* which is to allocate a specific airplane (identified by its tail number) to each flight leg. This step is quite similar to the fleet assignment problem, the only differences lie in the fact that individual airplanes are considered and the horizon of planning is smaller. The last step is *repair planning*, also called recovery planning or disruption management. It aims at adjusting the schedule in case of unexpected events (such as airport closure, absence of crew, delays, etc.). When a disruption occurs, all the previous planning steps should be reconsidered. In practice, this is done sequentially or in an integrated way.

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The management of operations within an airport should also be replanned in order to facilitate the smooth execution of repaired plans.

In the present paper, we discuss a general methodology for repair/recovery in connection with one of the most important steps in airline planning process which is the *tail assignment problem*, also referred to as aircraft routing problem (Clarke et al., 1997; Kabbani and Patty, 1992). As mentioned above, Tail Assignment is the problem of deciding which individual airplane should be assigned to each flight of a given timetable in order to optimize some objective function (minimizing assignment costs and/or maintenance costs) under a number of structural or operational constraints. It has to be solved shortly before the first day of the schedule horizon.

Let us suppose we have an optimal operational plan for the tail assignment problem obtained under some known environment parameters. There is a wide range of possible unexpected events or disruptions: delays, bad weather conditions leading to airport closure, malfunction of technical equipments etc. When this optimal plan is implemented, if a change occurs in one of these parameters, the initial plan may become infeasible or at least suboptimal. Therefore it is clear that the need to repair or revise the original plan in order to make it suitable for the new environment and conditions is very important for airlines. Repair management refers to this necessary adjustment process.

The adjustment of the disrupted plan does not only consider the adaptation with the changes but incorporates other considerations to be taken into account during the repair process. Commonly, the new repaired solution should enjoy four important characteristics:

(a) *Real-time optimization*: repair management is a real-time practice and often requires a quick solution. When a disruption occurs, it is critical to immediately provide a new solution to the personnel in charge. For a large-scale system, it is not always an easy job to find a high-quality solution that covers all the planning horizon. Therefore, real-time optimization techniques should be developed, possibly started by a quickly computed partial solution, covering the immediate decision. While executing this partial solution, we continue the process of repair with a longer horizon.

(b) *Minimum deviation from the initial plan*: One of the goals of repair management is to return to the original plan in a timely manner so as to reduce the recourse costs and the undesirable impacts.

(c) *Multi-criteria resolution*: In dealing with a disruption, it may be desirable to generate a variety of high-quality solutions for the decision maker to review. There is a notable need for multiple criteria resolutions because aggregating all objectives into a single criterion does not permit us to include all information in the optimization model. It should be mentioned that as a general rule the repaired solution will be coordinated with other operational plans (notably crew planning) and therefore generating multiple solutions could help to quickly find one that is suitable with respect to the next step of the planning.

(d) *Interactive repair*: Multi-criteria resolution generates multiple different solutions which will be presented to the decision maker. Some issues could arise in real time that cannot be handled by the optimization model. In such situations, the intervention of the decision-maker is necessary to choose, among the proposed repaired solutions, the best one that better addresses the issue. Considering the important number of possible repaired solutions presented, the decision maker may be confused and the choice of the best solution is a difficult task. Thus, repair should rather be viewed as an interactive process taking into consideration the preferences of the decision maker. Instead of having to work with multiple solutions (a time-consuming approach), it is better to generate the most relevant solutions complying with the preferences of the decision maker.

Based on a case study related to tail assignment, we are going to introduce a multi-criteria repair/recovery framework methodology featuring all the above desirable characteristics.

The paper is organized as follows. In Section 2, a review of up-to-date research on important methods dealing with disruption and uncertainties is presented and discussed. In Section 3, we briefly review the mathematical model for the tail assignment problem. Section 4 is dedicated to defining the main features and principles of the multi-criteria repair/recovery framework. Section 5 then discusses the repair/recovery problem on the tail assignment problem. Finally, in Section 6, it is shown how the main concepts for repair/recovery introduced for the tail assignment case study can be extended to many decision problems, giving rise to a generic framework for repair/recovery.

## 2. Management of uncertainties in airline industry

The study of disruption management originates from airline scheduling (Teodorovi and Guberini, 1984). It has many applications in other fields such as production, scheduling, telecommunications, and public sector (Clausen et al., 2001). We provide below an overview of the main approaches proposed so far to cope with disruptions or uncertainties.

### *2.1. Existing approaches to deal with uncertainties*

The two main types of existing approaches can be classified as: proactive planning and reactive re-planning (Clausen, 2007). The purpose of proactive planning is to generate optimal operational plans that estimate in advance the impact of all the possible uncertainties that the systems can undergo. In reactive re-planning, the purpose is to revise or repair the original plan whenever a disruption occurs.

**Proactive methods:** There have been various proactive methods to deal with uncertainties. The first most effective and well-known method is *robust planning*. It generates plans that are "good" for most of scenarios and minimizes the worst case. The second method is called *stochastic modeling*. It consists in using probabilistic models quantifying global uncertainty associated with the stochastic inputs of the system. The third method is *scenario planning* also called contingency planning which is completely scenario based.

**Reactive methods:** Reactive methods belong essentially to the repair or disruption management field. This approach is a real time reactive revision of the operation plan when a disruption occurs. No need to anticipate the occurrence of the disruption or to estimate the probability of events adversely impacting the system.

Referring to Table 1 below, the majority of approaches deals with uncertainty in a *proactive way*. They anticipate the occurrence of the disruption and build plans. The major advantage of repair/recovery management is that it copes in a *reactive way* with all unexpected disruptions without knowing in advance what is going to happen. It aims at providing optimal repaired solutions within real time constraints.

Formulated approaches, which require a finite set of anticipated scenarios, make the systems face adverse consequences when an unpredictable event not belonging to the preestablished list takes place.

Stochastic optimization and robust optimization are the most predominant means of handling uncertainties in a proactive way. They have been proved to be effective in many situations. However, a successful application of stochastic and robust models requires either the knowledge of probability distribution or the specification by the DM of a relevant uncertainty set (i.e. a set of scenarios against which hedging