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An efficient hybrid approach for resolving the aircraft routing and rescheduling problem

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ABSTRACT

In this paper, we address the aircraft routing and rescheduling problem under airspace capacities uncertainty due to unplanned weather conditions, which occurs before the take-off of scheduled flights. For this problem, we propose a hybrid approach that is based on Time Petri Net (TPN) tool. Furthermore, as a second step, a genetic algorithm is introduced in which a possible solution for ARRP is represented by a new encoding. Additionally, we integrate a post-step, which verifies the feasibility of the flight plans based on an improved Time Reduced Ordered Binary Decision Diagrams (TROBDDs). The conducted experiments on a collection of instances show that the TROBDDs can represent a large number of rescheduling flights locations with compact structure and reduce computation time. In addition, the genetic algorithm illustrates a good compromise between the obtained solutions and computation times.

1. Introduction

Aircraft Routing and Rescheduling Problem (ARRP) happens once unexpected events have disrupted scheduled flights, e.g. adverse weather conditions lead scheduled flights to be delayed or cancelled. In such case, ARRP attempts to define strategies to restore the air traffic flow as fast as possible. Moreover, it attempts to maximize the airline benefit (Monechi et al., 2015) by minimizing the full extra cost due to decisions of ground delay, airborne delay or cancellation, while respecting the available air capacity.

The issue of the air traffic routing and rescheduling in the air navigation and in particular within European Organization for the Safety of Air Navigation (EUROCONTROL), is periodically studied to analyze the resulting delays of flights before their departure or arrival. According to recent report by EUROCONTROL (CODA, February 2018), the number of flights per day grew by 3.4 % between February 2017 and February 2018. In the same study, the percentage of flight delayed at the departure airports (e.g. ground delay) has increased, as an example the ground delay whatever the cause longer than 60 mins enhanced from 2.9 % to 4.2 % in comparison with February 2017 (see Fig. 1). The average delay per flight has increased by 3.1 min to achieve 12.6 mins where the bad weather conditions were essentially contributed to these longer delays. The main motivation of this paper is to propose a decision support model intended for the different personnel of the air traffic management such as air controllers and airlines, in order to tackle ARRP constrained by the limited capacities due to the bad weather conditions, which concerns minimizing the minimal ground delay before taking-off.

ARRP has several definitions in the literature and its goal changes accordingly. Indeed, in the present paper the ARRP definition can be given as follows. ARRP consists of determining the efficient flight plans in order to reduce the impact of climatic disruption incurred on initial planning. Furthermore, aircraft carries out a closed cycle of flights with a stop-over at intermediate airports. According to available air capacity, the ground holds of flights are decided at the initial airport and intermediate airports. This ground holding decision is more efficient in an aeronautical field by the fact that ground delays are cheaper than airborne delays including kerosene and security costs.

Several research studies have dealt with ARRP and related issues go back to the early 1980's based on mathematical programming. Odoni (1987) is the first one who introduced ground holding decision for aircrafts performing only one flight, so-called Ground Holding Problem (GHP). Several works, such as (Andreatta and Romanin-Jacur (1987)), (Richetta and odoni (1993)), (Terrab and odoni (1993)) and ((Richetta and odoni (1994)), are the ones that then addressed this problem. Thereafter, the multi-Ground Holding Problem (MGHP) was studied by (Vranas et al., 1994-a, 1994-b) in which the aircraft executes more than one flight during the day. They developed an integer programming formulation, respectively, for the deterministic and stochastic version that was related to the knowledge of the air capacity and studied the ground delay effect on continuous flights (flights performed by one aircraft). Several other studies for MGHP, such as Lulli and Odoni

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Fig. 1. Percentage of flights delayed on departure.

(2007) and Agustin et al. (2012), included airborne delay and rerouting decision under stochastic and deterministic versions. As it can be seen in the above-mentioned paper and others in the literature, GHP and MGHP are always resolved using operational research methods based on mathematical programing.

A new resolution approach of ARRP under deterministic version using ground holding decision is presented in this paper where the air traffic system is considered to be Discrete Event System (DES) (Achour and Rezg, 2006; Kammoun et al., 2014) with time windows (Janssens et al. (2009), Thorwarth et al. (2016)). This latter evolves dynamically according to occurrence of certain events while respecting the specifications for safety reasons. Time windows in ARRP represent the time intervals in which the capacity of some air traffic elements is reduced due to adverse weather conditions. Besides, Time Petri Nets (TPN) is adopted as modeling method (Berthomieu and Diaz (1991)) and proved to be more advantageous for dealing with control problems. However, the use of TPNs methodology is always accompanied by the combinatorial explosion in ARRP due to the large number of flights, itineraries and air sectors. To overcome this problem, many studies have been developed such as partial-order reduction methods that are initially applied to untimed system (Lilius (1998)). In this study, a new method based on TROBDDs can be introduced that shows a great efficiency in the context of transport system and in the air traffic management especially in Kammoun el al (2016).

On the other hand, we use TROBDDs to check the feasibility of a given aircraft routing solution, in regards to specific constraints. It is well known that metaheuristic in the operational research field are the evolutionary algorithms and these are inspired from Darwin principal. Genetic algorithms belong to the evolutionary algorithm family, which provide efficient solution at low cost. In the context of the ARRP, each routing aircraft solution is encoded by a chromosome used in the new encoding.

This work contributes to the literature on ARRP in a number of ways. Firstly, it provides a theoretical framework based on Safe Time Petri Net (STPN) combined with a new genetic algorithm, which uses TROBDD to validate the feasible flight plans. Secondly, several constraints are considered (such as capacity constraints, connecting constraints which reflect real-world situations) and formulated with a new technic called Time Flow Generalised Mutual Exclusion Constraint (TFGMEC*). Finally, numerical evaluation is conducted to assess the proposed approach.

The rest of the paper is organized as follows: Section 2 defines the problem statement, the terminology used and the constraints formulation. The ARRP modeling approach using STBPN is presented in Section 3. The choice of the variable ordering and a new TROBDDs construction method is given in Section 4. Section 5 introduces the approach to resolve the ARRP using genetic algorithm. An illustrative example is presented in Section 6. The numerical application and the discussion part are given in section 7. Finally, we conclude this paper with some perspectives.

2. The aircraft routing and rescheduling problem formulation

2.1. Problem statement

Let us consider a set of Air Traffic Elements (ATE_s) consisting of airports and air sectors. Furthermore, an aircraft set is predicted to fly according to an initial scheduling. During one day, each aircraft executes consecutive flights starting and ending at the same airport. In other words, aircraft carries out a closed cycle of flights with a stopover time at intermediate airports. An ATE (i.e., airport or sector) is characterized by a capacity defining the number of aircrafts authorized to use it per time slice ($t.\ s$). Actually, the capacity of ATE varies over time due to adverse weather conditions and therefore limits its capacity. Therefore, the limited and uncertain capacity is the main cause of congestion, and it will be considered in this paper.

More accurately, the initial scheduling is carried out several days before scheduled flights, according with the capacity forecast. The unforeseen reduction of ATE_s capacities may disrupt the initial scheduling and make some or all flight plans impractical. In this situation, ground delay, airborne delay, rerouting or cancellation are the most possible decisions that can be taken in order to avoid the air traffic congestion (Bertsimas and Patterson, 1998). In this paper, ARRP considers a single rescheduling point (i.e., static rescheduling) at the initial departure airport level; i.e., the rescheduling options such as such ground delay, rerouting, and flight cancellation are not considered after taking-off of the first flight in the cycle. We point out that the delay imposed on a given flight leads to delay the following flights, which are executed by the same aircraft, and also delays its subordinated flights; flights having common passengers. The cumulative delay should not be affected by the arrival time of flights in the cycle. The cancellation decision of one flight produces the cancellation of all flights in the cycle, which is imposed whether arrival time happens after the airport closing time.

To sum up, the considered ARRP in this paper has as objective: Minimizing the total routing time of rescheduling aircrafts through determining the minimal ground delay and the shortest itinerary to avoid the unforeseen capacity reduction.