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An integrated optimisation approach to airport ground operations to foster sustainability in the aviation sector ☆

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HIGHLIGHTS

- A multi-objective approach is proposed to optimise airport problems simultaneously.
- Different objectives include fuel consumption, previously not considered in literature.
- A holistic economic optimisation framework is proposed to support the decision maker.
- A comprehensive comparative study compares approaches found in the literature.
- A genetic algorithm is adopted and tested on data from an international hub airport.

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ABSTRACT

With increasing air traffic, rising fuel costs and tighter environmental targets, efficient airport ground operations are one of the key aspects towards sustainable air transportation. This complex system includes elements such as ground movement, runway scheduling and ground services. Previously, these problems were treated in isolation since information, such as landing time, pushback time and aircraft ground position, are held by different stakeholders with sometimes conflicting interests and, normally, are not shared. However, as these problems are interconnected, solutions as a result of isolated optimisation may achieve the objective of one problem but fail in the objective of the other one, missing the global optimum eventually. Potentially more energy and economic costs are thus required. In order to apply a more systematic and holistic view, this paper introduces a multi-objective integrated optimisation problem incorporating the newly proposed Active Routing concept. Built with systematic perspectives, this new model combines several elements: scheduling and routing of aircraft, 4-Dimensional Trajectory (4DT) optimisation, runway scheduling and airport bus scheduling. A holistic economic optimisation framework is also included to support the decision maker to select the economically optimal solution from a Pareto front of technically optimal solutions. To solve this problem, a multi-objective genetic algorithm is adopted and tested on real data from an international hub airport. Preliminary results show that the proposed approach is able to provide a systematic framework so that airport efficiency, environmental assessment and economic analysis could all be explicitly optimised.

1. Introduction

Global air traffic is continuing to grow steadily and the 3.1 billion airline passengers carried in 2013 are forecasted to double to about six billion by 2030 [1]. By that time, many airports will reach their maximum capacity resulting in a great pressure to fully utilise the available resources and the need for efficient ground operations. Furthermore, the global effort to meet ambitious environmental targets such as reaching an emission-free airport ground movement in Europe by 2050 [2], together with rising fuel costs, push the airlines to cut fuel consumption as much as possible. Advances in research in the last decades have seen improvement in the fuel efficiency and mitigation of environmental impact for new aircraft due to innovative design [3] or the application of alternative fuels [4–6]. However, in addition to technological developments in maximising energy utilisation, there is a considerable potential to achieve the same objective by optimising operational procedures at airports, which is still untapped fully.

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Previously, different information (e.g. landing time, pushback time or aircraft ground position) were possessed by different stakeholders with limited sharing. However, with the abovementioned challenges imposed on airports, this approach cannot be sustained in the future. This was recognised by Eurocontrol with the introduction of the Airport Collaborative Decision Making (A-CDM) concept [7]. The core idea of A-CDM is the cooperation and real-time data sharing between airport operators, aircraft operators, ground handlers and air traffic control in order to reduce delays, improve the predictability of events and optimise the utilisation of resources. In line with A-CDM concept, optimisation of different airport ground problems such as ground movement, runway scheduling, gate assignment and scheduling of ground services need to be treated in a more integrated and coordinated manner instead of current isolated practices, to fully appreciate the same positive effects given by A-CDM.

Previous research on airport ground operations mostly focused on individual sub problems. A number of papers have been published on runway scheduling problem. The objective is often expressed as a minimisation of delay, the number of changes compared to First-come-first-served (FCFS) sequence, makespan or their combination. A wide range of exact and heuristic methods employed to solve this problem include dynamic programming [8], hybrid tabu search [9,10], genetic algorithm [11] and heuristics [12]. A detailed review of recent research on runway scheduling problem can be found in [13].

Previous papers on ground movement problem mostly focused on minimisation of the total taxi time or other time related objectives [14]. Minimisation of the total taxi time is the main goal of the genetic algorithm proposed by Pesic et al. [15], mixed integer linear programming formulation used in [16,17] or a graph-based approach utilised in [18] or [19]. Deviations from the scheduled time of departure or arrival are penalised in [20,21]. A combination of time related objectives is minimised in [22].

Recently, a few researchers started to consider also fuel consumption as a objective for the ground movement problem. Papers focused on the stand holding problem [23–25] take the fuel consumption into account indirectly, maximising the time an aircraft spends at the stand, with their engines off, rather than taxiing. Multi-objective optimisation has been employed by Ravizza et al. [26] to simultaneously minimise taxi time as well as fuel consumption. Their approach combines a routing and scheduling algorithm [18] with the Population Adaptive based Immune Algorithm (PAIA) [27] in search of the trade-off between the total taxi time and fuel consumption expressed as a fuel consumption index. The following work [28] introduced a fast heuristic procedure for speed profile optimisation to speed up the search. Results in [26–28] indicated that the fastest schedule normally leads to higher fuel burn due to heavy acceleration required to achieve short taxi time.

Only a few papers considered ground movement and runway scheduling as an integrated and interconnected problem. Deau et al. [29,30] proposed a two-stage approach in which a branch and bound algorithm was used, in the first stage, to find the best runway sequence regarding the deviation from assigned slots and then, in the second stage, a genetic algorithm was applied to find a solution for the ground movement problem minimising the difference from the target times resulting from the runway sequence found in the first stage. A mixed integer linear programming formulation by Clare and Richards [31] minimises a weighted sum of taxi time and distance related objectives with respect to runway scheduling constraints. Frankovich and Bertsimas [32] introduced an integer programming formulation for selecting a runway configuration, assigning flights to runways and determining their sequence, and after solving these and fixing them, determining the gate-holding duration of departures and routing of flights on the airport surface with the aim of minimising delays.

Research on the optimisation of ground services includes scheduling of airport buses [33], optimisation of luggage handling process [34], or scheduling of other services [35] such as fuelling [36], catering [37], cleaning, water and sanitation processes. As pointed out in [38,33,35], optimisation of ground services shares similar characteristics. As a result, and due to the fact that the particular airport under investigation in this study does not have gates, only stands, in this paper we focus only on the scheduling of airport buses which is an example of ground service optimisation problems. Although gate assignment has a direct impact on ground movement through the location of gates/stands assigned to flights [39], its planning is normally carried out at a tactical level usually for the whole day. Since ground movement, runway scheduling and scheduling of ground services requires operational planning, gate assignment is not main focus of this work. It is worth pointing out that these optimisation problems are closely interrelated with each other, for example, a runway sequence determines times at which aircraft have to start/finish their taxi and subsequently the schedule of ground services needed at the gates.

Recently, this kind of optimisation problems has been introduced in [40] as multi-component optimisation problems, which are common in transportation research [41,42,9]. As shown in [40,43], optimisation of multi-component problems in an isolated manner may not find globally optimal solutions, since solution for one problem can fail in the objective of the other one and thus miss the global optimum. Furthermore, these problems are not only difficult to solve in their own right, but even more so when combined, due to the interdependence among them. The proposed approach in this paper follows the same line of research. Legitimately, this type of problems with different stakeholders and objective functions can be tackled more easily with a multi-objective optimisation approach [43], in which each objective can be addressed appropriately. Furthermore, as the result of multi-objective optimisation is a set of solutions, under unprecedented events, the decision maker will have more readily available alternatives as backup plans without sacrificing too much cost or other resources. Finally, improving predictability of events by implementing A-CDM concept both in operation and optimisation means that previously conservative planning can now be reviewed in order to further improve the airport capacity, decrease excessive waiting time, avoid fuel-intensive speed profiles or requirement of extra resources.

In the light of the above discussions, in this paper, we propose to use a multi-objective genetic algorithm framework, namely the Non-dominated Sorting Genetic Algorithm-II (NSGA-II) [44], which considers several elements: ground movement problem, runway scheduling and scheduling of airport buses in a more holistic manner. This integrated multi-objective approach incorporating the optimal 4-Dimensional Trajectory (4DT) [27] enables the investigation of the trade-off between different objectives and, assuming the A-CDM system is in place, facilitates more precise control of the taxiing aircraft in order to take full advantage of optimised scheduling. Furthermore, a holistic economic optimisation framework is introduced in this paper to support the decision maker in selecting the most cost-effective solution from a Pareto front of optimal solutions. The main contributions of this paper can be summarized as follows:

- The proposed integrated multi-objective approach optimises ground movement problem, runway scheduling and scheduling of airport buses simultaneously with respect to different objectives, in particular fuel consumption, which was not considered in previous studies. It is worth mentioning, that runway scheduling and ground movement problem are in itself multi-objective problems.