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Real-time airport surface movement planning: Minimizing aircraft emissions ☆

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A R T I C L E   I N F O

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A B S T R A C T

This paper presents a study towards the development of a real-time taxi movement planning system that seeks to optimize the timed taxiing routes of all aircraft on an airport surface, by minimizing the emissions that result from taxiing aircraft operations. To resolve this online planning problem, one of the most commonly employed operations research methods for large-scale problems has been successfully used, viz., mixed-integer linear programming (MILP). The MILP formulation implemented herein permits the planning system to update the total taxi planning every 15 s, allowing to respond to unforeseen disturbances in the traffic flow. Extensive numerical experiments involving a realistic (hub) airport environment bear out that an estimated environmental benefit of 1–3 percent per emission product can be obtained. This research effort clearly demonstrates that a surface movement planning system capable of minimizing the emissions in conjunction with the total taxiing time can be beneficial for airports that face dense surface traffic and stringent environmental requirements.

1. Introduction

Major hub airports are often confronted with the need to increase airside capacity, while meeting sustainability goals at the same time. Indeed, the increasing air traffic demand necessitates airports to find ways to increase their throughput capacity. Yet, at the same time airports also have to find a way towards more sustainable operations, as a result of more stringent environmental regulation and the growing awareness of sustainable development among the general public (Atkin et al., 2010; Visser et al., 2009).

During peak hours, major Air Traffic management (ATM) bottlenecks often occur in the terminal air space as well as on the airport ground surface, which can e.g. be observed by aircraft lining up in queues in front of runways or aircraft flying holding patterns in the terminal airspace. This problem of insufficient ATM capacity, not only results in a loss in efficiency, but it also leads to more environmentally demanding operations. Congestion problems can be resolved not only by increasing the throughput capacity of runway and taxiway systems, but also by making better use of the resources already available through improved airport terminal area operations. With respect to the latter issue, the current practice in routing and scheduling of airport surface traffic leaves ample room for improvement in terms of taxiway grid efficiency, notably through the introduction of advanced surface traffic automation systems Atkin et al. (2010).

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This study focuses on the synthesis of optimal airport surface movement planning, anticipating the implementation of improved surface movement surveillance systems and avionics that enable pilots to follow a precisely timed taxiing route. Optimal taxi movement planning has the potential to reduce gaseous emissions and fuel burn of taxiing aircraft on airports, thereby helping airports to meet the imposed environmental regulations. To the best of the authors' knowledge, the problem of routing aircraft ground movements with the aim to optimize local emissions has yet to be adequately addressed. The development of a real-time surface movement planning system that allows to include (local) emission considerations in the optimal routing of the surface movements is the focus in this research.

This article is organized as follows. Firstly, the state of the art will be described in Section 2. Then, the requirements and preliminary design of the optimization-based planning system will be given in Section 3. This is then followed by a description of the employed fuel burn and emission models in Section 4. The technical implementation of the proposed planning system will be explained in Section 5. Finally, the results pertaining to a comprehensive case study and the conclusions will be given in Sections 6 and 7, respectively.

2. State of the art

This section presents a concise literature survey on existing research efforts related to the mathematical models and solution methods used in airport surface movement problems. A brief survey will be given particularly focusing on categorization according to the issues (1) solution methods, (2) optimization objectives, and (3) rolling time horizons.

A vast amount of research has been conducted in the last decade on the subject of surface movement planning optimization for taxiing aircraft on airports. The survey by Atkin et al. (2010) provides an excellent overview on ground movement planning formulations and resolution methods. This section repeats some of the main insights provided in Atkin et al. (2010), augmented with some more recent developments.

2.1. Solution methods

One of the most distinctive features in the reported studies on this subject relates to the type of solution method that has been used. Essentially, the following three different types of quantitative solution methods were found:

- *Mixed integer linear programming* (*MILP*). MILP is an exact method in the sense that it yields an optimal solution. Optimality is guaranteed unconditionally. Although the airport surface movement optimization problem is essentially NP-hard Clare and Richards (2011), the reported computational times are typically low, provided that the employed MILP problem formulation is not overly complex. It is noted that a mixed integer linear program considers a set of linear objectives and constraints, while some of the variables are defined as integers or binaries, leaving the rest as continuous variables. Successful examples of the use of MILP can be found in (Clare and Richards, 2011; Visser and Roling, 2003; Smeltink et al., 2004; Balakrishnan and Jung, 2007; Marín and Codina, 2008.).
- *Heuristics.* These are custom made algorithms, that are capable of finding a near-optimal solution within a relatively short time span. Although in theory heuristic algorithms offer a chance to find a global optimal solution, in practice that chance can be remote, as heuristics often get stuck at some local optimal solution. For some problems that are too hard to solve with an exact method, a heuristic might be used to explore the states of the problem that are most likely to contain the optimal solution. Examples of applications to the taxi movement planning problems are reported in (Ravizza et al., 2012; Weiszer et al., 2014).
- *Metaheuristics.* Metaheuristics can be used when exact optimization methods fail to generate a solution in an acceptable amount of computation time, or if they fail to generate a solution at all. Metaheuristic methods are capable of solving nonlinear problems and they can work with a higher problem complexity than MILP. Moreover, they are able to quickly generate multi-objective graphs or Pareto-fronts. A common characteristic of metaheuristics is that, in contrast to heuristics, they apply some kind of mechanism to avoid local optima or to provide the ability to move out of a local optimum. However, global optimality is still not guaranteed. Another disadvantage is that metaheuristics only outperform MILP in terms of computational speed in problems above a certain degree of complexity. See (Chen and Stewart, 2011; Chen et al., 2016; Pesic et al., 2001; Herrero et al., 2005; Garcia et al., 2005; Gotteland et al., 2003) for metaheuristics applied to the airport surface planning problem.

2.2. Optimization objectives

Airport surface movement optimization models can also be classified with respect to the main objectives considered. Objectives typically found in the literature include, total taxi time (Visser and Roling, 2003; Smeltink et al., 2004; Herrero et al., 2005; Ravizza et al., 2012) waiting times during the trajectory (Visser and Roling, 2003; Ravizza et al., 2012), fuel burn and emissions (Ravizza et al., 2012; Chen et al., 2015), delay (Visser and Roling, 2003; Herrero et al., 2005), taxi distance (Clare and Richards, 2011) and Central Flow Management Unit (CFMU) departure slot violation (Gotteland et al., 2003), or a combination of criteria (Chen et al., 2016). In Section 3 it will be outlined in detail which factors have been included in the objective function considered in this study.