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A real-time Active Routing approach via a database for airport surface movement

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ABSTRACT

Airports face challenges due to the increasing volume of air traffic and tighter environmental restrictions which result in a need to actively integrate speed profiles into conventional routing and scheduling procedure. However, only until very recently, the research on airport ground movement has started to take into account such a speed profile optimisation problem actively so that not only time efficiency but also fuel saving and decrease in airport emissions can be achieved at the same time. It is envisioned that the realism of planning could also be improved through speed profiles. However, due to the multi-objective nature of the problem and complexity of the investigated models (objective functions), the existing speed profile optimisation approach features high computational demand and is not suitable for an on-line application. In order to make this approach more competitive for real-world application and to meet limits imposed by International Civil Aviation Organization for on-line decision time, this paper introduces a pre-computed database acting as a middleware to effectively separate the planning (routing and scheduling) module and the speed profile generation module. Employing a database not only circumvents duplicative optimisation for the same taxiway segments, but also completely avoids the computation of speed profiles during the on-line decision support owing a great deal to newly proposed database initialization procedures. Moreover, the added layer of database facilitates, in the future, more complex and realistic models to be considered in the speed profile generation module, without sacrificing on-line decision time. The experimental results carried out using data from a major European hub show that the proposed approach is promising in speeding up the search process.

1. Introduction

European airports are likely to become bottlenecks in the air transportation system due to the forecast growth in traffic and passenger numbers (EUROCONTROL, 2013). As many airports approach maximum capacity, European Commission (2011) recognised the need for airport capacity to be increased in order to mitigate the growing demand for travel. To increase throughput, large investments in infrastructure of airports have to be made and/or the operation of airports have to be optimised to fully utilise the available resources. From an optimisation point of view, ground movement is one of the key airside operations at the airport as it links other airport operations such as departure sequencing, arrival sequencing

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and gate/stand allocation and its performance can affect each of these (Atkin et al., 2010b). Therefore, any improvement in ground movement leading to time efficient operation will be of significant importance to airport stakeholders.

Another great challenge faced not only by airports but the whole air transportation sector is environmental impact. The white paper issued by European Commission (2011) outlines very ambitious environmental targets for air transportation. Stricter emissions regulations together with efforts of airlines to reduce fuel costs result in a demand to cut fuel consumption. As shown in Ravizza et al. (2013b), minimum time taxiing and minimum fuel burn are conflicting objectives, as shorter times normally lead to higher rates and longer periods of acceleration. Ideally, both time and environmental objectives should be minimised simultaneously, in a form of a global optimum.

Previous research on ground movements mostly focus on the taxi time objective with aircraft assumed to taxi with a speed which is constant or within some defined boundaries. Minimisation of the total taxi time is the main goal of the genetic algorithm used by Pesic et al. (2001). A time–space network is employed in Marín (2006) and Roling and Visser (2008) to solve the mixed integer linear programming formulations of the problem with the same objective function of the minimum taxi time. A sequential, label-setting the Quickest Path Problem with Time windows (QPPTW) algorithm working on a graph representation is proposed in Ravizza et al. (2013a). A similar graph-based approach is utilised by Lesire (2010) who devised a modification of the A* algorithm to route and schedule aircraft. The total taxi time is minimised in both graph-based algorithms. In addition to the total taxi time, several researchers also considered other time related objectives. Deviations from the scheduled time of departure or arrival are penalised in Balakrishnan and Jung (2007) and Smeltink et al. (2004). A genetic algorithm employed by Gotteland et al. (2003) and Deau et al. (2009) minimises the taxi time together with the deviation from assigned slots. Similarly, a weighted sum of objectives including the total taxi time, the delays for arrivals and departures, the number of arrivals and take-offs, the worst routing time and the number of controller's interventions is minimised in Marín and Codina (2008). The paper by García et al. (2005) minimises another time related objective: the makespan, i.e. the duration from the first to the last aircraft movement. A mixed integer linear programming formulation by Clare and Richards (2011) minimises a weighted sum of taxi time and distance related objectives with respect to runway scheduling constraints. As all the aforementioned algorithms do not consider conformity to real-life scenarios, the assumption that the participating aircraft can meet the given time slots without excessive acceleration/deceleration is questionable.

Fuel consumption is only taken into account indirectly in work focusing on the stand holding problem (Atkin et al., 2010a; Atkin et al., 2011; Burgain et al., 2009), where the primary aim is to maximise the time an aircraft spends at the stand, with their engines off, rather than taxiing. The main assumption is that a shorter taxi time will result in lower fuel burn. More recently, following a wide adoption of the *4D trajectory* concept (consisting of three spatial dimensions and time as the fourth dimension) in other air transport research, e.g. (Ruiz et al., 2013; Yousefi and Zadeh, 2013; Zúñiga et al., 2013), a few researchers have started to consider a related approach during ground movement. However, for the purpose of ground movement in this paper, not all dimensions are required as aircraft's movement are bounded by taxiways. In this case, it is sufficient to completely define their position in time with routes and speed profiles. Therefore, for consistency and clarity, speed profile is the term used throughout the paper. While the total taxi time remained the main objective of optimisation in previous studies, the speed profile is generated in a post-processing manner with respect to the optimised taxi times. A surface management tool TRACC (Taxi Routing for Aircraft: Creation and Controlling) (Schaper and Gerdes, 2013) employs a genetic algorithm to optimise routes of aircraft. The output specifies the route, speed profile and holding times for each aircraft. A similar system, the Ground-Operation Situation Awareness and Flow Efficiency (GoSafe) system (Cheng and Sweriduk, 2009) utilises dynamic programming for taxi route optimisation. However, it is worth pointing out that none of these methods take into account speed profiles proactively in their planning modules, leading to suboptimal speed profiles in terms of fuel consumption.

A recently published paper by Ravizza et al. (2013b) presents a new concept for the ground movement problem which uses multi-objective optimisation to simultaneously optimise routing, scheduling and speed profiles, with regard to taxi time and fuel consumption. In their approach, the routing and scheduling algorithm (Ravizza et al., 2013a) is combined with the Population Adaptive based Immune Algorithm (PAIA) (Chen and Stewart, 2011; Chen and Mahfouf, 2006) in search of the trade-off between the total taxi time and fuel consumption. However, fuel consumption is represented by a fuel index rather than actual fuel burn, and the final decision is left to controllers subjective judgement without any quantitative indicators. Based upon (Ravizza et al., 2013b), an Active Routing (AR) framework is proposed in Chen et al. (2015b) and Chen et al. (2015a), aiming at more seamless integration of speed profiles into route and schedule optimisation. A more detailed actual fuel burn modelling and an airport economic optimisation framework are also introduced to facilitate controllers making a more objective decision. The ultimate aim is to produce a more realistic, cost effective, and greener ground movement. Although the aforementioned framework is flexible to include more factors, such as a noise model, in a more holistic way, it suffers from high computational demand. The work proposed in Weiszer et al. (2014) attempted to speed up the search process using a heuristic procedure for speed profile optimisation. Despite improvement, the computational time of the optimisation framework, as well as the realism of the assumed simplified aircraft dynamic model and fuel consumption model, still prohibits its effective use in a real-time airport decision support environment. Experience of high computational demand in generating speed profiles is also evident in other application fields, such as in car (Mensing et al., 2011; Mensing et al., 2014) or train (Li and Lo, 2014) speed profile optimisation. With more complex models, particularly with exact methods such as dynamic programming, speed profile optimisation is generally computationally intensive and not suitable for on-line, real-time optimisation.