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Applications

Obtaining the optimal fleet mix: A case study about towing tractors at airports ☆

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ABSTRACT

Planes do not have a reverse gear. Hence, they need to be towed by tractors when leaving the gate. Towing tractors differ with respect to investment as well as variable costs and plane type compatibility. We propose a model which addresses the problem of a cost minimal fleet composition to support towing service providers in their strategic investment decisions. The model takes into account a maximum lifetime, a minimum duration of use, an overhaul option and a sell option. In a case study with a major European airport (our cooperating airport) we generate a multi-period fleet investment schedule. Furthermore, we introduce a 4-step approach for demand aggregation based on flight schedule information. We analyze the impact of demand variation, flight schedule disruptions and cost structure on the optimal buy, overhaul and sell policy. The scenario analyses demonstrate the robustness of the investment schedule with respect to these factors. Ignoring the existing fleet, a green field scenario reveals saving potentials of more than 5% when applying this model.

1. Introduction

Planes do not have a reverse gear. Hence, they need assistance to leave the gate. Furthermore, over long distances it is often more economical and ecological to use towing tractors (see [2]). Towing can be distinguished between (i) *push-back*: the fully boarded plane is pushed backwards from the gate to the taxiway; (ii) *repositioning*: the empty plane is towed from one parking position to another; and (iii) *maintenance towing*: the empty plane is towed to the hangar area for maintenance or repairs.

Towing tractors differ with respect to technical compatibility with plane types, investment costs and variable costs. From the perspective of a towing service provider, there are two key questions:

1. *What is the cost optimal assignment of towing jobs to towing tractors in daily operations*? The towing service provider is responsible for carrying out all towing jobs on time. The assignment of tractors to towing jobs is part of their daily operations. Today most towing service providers apply manual planning tools, often resulting in inefficient schedules. The assignment significantly impacts service quality as well as operating costs. In the short-term the available fleet for the assignment is given by the existing tractors. This operative planning problem is covered in Du et al. [7].
2. *What is the cost optimal fleet composition and respective (dis-) investment strategy*? On a strategic level the towing service provider is responsible for deciding on the fleet size and mix and thereby determining in each period (typically of 6 month length) how many tractors are to be bought, overhauled or sold. This decision impacts investment costs, operating costs, as well as the service level. This paper addresses the strategic planning problem. We introduce a model that generates a cost optimal schedule for a heterogeneous set of towing tractors considering a long-term horizon of e.g. 10 years with a period length of 6 months. We formulate the model using an extended formulation, which is solved by standard column generation technique (see [6]). We allow the fleet size and mix to change from period to period. The model includes aspects like a selling option, a general overhaul option, minimum duration of use, maximum lifetime and the technical compatibility of tractor types with plane types. For the strategic problem addressed in this paper, a "schedule" refers to an investment schedule which determines in which period to buy, overhaul and sell tractors of different types.

In the literature determining the number of vehicles for a homogeneous fleet is referred to as Fleet Sizing Problem (FSP),

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while a Fleet Composition Problem (FCP) addresses the problem of deciding on the fleet size and mix simultaneously for a heterogeneous set of vehicles (e.g. see [8]). FSP and FCP literature can be categorized in those considering routing (e.g., see [15]) and those ignoring routing. Our proposed model does not include routing aspects since we focus on a long-term strategic perspective. At a strategic level, demand, costs and revenue uncertainties related to fleet operations are high, thus taking into account routing aspects on a detailed level is ineffective (see [10]).

Kirby [11] and Wyatt [18] are among the first to address the FSP. Kirby [11] investigates the wagon fleet size of a railway system. He concludes that the fraction of days to hire external vehicles should be equal to the ratio of costs for external vehicles and fixed costs of internal vehicles. Wyatt [18] considers a fleet of barges. He extends the idea of Kirby [11] by adding variable costs.

Papers investigating a heterogeneous fleet are Gould [9], Loxton et al. [12] and Redmer et al. [14]. In contrast to this work, their fleet composition is determined for a single period or is constant in all periods.

New [13], Schick and Stroup [16], Etezadi and Beasley [8], Couillard and Martel [5], Wu et al. [17] and Burt et al. [4] examine a planning horizon of multiple periods and allow fleet composition to change over time. New [13] presents a linear programming model which minimizes the operating costs of an airline fleet by deciding on the timing of investment and disposal of planes. Schick and Stroup [16] propose a model to address the multi-year aircraft fleet planning problem which takes passenger demand requirements, a minimum and maximum flight frequency and aircraft balance equations into account. The authors discuss the application of their model in a real life environment. Etezadi and Beasley [8] propose a mixed integer program to determine the optimal fleet composition of vehicles which serve several customers from a central depot. Their model minimizes the fixed and variable costs of own and hired vehicles, while ensuring a sufficient number of vehicles in each period to cover the distance to and capacity for all customers. Couillard and Martel [5] introduce a stochastic programming model to tackle the FCP for road carriers. The model determines the cost minimal purchase, sell and rental policy for a set of heterogeneous trucks, while demand is subject to seasonal fluctuations. It considers among others the age of vehicles in the fleet as well as tax allowances for owning a vehicle. Wu et al. [17] apply the FCP to the specifics of the truck-rental industry. The authors introduce a linear programming model which decides on truck investment and divestment, demand allocation and repositioning of empty trucks. The solution procedure applies Benders decomposition and Lagrangian relaxation in a two stage approach. It can solve instances with 3 tractor types, 60 periods and 25 locations within 12 h. The work of Burt et al. [4] investigates the FCP for the mining industry. The proposed integer program determines the optimal buy and sell policy for trucks and loaders used in a mining location. A unique aspect of this model is the consideration of compatibility between trucks and loaders. In a case study the authors determine the optimal solution for a problem with eight trucks, 20 loaders and 13 periods within 2.5 h. Although the discussed papers are relevant, none of these papers capture a general overhaul option and a minimum duration of use.

To the best of our knowledge, the towing fleet investment decision has not been investigated yet in the FCP literature. New [13], Etezadi and Beasley [8], Couillard and Martel [5], Wu et al. [17] and Burt et al. [4] come closest to this work. A general overhaul option and the minimum duration of use are not included in any of the models. Furthermore, technical compatibility is in most cases not taken into account. Yet, these aspects are essential when determining the optimal investment strategy in a real-world towing setting at airports. Our work closes the gap and contributes to the FCP literature by introducing a model which takes into account a maximum lifetime, a minimum duration of use, an overhaul option and a sell option. Furthermore, our main contributions are a 4-step approach for demand aggregation and demonstrating the application of the model in an extensive case study.

The remainder of this paper is organized as follows: in the next section we introduce the problem and explain the mathematical formulation and the solution approach. Section 3 presents an approach to aggregate demand using flight schedule information and describes how the existing fleet can be incorporated in the model. In Section 4 we demonstrate how the model can be applied in a real-world setting. For this, we determine the schedule at our cooperating airport. Additional scenario analyses are conducted to investigate the impact of demand and costs deviations. We conclude with a summary of the main findings and outline directions for future research in Section 5.

2. Model and solution approach

The presented model generates a cost optimal multi-period schedule for a set of heterogeneous towing tractors. It considers a planning horizon of $|\mathcal{T}|$ periods. The model determines for each tractor type b the number of required tractors in each period t in order to satisfy a demand $DM_{d,t}$ of each demand pattern d in period t. A demand pattern is an aggregation of simultaneous towing jobs taking into account plane type and overlapping tractor type compatibility. The demand for one period is expressed by a set of demand patterns (see Section 3.1). To fulfill demand, a tractor type b has to be technically compatible with demand pattern d, i.e. $CP_{b,d}=1$. The model takes into account the existing fleet. NE_b denotes the number of existing tractors of type b. The fleet size and mix is adjusted from period to period by buying new tractors, overhauling or selling existing ones. A general overhaul is required, if a tractor is used beyond its maximum duration of use DU. A general overhaul extends a tractor's lifetime by additional AD periods. A tractor can be sold on the market before reaching its maximum lifetime DU (without general overhaul) or $DU+AD$ (with general overhaul). However, a tractor has a minimum duration of use of MU periods, before it can be sold. MU does not reflect a technical feature of a tractor, but rather is set by the management. Buying, using, overhauling and selling a tractor in period t is associated with investment costs IC_t, variable costs VC_t, overhaul costs OC_t, and sales revenue SR_t, respectively. In the case of a planning horizon of up to 10 years, costs and revenue are time-dependent by, amongst others, taking into account discount rates. Therefore, all cost and revenue parameters are time-indexed. Both cost changes and the discount rate are incorporated in the cost data, and do not explicitly appear in the model. The parameters DU, AD, MU, IC_t, VC_t, OC_t and SR_t are tractor type specific and assume different values for each tractor type b.

We formulate the model using an extended formulation and propose a Column Generation Heuristic (CGH) as solution procedure. We do not present the compact mixed-integer linear programming model for the problem. In simple terms, column generation decomposes the problem into a Master Problem (MP) and a Subproblem (SP), which generates feasible columns (i.e. schedules). A feasible column $a\in\mathcal{A}(b)$ represents one schedule for a specific tractor type b. The schedule defines in which periods the tractor is in use and accordingly when to buy, overhaul and sell the tractor. $\mathcal{A}(b)$ is the set of all schedules associated with tractor type b. Each schedule $a\in\mathcal{A}(b)$ is associated with total schedule costs of $TC_{b,a}$ that are a function of IC_t, VC_t, OC_t, and SR_t.

MP determines the fleet size and mix by selecting the schedules to follow. It minimizes the costs while ensuring demand satisfaction. Only a subset of all feasible schedules are considered