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Optimal assignment of airport baggage unloading zones to outgoing flights

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ABSTRACT

The outbound airport baggage handling system (BHS) consists of a set of unloading zones (chutes) which are assigned to outgoing flights. Airport baggage operations have inherent uncertainties such as flight delays and varying number of bags. In this paper, the chute assignment problem is modeled as a Stochastic Vector Assignment Problem (SVAP) and multiple extensions are presented to incorporate the various design needs of the airport. A real airport outbound BHS is presented. This case study also guided the optimization models' design process. The performance of the optimization models is compared with the methods used in practice and literature.

1. Introduction

The air travel consumer report 2014 (U.S. Department of Transportation, 2014) ranked mishandling of baggage second in the complaints category, after flight problems. It moved from being ranked third in the year 2012 to second in the year 2013. The baggage handling system (BHS) at the airport deals with the collection of baggage from either the passengers at the check-in counters, or via connecting flights, to the loading of baggage inside the aircraft. BHS forms a large fraction of the operating costs at the airport (Tagawa, 1968). Based on our discussion with the airport that we have modeled, as the number of flights and the number of people traveling through air (Airports Council International, 2013) are increasing every year, having an efficient BHS has become a challenging task. Complexity of the BHS is further discussed in Scholing (2014) and Alsyouf et al. (2014). The efficiency of the BHS has a direct impact on the performance of the airport and the satisfaction of the passengers. Therefore, solutions to improve this system are extremely valuable.

As described in Lin et al. (2015), the classical process of the BHS can be as follows. When the customers check-in their baggage or the baggage is transferred from a connecting flight, the conveyors transfer the baggage and pass it though the X-ray security screening machine. If it passes screening, the baggage is then transported to the main sorter, where each baggage is identified by a barcode scanner. Then, the control system assigns a destination for each baggage. The destination of a baggage can be either a buffer zone where the baggage will be re-sorted later or a baggage unloading zone, which is also called a chute. Usually, the chute for a specific outbound flight is assigned before the departure time. If the unloading zone of a baggage is not available, i.e., the baggage arrives before its chute is assigned, it will be transported to the buffer zone and

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the baggage will wait until the controller releases all waiting baggage back to the main sort. A more generic BHS process can be found in Barth et al. (2013).

The major decision of the outbound BHS is to assign the outbound flights to the chutes. If a flight is assigned to a far-away chute, the BHS workers need more time and effort to process to the corresponding aircraft. If more than one flight is assigned to the same chute at the same time, the baggage handlers will need to sort the baggage manually for the respective flights, which is quite labor-intense.

The problem being tackled in this paper is the assignment of baggage unloading zones (chutes) to scheduled outgoing flights under uncertainty, such that the total expected assignment cost in the system in minimized. Each flight needs to be assigned to a chute, which is a decision variable in this problem. Chutes are occupied by a flight for a period of time before departure. The baggage handling start time and duration may depend on the number of bags. The sources of uncertainty are in the departure times of flights, number of bags on each flight, and assignment time of baggage chutes to outgoing flights.

The deterministic version of this problem falls under the category of a new type of the optimization problem named as the Vector Assignment Problem (VAP). The VAP belongs to the class of Assignment Problems (AP) (Ahuja et al., 1988) but constitutes a sub class with unique problem properties. The VAP is the problem of assigning a number of activities with fixed arrival (start) and departure (stop) times to a set of resources. Any activity can be assigned to any resource. There is a unique cost associated with assigning an activity to a resource. Activities occupy a single resource completely and without interruption throughout their stay in the system. The decision to assign an activity to a resource is naturally modeled by a binary decision variable. The class of decision variables has two dimensions, corresponding to the activities and the resources, respectively. This formulation is neither a standard AP nor a three-dimensional assignment problem (3DAP) (Spieksma and Gerhard, 1996), where the decision variable has three indices including one for the time period. This variant of the assignment problem is denoted as a VAP. The VAP occurs naturally in many scheduling and assignment problems. Other examples apart from the problem being addressed in this paper are the assignment of unit loads to storage locations in a warehouse (Goetschalckx, 2012), of trucks to warehouse docks, and of airplanes to gates (Riccio and Ron, 1985).

To model the stochastic airport chute assignment problem, we expand the VAP to the Stochastic Vector Assignment Problem (SVAP). The objective of the SVAP is to minimize the aggregate cost of using resources while assigning resources to all activities.

There are three major components of the baggage assignment problem that have been studied in the literature: assignment of incoming flights to baggage carousels, transfer baggage handling, and assignment of baggage chutes to outgoing flights. The problem of assigning incoming baggage to baggage carousels can be categorized as an online scheduling problem. Albers (2010) gives a description of the online scheduling problems and a number of researchers have tackled the inbound baggage problem (Barth and Bockmann, 2012; Barth, 2013; Delonge, 2012; Frey et al., 2012). The outbound and inbound baggage assignment problems have similarities but there are some key differences as summarized in Barth (2013): arrival time of baggage in the inbound assignment problem is assumed fixed whereas in the outbound process, bags can be stored in a buffer area before getting loaded on the chutes, and, objectives of these two problems are different with a focus on feasibility in the outbound baggage handling system and on minimizing delivery time in the inbound baggage system.

Transfer baggage handling systems have also been modeled at Frankfurt Airport by Barth and Franz (2008), and Barth (2012), and at Munich Airport by Kiermaier and Kolisch (2012). These approaches present the mathematical formulation and develop techniques to handle uncertainty in the dynamic environments at the airports. Clausen and Pisinger (2010) developed a solution algorithm for the analogous problem of handling critical baggage transfer. Barth et al. (2013) present a general model for transfer baggage handling and to account for uncertainty in data.

The outbound baggage assignment problem to chutes has also been tackled in the literature, but most of the solutions developed for this problem are heuristics-based. Ghobrial et al. (1982) address this problem and use a first-in-first-out (FIFO) rule to solve it. Asćo et al. (2012, 2014) address the same problem by using heuristic-based approaches, such as construction and greedy algorithms. Abdelghany et al. (2006) use a last-in-first-out (LIFO) heuristic to solve the problem. Other papers including Barth and Pisinger (2012) and Frey et al. (2010) also address the problem of assigning baggage stations to outgoing flights. Barth and Pisinger (2012) develop a multi-criteria optimization problem to assign handling facilities to outbound flights and decide the handling start times. They develop a heuristic approach and a decomposition approach to solve the model. If the handling times are assumed to be fixed then the approach by Barth et al. (2013) is optimal. Zeinaly et al. (2012) tackle the line balancing problem of automated baggage handling systems in the airport. They address the assignment of baggage stations to flights such that the overall baggage waiting time is minimized and the energy spent by vehicles carrying the baggage is minimized. They develop a continuous time non-linear model which can be converted into a Mixed-Integer Programming (MIP) and a Linear Programming (LP) model using certain assumptions.

In all the models discussed above, heuristics have been used for solving the problem. However, getting the optimal solution through the use of heuristics is never guaranteed, and there is a dearth of methodology in the literature which solves the chute assignment problem optimally. Moreover, from our interaction with the airport at which we have implemented our model, and survey of the literature, it is evident that modeling uncertainty in the airport operations is really important for the decision makers. Hence, it is important to develop a robust baggage handling system model that incorporates the uncertainty in the system.

In our model, the uncertainty in the airport operations is captured in a number of possible scenarios, each of which have a different probability of occurrence. An individual scenario has a set of values for each of the uncertain parameters and, hence, the performance of the outbound baggage handling system under that scenario can be computed. The performance objective