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Bin Packing Problems with uncertainty on item characteristics: an application to capacity planning in logistics

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Abstract

Most modern companies are part of international economic networks, where goods are produced under different strategies, then transported over long distances and stored for variable periods of time at different locations along the considered network. These activities are often performed by first consolidating goods in appropriate bins, which are then stored at warehouses and shipped using multiple vehicles through various transportation modes. Companies thus face the problem of planning for sufficient capacity, e.g., negotiating it with third party logistic firms (3PLs) that specify both the capacity to be used and the logistical services to be performed. Given the time lag that usually exists between the capacity-planning decisions and the operational decisions that define how the planned capacity is used, the common assumption that all information concerning the parameters of the model is known is unlikely to be observed. We therefore propose a new stochastic problem, named the Variable Cost and Size Bin Packing Problem with Stochastic Items. The problem considers a company making a tactical capacity plan by choosing a set of appropriate bins, which are defined according to their specific volume and fixed cost. Bins included in the capacity plan are chosen in advance without the exact knowledge of what items will be available for the dispatching. When, during the operational phase, the planned capacity is not sufficient, extra capacity must be purchased. An extensive experimental plan is used to analyze the impact that diversity in instance structure has on the capacity planning and the effect of considering different levels of variability and correlation of the stochastic parameters related to items.

Keywords: Stochastic Bin Packing; logistics capacity planning; supply chain; third party logistic.

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1. Introduction

Most modern companies are part of international economic networks, where goods are produced under different strategies (made-to-stock or made-to-order), then transported over long distances, and stored for variable periods of time at different locations along the considered network. In this context, having enough capacity to properly perform crucial activities such as the supply, storage and distribution of goods is paramount if a company is to be competitive. It should be noted that these activities are often performed by first consolidating goods in appropriate bins, which are then stored in warehouses and shipped using multiple vehicles through various transportation modes. Thus, companies face the problem of having to plan for sufficient capacity, expressed here in terms of bins, to be available at different locations throughout their network and for different periods of time, in order to satisfy demand, expressed here as a number of items of variable size to be shipped and stored. Given that logistics activities are often subcontracted, capacity planning entails negotiations with third party logistics firms (3PL's) to book the needed capacity. The results of these negotiations often take the form of medium term contracts specifying both the capacity to be used (the quantity and type of the bins) and the additional services to be performed (storage, transportation, bin operations, etc.). Therefore, bin packing models represent important decision support tools for logistics managers, who bear the responsibility for these tactical planning decisions.

Although bin packing optimization problems have been extensively studied, e.g., Martello & Toth (1990) and Wäscher et al. (2007), this research has mainly been conducted under the assumption that all the necessary information concerning the different parameters used to model the problems is known and readily available (i.e., deterministic parameters). Given the time lag that usually exists between the capacity-planning decisions and the operational decisions that define how the planned capacity is used, such an hypothesis in unlikely to be observed. Moreover, when the information becomes really known, an additional negotiation phase becomes necessary, in order to rent additional space and services, normally at a higher price. Therefore, we propose a new stochastic bin packing model, referred to as the *Variable Cost and Size Bin Packing Problem with Stochastic Items* (*VCSBPSI*). The VCSBPSI is an extension of the *Variable Cost and Size Bin Packing Problem* (Crainic et al., 2011) that explicitly takes into account more container types, the uncertainty related to their costs at the time of the full availability of the information, as well as the uncertainty related to the items appearing in capacity planning problems (both in terms of their volume and presence). The model is based on a two-stage stochastic programming formulation with recourse (Birge & Louveaux, 1997) that separates the tactical capacity planning decisions (Monczka et al., 2009) of the first stage, i.e., the *a priori* plan often performed in practice by considering a point estimation of future demand, from the operational decisions, that is, the *recourse* actions, taken repeatedly over the planning horizon, and defining the adjustments that can be made to the plan whenever the information becomes known.

We investigate the use of this model in the context of an international supply chain for a major retail firm (Crainic, et al., 2013). We focus, specifically, on the contract between the firm and a 3PL service provider to secure capacity for regular long-haul container shipping. In this context, the contract specifies the numbers of containers of various sizes and costs to be provided by the 3PL at shipping date, for a given planning horizon. On shipping dates, whenever the demand exceeds the planned capacity, additional containers may be secured at premium costs. In this paper, we first examine the impact of problem characteristics on the efficiency of an exact solver. We then analyze the value of explicitly accounting for uncertainty within the tactical plan.

The remainder of this paper is organized as follows. In Section 2, a detailed formulation of the VCSBPSI problem is provided, while Section 3 describes the solution approach proposed and the experimental plan that is conducted. Section 4 presents the computational results and analyses the impact of the different problem characteristics on the problem solutions. Finally, conclusions and future research directions are presented in Section 5.