The optimization of crop seeds packaging production planning based on dynamic lot-sizing model

Yihang Zhu, Jingjin Zhang, Danfeng Huang, Na Geng

Dept. of Plant Science, School of Agriculture & Biology, Shanghai Jiao Tong University, Shanghai 200240, China

Dept. of Industrial Engineering & Management, Shanghai Jiao Tong University, Shanghai 200240, China

Abstract

With the competitive seeds market and development needs of seed companies, the production of crop seeds, including raw seeds procurement, processing, storage, packaging, and logistics, is complicated. Seeds packaging is one of the most important phases, including automatic and manual packaging. Automatic packaging is highly efficient with high setup costs, whereas manual packaging is the opposite. It is difficult for the managers to make the packaging planning, i.e., the number of automatic and manual packaging, based on the forecasted demand. This problem is considered to be a special dynamic lot-sizing problem but it is more complex compared to the general ones. To deal with this problem, this paper proposes a mathematical programming model with the objective of minimizing the total costs. Because the problem is Non-Deterministic Polynomial (NP) hard, the computational time for solving this model is very long. Therefore, this paper proposes a heuristic algorithm (HA) to solve the problem. Numerical results showed that the total costs calculated by the proposed HA are close enough (8.12%) to the optimal total costs of the proposed model and 22.6% lower than the traditional planning. At different scenarios, the HA can keep beneficial and reliable to a certain extent. The proposed model and HA provided detailed illustration for understanding the complexity of the seeds packaging planning and were able to deal with real situations in the seed company.

1. Introduction

The seed is one of the most important agricultural raw materials which have significant impact on crop cultivation and food production. In developing countries, the most important and fundamental issue is to supply seeds to growers to increase agricultural productivity, food provisioning and rural sustainability (Coomes et al., 2015). However, with fiercer competition, seeds suppliers tend to provide large numbers of raw seeds for scale-of-economy, while growers cannot afford buying or storing that large amount of seeds. In such case, seed companies carry out raw seeds procurement, quality inspecting, seeds storage, packaging and logistics, which act as bridges between seeds suppliers and growers. Seeds packaging is one of the most important procedures in seed companies. It is usually realized by automatic or manual packaging. Both packaging approaches have different working efficiency and costs. It is difficult for the manager to balance the efficiency and costs to make the seeds packaging planning. Raw seeds procurement is sophisticated and involves competition with other companies because the upstream raw seeds suppliers tend to sign long-term contracts to those who purchase larger amounts. For this reason, a seed company expands its raw seeds inventory to secure the source of raw seeds, meanwhile inevitably generates a large number of inventory holding costs. Another consideration is that raw seeds procurement has specific time windows, which are usually specific for specific types of seeds. A seed company usually has fixed raw seeds procurement planning that determines what and how many to purchase every year. Due to the fixed procurement planning and specific time windows, the manager usually purchase the seeds in time and store them in the warehouse.

When the order is received or the seeds demand is forecasted, seeds will be packaged as products that are strictly wrapped, sealed and labeled before being delivered to growers. Seed companies usually pay much attention to improving high-quality and efficient seeds packaging. The main procedure of seeds packaging is to divide raw seeds into aliquots and package them to seeds products according to customers’ orders, as is shown in Fig. 1A.
Raw seeds are either manually packaged or processed through the packaging line. The packaging line is faster but with higher setup costs, while manual work, on the contrary, is slow but with lower setup costs. When switching the varieties of seeds, automatic packaging line must be cleaned and replenished with new raw seeds, which leads to high setup costs. The trade-off between the automatic and manual packaging approaches is shown in the axe in Fig. 1B.

A seed company sells varieties of crop seeds. Seeds products are sold through the entire year due to various growth seasons of crops. Moreover, the demands of different seeds products are quite varied. Also, compared to raw seeds, seeds products occupy more space and require warehouses with strictly controlled temperature and humidity, which generate higher inventory holding costs than raw seeds. Therefore, a seed company tends to pack raw seeds into seeds products based on the FCFS (First-Come-First-Serve) rule. That is, seeds products are prepared based on the sequence of orders. Nevertheless, this FCFS packing rule has the following problems:

1. Certain demands but sporadic orders. When the order arrives, the seed company prepares the seeds products immediately even if the order quantity is low. In this case, manual packaging is preferred. However, the managers ignore the possibility of combining several orders together to use the automatic packaging line. But one issue should be pointed out that each time the packing line switches the varieties of seeds, it causes an amount of setup costs. As more sporadic orders come, more setup costs are generated.

2. Trade-off between automatic and manual packaging. To setup the automatic packaging line, the order quantity must exceed a certain lower bound \((LB)\), axes in Fig. 1B. Otherwise, the packaging line is not worthy starting. Therefore, combining sporadic orders is a probable way to increase the packaging efficiency and reduce the total costs.

Due to the complexity of packaging planning problem, the crop seeds need to be classified by ABC analysis to grasp the critical sales [Nahmias and Olsen, 2015a]. As shown in Fig. 2, sales seeds are classified into 3 groups (A, B and C) by their cumulative percentage of sales. For group A, accounting for more than 70% of total sales, and their packaging planning requires more sophisticated procedures and detailed parameters for calculating. For group B, less attention should be paid and package tasks should be integrated for each batch of raw seeds. For group C, package tasks are frequent and scattered, thus they can simply be packaged when orders come.

Seeds products packaging planning is complicated when considering crop seeds varieties, packaging approaches (manual or automatic packaging line), sporadic orders, raw seeds procurement, inventory holding costs, and setup costs together. The packaging planning problem can be summarized as Multi-item Dynamic Lot-sizing Problem [van Norden and van de Velde, 2005], which considers finite planning horizon, lead time, a general objective function, and multiple constraints in setup costs and inventory holding [Authors et al., 2015]. According to Kuo and Yang (2006), this problem is NP-hard even for a single-item dynamic lot-sizing problem with capacity constraints. Generally, the optimal solutions were obtained when applying Mixed integer
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