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Lot sizing and sequencing optimisation at an animal-feed plant

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ABSTRACT

This paper studies a challenging case of joint lot sizing and scheduling in a manufacturing plant for animal feed compounds. A key characteristic of this industry is that certain products can perform a production line "cleaning" function if a sufficiently large lot is produced between two products that would otherwise require a cleaning setup. Thus the sequence-dependent setup times do not always obey the triangular inequality. A mixed integer programming model is applied and tested on multiple sets of real data from different seasons. The model takes too long to solve exactly and so alternative formulations and methods are developed to solve the model more quickly, based on two variants of the Relax and Fix heuristic. Test results demonstrate that the formulations are computationally effective and able to take economic advantage of the intermediate cleaning products. The model schedule substantially improves on that practiced at the plant and can be useful for similar companies in the animal-feed industry.

1. Introduction

In a manufacturing system, many products often share valuable capacity which is wasted and not used productively when setting up (changing over) from one product to another. Although automation and process engineering has often reduced the magnitude of setups, a large number of companies still face substantial production setup costs and times within an increasing range of products, with consequent losses of production capacity and missed deadlines if setups are not well managed and controlled. Weak performance in this area generally results in backlogs of unmet demand, customer dissatisfaction and loss of company competitiveness.

While many production lots or batches correspond to specific orders and so have a predetermined size, a product or part may instead feed into many small distinct orders with different deadlines. In such a situation, it makes sense to relate the product or part's lot sizes to its total demand aggregated from the different orders. In other words, the problem becomes one of simultaneous scheduling and sizing of production lots or batches, based on forecasts of product orders and demand, often under limited production capacity (Askin & Standridge, 1993).

This paper investigates such a challenge at Anifeed, a Brazilian animal feed compound company (whose real name has been altered to protect its identity). Two mixed integer programming (MIP) models for joint lot sizing and scheduling with sequence-dependent setup times are applied, taking into account that the setup times, like those in many feed plants, do not always obey the triangular inequality. The first model sequences each period independently of the others. The second model sequences all periods simultaneously, taking into account the linking setup states between periods.

Tests on Anifeed data indicate that in general neither model can be solved optimally within an hour's computing time. In particular, the incumbent solution after an hour is poor for the second model so several alternative formulations and methods are developed to accelerate the solution time, making use of Relax and Fix methods (Wolsey, 1998) on the integer lot sizes or binary setup variables over time.

Computational tests show that the Relax and Fix acceleration is effective while maintaining quality. The solutions show that the second model is able to take advantage of the cleaning function that certain intermediate products can perform if a sufficiently large lot is produced between two products that would otherwise require a cleaning setup. The model's schedules showed a very marked improvement over the schedules implemented at Anifeed. Randomly generated and perturbed data was then used to better evaluate the models and methods through experimental tests.

The rest of this section describes Anifeed's production process and its scheduling context. Section 2 reviews previous research while Section 3 proposes and explains the two optimisation models. Section 4 develops alternative solutions methods which are then tested and analysed in Section 5 and compared to Anifeed's practice in Section 6. Finally Section 7 concludes and points out future directions for research.

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1.1. The Anifeed production process

Anifeed produces about 200 animal feed supplements which can be grouped into approximately 20 product families. Products within the same family do not contaminate each other and have the same production time per batch. All animal feed supplements follow the same basic production route, and make use of the same key resources: silos, dosing machines, pre-mix machines, mixer, and post-mix packaging, as shown in Fig. 1.

The first stage in the production process is to weigh the raw materials based on pre-established formulations. After the operator has specified the feed product and number of batches to be produced, appropriate quantities of the bulkier raw materials are automatically released from the silos into the dosing machines and then held as pre-mix in-process inventory. The bulk materials are transferred to the mixer only after they are all ready in the pre-mixers. Less bulky materials are stored in bags from which they are manually weighed and added directly to the mixer. Mixing occurs in three phases: dry mixing, addition of fluids, final mixing. The mix is then unloaded into the post-mixer and subsequently bagged. The amount of time spent at these operations varies between product families.

A certain number of batches of each product is made before changing to another product. Each batch measures about 2000 l, the capacity of the mixer. The amount produced in the mixer depends on the product density, for example, 2000 kg of basic feeds, 1440 kg of premixes or 2400 kg of mineral salts. Technically, the mixer must be at least half-full to ensure efficient mixing, but economically it makes sense for Anifeed to produce a full batch. However, small batches can be produced in the micro-ingredient mixer, and so small orders are not considered in Anifeed's planning and scheduling of feed supplements.

Further details are available in Toso (2008).

1.2. Production planning and scheduling

Although Anifeed's production process has several stages, logically it can be considered to be single-stage given that the stages are arranged serially, the batch flow is continuous and there is no in-process inventory. The capacity bottleneck is the mixer, so it is at this stage that the whole process can be modelled as a one-machine problem, taking total process times into account.

Product changes are frequent, typically about 30–40 per week. A complicating feature of the animal-feed industry is that some feed families contaminate others if produced in successive batches. As a result the mixer must be often cleaned, consuming potential production time. Products in the same family have negligible changeover times, and identical batch weights and processing times. Thus the amount of mixer cleaning time can be minimised by good sequencing of the production of families.

Furthermore, most of Anifeed's products follow a seasonal pattern of demand, with peaks in certain months. Since employee turnover is high, manpower levels can be adjusted to cope with this seasonality, thus determining basic (pre-overtime) production capacity. The demand in a particular period often exceeds basic capacity, and so overtime is frequently worked to satisfy demand without shortages. When generating production schedules the production manager is particulary concerned to balance overtime and inventory costs, while fulfilling demand without backlogs. The animal feed market is highly competitive, and so delivery delays to clients must be avoided if possible by producing some feed ahead of demand when slack capacity is available.

Thus Anifeed needs to make effective use of production capacity by good lot sizing and sequencing of the production of families. This problem is especially complex for the feed industry due to certain particularities such as highly seasonal demand and sequence-dependent setup times.

The mixer can be completely cleaned during non-productive time between periods (e.g., at weekends), allowing the line to begin and end a period with any product without the initial setup in a period impacting on the total time spent on setups. The setup sequences in consecutive periods are thus delinked and independent of each other. This approach, called *Independent Sequences*, is appropriate in months of slack capacity, and was used not just at Anifeed but also in a second company observed by the authors. It contrasts with a second approach called *Dependent Sequences* which is appropriate in months of tight capacity, when Anifeed's plant is active 24 h a day with no non-productive time between periods. In this case, the cleaning of the mixer at Anifeed is incorporated within the production setup sequencing. Thus the sequences of consecutive periods are linked and dependent, impacting on the total time spent on setups. The Dependent Sequences approach is a more difficult problem as a sequence has

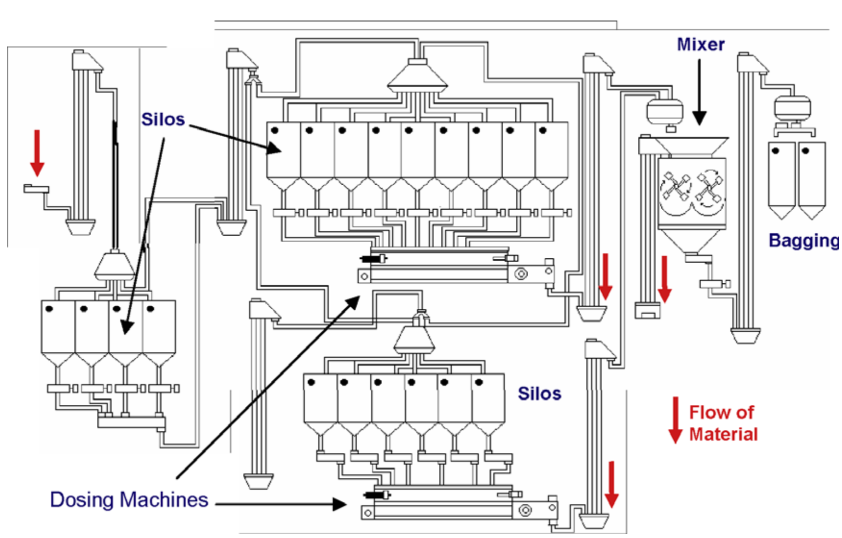

Fig. 1. Production process of Anifeed's food supplements.