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Lot sizing versus batching in the production and distribution planning of perishable goods

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ABSTRACT

Joint production and distribution planning at the operational level has received a great deal of attention from researchers. In most industries these processes are decoupled by means of final goods inventory that allow for a separated planning of these tasks. However, for example, in the catering industry, an integrated planning framework tends to be more favorable due to the perishable nature of the products that forces a make-to-order production strategy. So far this planning problem has only been addressed by allowing the batching of orders. The main contribution of this paper is to extend this approach and prove the importance of lot sizing for make-to-order systems when perishability is explicitly considered. The value of considering lot sizing versus batching is further investigated per type of production scenario. Overall, results indicate that lot sizing is able to deliver better solutions than batching. On average, for the improved instances, the cost savings ascend to 6.5% when using lot sizing. The added flexibility of lot sizing allows for a reduction on production setup costs and both fixed and variable distribution costs. The savings derived from lot sizing are enhanced by customer oriented time windows and production systems with non-triangular setups.

1. Introduction

Strategic, tactical and operational integration of the production and distribution processes is reported as being able to deliver better results for companies than a decoupled approach (Park, 2005; Amorim et al., 2012). Very often this integration is driven by a management decision, rather than by an actual need of the underlying processes. However, when the final products are not allowed to be stocked due to, for example, freshness reasons this integration scenario becomes imperative. Within these three decision levels, it is on the operational one where more research needs to be conducted (Chen, 2009), since actual models fail to be accurate and detailed enough for the real-world problems.

The motivation for studying the operational integrated production and distribution problem comes from very practical industry situations when it is not possible or advisable to keep final inventory decoupling these two processes. In this case, companies are forced to engage in a make-to-order production strategy. Therefore, the production for a certain demand order may only start after the order arrival. The examples found in practice are related to the computer assembly industries, the food-catering, the industrial adhesive materials or the ready-mixed concrete. The importance of a holistic vision of these processes is driven by very demanding customers requiring a product that cannot wait a long time to be delivered after production. These products, having a very short lifespan, will be called hereafter as perishable. Hence, the considered operational integrated production and distribution problem relates to the decisions on how to serve a set of customers with demand for different products. The planner has to simultaneously decide on the production planning and vehicle routing, in a setting where inventory is not allowed (i.e. no inventory is carried from one planning horizon to the subsequent).

Regarding the production process, the definitions proposed by Potts and Van Wassenhove (1992) are followed, where batching is defined as the decision of whether or not to schedule similar jobs contiguously and lot sizing refers to the decision of when and how to split a production lot of identical items into sublots. Note that processing times are proportional to the quantities processed in both cases. The modelling of our problem considers a complex production system that is accurately synchronized with the distribution process to allow for as much flexibility as possible. Therefore, no specific industry constraints are modelled, but

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instead the formulation is as general as possible. Several parallel production lines with sequence dependent setups are taken into account. Moreover, the demand from different customers for a set of products has to be delivered within strict time windows on different routes that have to be determined together with the production planning.

So far the research community has tackled this operational integrated production and distribution problem by batching orders of customers as if lot sizing decisions were never to yield a better solution. This is clearly not the case in the production planning literature where the importance of considering lot sizing and scheduling simultaneously is consensual for the multi-period setting (for example Almada-Lobo et al., 2010). By just considering batching operations one could not achieve a production plan in which a product to a given customer is processed on different lines for example. Intuitively, however, it is observable that if the requested product is strongly perishable, then it may make sense to produce it simultaneously on both lines to ship it as soon as possible. To the best of our knowledge, the incorporation of lot sizing decisions in the operational production and distribution problem has never been analyzed. Therefore, a major contribution of this paper is to evaluate whether lot sizing decisions may deliver better results than batching when this integrated problem tackles perishability. After proving that lot sizing should be considered in this problem setting, the secondary contribution is to understand the conditions that improve the benefits of lot sizing versus batching.

The remainder of this paper is organized as follows. The next section reviews the literature on the operational integrated production and distribution problem. Section 3 describes the considered problem and proposes two mathematical formulations for the operational production and distribution problem of perishable goods: one considering batching and the other lot sizing. In Section 4, the results of the computational study are presented and the impact of considering lot sizing versus batching is assessed. Finally, the paper is concluded in Section 5 with the main findings and ideas for future work.

2. Literature review

The literature in integrated production and distribution problems is vast and, therefore, only the papers very related to the scope of this work will be reviewed here. Our problem statement refers to the gap pointed out, in the review of Chen (2009), about operational integrated models dealing with *multi-customer batch delivery problems with routing*.

The research community has tackled this integrated production and distribution problem by batching orders in the production process. In Chen and Vairaktarakis (2005) orders are delivered right after their production completion time. The authors model a single product to be scheduled on the production line(s) and an unlimited number of vehicles, with a fixed capacity, which perform the routing. This work also investigates the value of integration, comparing the use of a decoupled versus an integrated approach. They conclude that the improvement is more significant when the goal is to minimize the average delivery time than the maximum delivery time. In Geismar et al. (2008) product perishability is taken into account and there is a single production facility with a constant production rate. The routing process is performed by a single, capacitated vehicle that may return to the facility, therefore, performing multiple trips during the planning period. The objective is to determine the minimum makespan of the integrated production and distribution for a given set of customers. Armstrong et al. (2007) solve a related problem with a single product subject to a fixed lifespan that is also delivered by a single vehicle, but, in this case, there is no possibility of performing multiple trips. Moreover, the sequence of production and distribution is fixed and forced to be the same. Chen et al. (2009) present a model that considers stochastic demand for multiple products subject to perishability. The production environment does not consider setups between products and the delivery function is assured by a set of capacitated vehicles, however, the vehicle operating costs are disregarded. Finally, Chiang et al. (2009) shifts the focus to the distribution process. The production constraints influence their simulation–optimization framework through the variability of production rates and possible delays. The remaining problem is formulated as an extension to the vehicle routing problem with time windows.

Again, none of the aforementioned papers on the operational integrated production and distribution planning include lot sizing decisions. However, on pure production scheduling, the advantages of lot sizing over batching for a leaner environment have been proven. Santos and Magazine (1985), Wagner and Ragatz (1994), Low and Yeh (2008) show how lot sizing can reduce lead time in the scheduling of machines and the impact of setup times is investigated. Nieuwenhuyse and Vandaele (2006) proves that lot sizing improves the reliability of the deliveries in a system accounting for production and direct deliveries to customers. Moreover, in make-to-order environments with a multi-level production structure, Anwar and Nagi (1997) show the advantages of lot sizing compared against a lot-for-lot strategy. The scope of these related papers, however, does not include the distribution decision carried in the present work.

Based on this literature review the contribution of this paper is clearer. Firstly, it investigates the potential performance improvement that lot sizing decisions may add to the operational production and distribution planning (in relation to only batching orders). Secondly, previous studies are extended by considering a more general production system with sequence-dependent costs and times between products.

3. Problem statement and mathematical formulations

In this section, the problem statement is given as well as two mathematical formulations for this problem. The first formulation models the operational integrated production and distribution problem that only considers batching of orders (I-BS-VRPTW) and the second formulation extends the first one by considering the sizing of the lots (I-LS-VRPTW). Both models are then compared.

The operational integrated production and distribution planning problem considered in this work consists of a set M of parallel lines $l=1,\dots,m$ with limited capacity that produce a set P of items (or products) $i,j=1,\dots,p$ to be delivered to a set N of customers $c,d=1,\dots,n$ through a set A of arcs (c,d). The delivery is assured by a set K of identical fixed capacity vehicles indexed by $k=1,\dots,o$ initially located at a depot. Hence, the routing can be defined on a directed graph $G=(V,A)$, $V=N\cup\{0,n+1\}$, where the depot is simultaneously represented by the two vertices 0 and $n+1$, and, therefore, $|V|=n+2$.

Some of the products may be perishable while others last substantially beyond the considered planning horizon. Furthermore, the utilization of equipment, such as ovens in the food-catering, makes the changeover between different products dependent on the sequence. Hence, products are to be scheduled on the parallel production lines over a finite planning horizon that ranges up to the time of the last scheduled delivery.

The distribution is performed using several vehicles serving multiple customers on different routes. There exists a variable cost dependent on the total distance travelled and a fixed cost for each