Lot sizing and scheduling: industrial extensions and research opportunities

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Editorial

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Production planning and scheduling seeks to efficiently allocate resources while fulfilling customer requirements and market demand, often by trading-off conflicting objectives. The decisions involved are typically operational (short-term) and tactical (medium-term) planning problems, such as work force levels, production lot sizes and the sequencing of production runs.

Lot sizing seeks to determine the optimal timing and level of production. The early developments in this field have their roots in the Economic Order Quantity model developed by Harris (1913), extended some decades later by Wagner-Whitin (1958). Since then, researchers have developed successive generations of models combining capacitated and dynamic approaches, with a blurring of the boundaries between lot sizing and other research fields (Drexl and Kimms, 1997; Karimi et al., 2003).

Most of the lot sizing literature is focused on discrete manufacturing. Currently, with changes in the philosophy of production planning and control, along with lean manufacturing processes and the shift from make-to-stock to make-to-order, there is a debate about whether or not lot sizing as a trade-off between setups and stocks is still an issue. Nonetheless, a high number of production processes are characterized by strong fluctuations of seasonal demand (with not enough capacity in some periods to process all the orders), by significant setup times and costs and by the economical advantage of holding stock rather than maintaining a capacity surplus. This is the case in process industries, where just-in-time systems cannot be implemented (Pochet, 2001). As a result, process industries are a promising research area which is, in fact, addressed by the most recent papers on lot sizing and its extensions (Suerie, 2005; Quadt and Kuhn, 2008).

The scheduling of production lots, as well as their sizing, is an area of increasing research attention within the wider field of production planning and scheduling. In many industrial applications, especially from the process industries, the close relationship between lot sizing and scheduling makes it imperative that both decisions are made simultaneously in order to efficiently use capacity. Traditional models have been increasingly refined to incorporate more detail and integrate lot sizing with scheduling. The current trend is also to couple lot sizing and scheduling with distribution, vehicle routing or cutting and packing decisions, etc. (Pochet and Wolsey, 2006).

Besides the integration of several “independent” and previously self-contained research fields, researchers and practitioners worldwide have been trying to incorporate more specificities of the production environment in their models (Jans and Degraeve, 2008). Recent hot topics in the area include perishability, synchronization of resources, non-triangular setups, time windows, and multiple stages with parallel machines. Nevertheless, there is a lack of research on the effect of using real life instances (some with “dirty data”) to carry out computational experiments, instead of relying on random instance generators, and on the integration of the algorithms with interactive decision support systems.

Naturally, increasing realism turns the mathematical models larger and more complex. This added complexity, and the need to increase the size of instances solvable to near-optimality, requires the integration of existing methods with novel and efficient optimization algorithms, along with the development of tighter models and stronger valid inequalities based on the model polyhedral structures. Moreover, there is a continuing need to trade off the complexity of reality in planning models with mathematical and computational tractability. The research community is committed to the cross fertilization between exact and approximate algorithms which exploit simultaneously the advantages of both methods (Jans and Degraeve, 2007; Buschkühl et al., 2010). Decomposition methods appear to be an intuitive way of separating the different sub-problems that are being integrated. Previous research on each separated problem can then be exploited.

This special issue is not the only evidence of a very active research community working on lot sizing related problems. Among the numerous publications, projects and meetings, we want to mention two recent representative activities. In May 2010 a three-year Marie Curie FP7 project of the European Union on "Industrial Extensions to Production Planning and Scheduling" started, involving researchers from five institutions in Europe and Brazil. The outcome of this collaboration aims to be a set of mathematical models that effectively represent the production planning and scheduling challenges in a wide variety of industries, along with operationally viable and novel solution methods tested and validated with real data from a diverse range of industrial sectors: animal nutrition, pulp and paper, beverages, glass, dairy products, textiles, and furniture among others. (More information can be found at http://www.fe.up.pt/~ppext.) In July 2010 at the European Conference on Operational Research (EURO'10) in Lisbon, a stream on lot sizing was organized for the first time in the history of this conference, containing seven sessions with more than 25 talks.

This special issue of IJPR on *Lot Sizing and Scheduling (LSS)* aims to bring together much of the recent research from around the world, particularly that which addresses more realistic and practical variants of models, and the use of novel solution techniques. The integration of lot sizing and scheduling poses special challenges, and so pure scheduling papers were specifically excluded from the call. The papers in this special issue cover the range from applications in different industries to extensions of classical lot-sizing approaches in different directions. It is evident that researchers are trying to incorporate more "real-world" features such as production and delivery time windows, parallel machines, supply chain and reverse logistic aspects. Many of the papers also tackle different solution approaches ranging from exact dynamic programming methods for special cases to heuristic and metaheuristic algorithms.

The first section of this issue contains three papers devoted to applications in industry. *Transchel et al.* take inspiration from chemical industry data to test two alternative transportation-type reformulations of a multi-product LSS problem with sequence-dependent setup costs and times that combines discrete and continuous representations of time. Their results show significant improvements over a standard Inventory and Lot size (I&L) formulation. *Hans and van de Velde* tackle a real-world production planning problem arising in sand casting operations in metal foundries. The authors address the complexities when dealing with real data and all kinds of industrial hard and soft- constraints from a practical point of view. The overall problem can be seen as a generalization of the capacitated parallel machine LSS. A three-step hierarchical planning approach solution procedure is embedded within a Decision Support System, involving mathematical programming and iterative local search improvements. *Tang et al.* use data and parameters from a Chinese steel complex to evaluate an improved Lagrangian Relaxation method to solve an integer programming model to decide which steel coils should be batched together in annealing furnaces, both statically and with a rolling horizon.

The two papers of the second section address the integration of consumption and recovery flows. The lot sizing community has been driven by forward logistics, optimising lot sizes from the manufacturer to the customer. However, green or sustainable supply chains cannot neglect the impact of reverse logistics in running operations. *Schulz* studies the single-item dynamic lot sizing problem where returning products can be remanufactured with separate setup costs. He proposes a generalization of an existing Silver-Meal heuristic for static problems and then improves on its performance with a further heuristic, resulting in a halving of the percentage gap to the optimal solution. *Kim and Goyal* address a closed-loop single-manufacturer-single-retailer supply chain by integrating both consumption and recovery logistics. The authors analyse simultaneously from the manufacturer viewpoint the production lot size and the optimal recovery rate of used products, considering three types of recovery decisions: non-recovery, full-recovery and partial-recovery policies. The optimality domains of the three policies are assessed by means of a sensitivity analysis in the operational parameters of the problem.

The two papers of the third section are related to a recent family of problems, namely LSS with time windows (TW). Traditionally, lot sizing problems consider dynamic demand within a finite planning horizon, without imposing any restriction on the production or delivery time frames. In the presence of production (delivery) TWs an order must be processed (delivered) within a given time interval. *Absi et al.* extend the single-item lot sizing problem with non-strictly included production TWs so that lost sales, backlogs and early production can be considered. The TW structure causes the zero-inventory ordering policy not to be valid anymore, but other useful properties are derived. They develop dynamic programming algorithms of complexity $O(T^2)$ to compute the optimal solutions. *Akbalik and Penz* address the single-item capacitated lot sizing problem coupled with TW deliveries. The flexibility gains of integrating production, transportation and storage decisions under different cost configurations and TW shipments are discussed. An exact MIP formulation and a new pseudo polynomial dynamic programming algorithm of complexity $O(T^2)$ are proposed.

The fourth section contains four papers which deal with parallel resources that complicate considerably the LLS underlying problem. *Gicquel et al.* tackle a difficult variant of the small-bucket discrete lot sizing and scheduling problem on identical parallel resources. The authors propose a family of strong valid inequalities that can be separated in polynomial time, and which strengthen significantly the original MIP and enable instances of medium-size to be solved until optimality. *Kaczmarczyk* introduces new formulations based on integer variables (instead of binary variables) for the small-bucket proportional lot sizing and scheduling problem with identical parallel machines. By aggregating the machines, more compact formulations are possible which are advantageous when solving the problems. *Haksoz and Pinedo* obtain new insights into the Economic Lot Scheduling problem about how setup costs and inventory carrying costs affect assignments of items to non-identical machines that operate at different speeds. Several models and practical heuristics are proposed based on different assumptions about the rotation schedules. Finally, *Drechsel and Kimms* study the cooperative capacitated lot sizing problem with common parallel resources and payable transshipments between players. The underlying idea is that each decision maker (player) can produce not only to meet own demand, but also to fulfill other players' demand. The authors discuss the conflicting and hard objectives of minimizing totals costs on the one hand and distributing stable and fair cost shares among players on the other hand. They suggest a minimax core costs allocation which is then modelled as a mathematical programme and solved using commercial optimisation software.

The final section of this special issue comprises two papers that are more focused on solution procedures, namely on exact and hybrid approaches, respectively. *Glass and Possani* tackle the lot streaming problem of multiple jobs in a flow shop. For two special cases, the problem with identical jobs and the two machine flow shop problem, the authors develop polynomial time algorithms for minimizing the makespan. *Gonçalves and Sousa* address the economic lot scheduling problem (ELSP) for multiple products. They make use of a very flexible non-linear mixed-integer programme formulation to model initial inventories, backorders and setup times. They design a genetic algorithm determining the production sequence. The resulting production quantities are determined by using a standard LP-solver.

In total we received more than 50 submissions. We hope the papers selected for this special issue will be a source of latest research results on lot-sizing and scheduling, stimulate the readers for this important area and provide a direction for future research. We are very grateful to all referees who have provided their constructive comments in order to improve the quality of the papers. We would like to thank the authors who have contributed their work in this special issue.

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