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An inverse economic lot-sizing approach to eliciting supplier cost parameters

Péter Egri [a], Tamás Kis [a], András Kovács [a,*], József Váncza [a,b]

[a] Fraunhofer Project Center for Production Management and Informatics, Institute for Computer Science and Control, Hungarian Academy of Sciences, Hungary

[b] Department of Manufacturing Science and Technology, Budapest University of Technology and Economics, Hungary

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ABSTRACT

Recent literature on supply chain coordination offers a wide range of game theoretic and optimization approaches that ensure efficient planning in the supply chain, but assume that the involved parties have complete information about each other. However, in reality, complete information is rarely available, and those models alone do not present any incentive for the parties to reveal their private information, e.g., the cost parameters that they use when solving their planning problems.

This paper proposes an inverse lot-sizing model for eliciting the cost parameters of a supplier from historic demand vs. optimal delivery lot-size pairs, gathered during repeated earlier encounters. It is assumed that the supplier solves a single-item, multi-period, uncapacitated lot-sizing problem with backlogs to optimality to calculate its lot-sizes, and the buyer is aware of this fact. The inverse lot-sizing problem is reformulated to an inverse shortest path problem, which is, in turn, solved as a linear program. This model is used to compute the ratios of the supplier's cost parameters, i.e., the setup, the holding, and the backlog cost parameters consistent with all the historic samples.

The elicited cost parameters can be used as input for various game theoretic or bilevel optimization models for supply chain coordination. Computational experiments on randomly generated problem instances indicate that the approach is very efficient in predicting future supplier actions from the historic records.

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1. Introduction

Planning inventories in a supply chain necessarily calls for the interaction of autonomous partners operating with distinct, potentially conflicting objectives, different decision mechanism and asymmetric information. Satisfying external demand requires the interaction of these partners in the supply chain. The literature offers a wide spectrum of coordination mechanisms (Albrecht, 2010; Váncza et al., 2011) based on game theoretic and optimization approaches, which make different assumptions on the information available to the different partners. Nevertheless, there is a considerable gap between the incomplete information models, which usually assume a single encounter of the buyer and the supplier with some well-defined asymmetric information situation, and the complete information models, which consider that the companies are mutually aware of their partners' decision situation. Namely, in case of repeated encounters, a significant amount of information is hidden in historic records of earlier interactions. These records can contain earlier orders, delivery lot-sizes, or delivery lead times. Furthermore, by the widespread application of tracking and tracing systems (Holmström et al., 2010; Ilie-Zudor et al., 2011), the buyer can observe even the production lot-sizes and the manufacturing parameters applied by the supplier. Exploiting this information enables a company to use well-informed, e.g., Stackelberg or bilevel optimization approaches for planning its production and logistics, providing a considerable competitive advantage compared to using models with restricted information.

In this paper, we tackle the issue of how the historic records of earlier encounters between a buyer and a supplier can be utilized in decision making. We take the stance of the buyer and aim at eliciting the cost parameters of the rational supplier's decision problem. It is assumed that the buyer possesses a historic record of *demand* vs. *delivery lot-size* pairs. It is noted that the same approach could be used for eliciting the supplier's cost parameters in its *production lot-sizing problem*, given that the production lot-sizes are observed. We introduce an inverse combinatorial approach to eliciting the cost parameters of a supplier who determines its delivery periods and quantities by solving a

* Corresponding author. Tel.: +36 1 279 6299.
E-mail addresses: egri@sztaki.mta.hu (P. Egri), tamas.kis@sztaki.mta.hu (T. Kis), andras.kovacs@sztaki.mta.hu (A. Kovács), vancza@sztaki.mta.hu (J. Váncza).

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single-item, multi-period, uncapacitated lot-sizing problem with backlogs (ULSB). Specifically, the proposed model computes the *ratios* of the supplier's *setup*, *holding*, and *backlog* cost parameters. It is noted that eliciting the *absolute values* of the cost parameters from the above input data is impossible, since the optimal delivery lot-sizes according to the ULSB model are invariant to the multiplication of the cost parameters by a common constant. To the best of our knowledge, this is the first inverse lot-sizing model investigated in the literature.

The elicited cost parameters can be useful in various scenarios involving a buyer–supplier relationship. A specific application is the utilization of the elicited cost parameters as inputs to one of the recent Stackelberg or bilevel approaches to lot-sizing in supply chains (Kovács et al., 2013). Such models require the knowledge of the supplier's cost parameters, but the coordination mechanisms themselves do not present any incentive for the supplier to reveal their true values. It is emphasized that in the above applications, eliciting the ratios of the cost parameters is sufficient, since, likewise the ULSB problem, the rational actions of the parties are insensible to the multiplication of the cost parameters by a common constant. Hence, our method can be a precious complement of those supply chain coordination approaches. On the other hand, a shortcoming of the approach is that it cannot compute the *absolute values* of the cost parameters, which can be an important limitation in other applications, e.g., in price negotiations.

In what follows, the related literature is surveyed first (Section 2). Then, the problem is defined formally and the inverse optimization solution method is introduced (Section 3). Next, the results of computational experiments are presented (Section 4), and finally, the paper is concluded with a discussion of the application opportunities and the directions for future research (Section 5).

2. Literature review

2.1. Lot-sizing

Fundamental results on dynamic lot-sizing models have been published in Wagner and Whitin (1958) and Zangwill (1969). These papers consider uncapacitated lot-sizing models where the deterministic, time varying demand is known in advance over a finite planning horizon. Over the past decades the basic models have been extended by production capacities and various side constraints, for an overview see, e.g., Axsäter (2006), Pochet (2001) and Pochet and Wolsey (2006). The modeling of various features in lot-sizing by mixed-integer programs (MIP) is investigated, e.g., in Belvaux and Wolsey (2001) and Cordier et al. (1999).

The need for studying the interacting lot-sizing decisions of multiple autonomous parties in a supply chain is widely recognized. One of the possible approaches is *integration*, when the different parties jointly solve the interrelated planning problems, see, e.g., Li and Wang (2007). A drawback of integration is the mutual sharing of all the planning relevant information, which is sometimes unrealistic. A game theoretic approach alleviates this burden by using coordination mechanisms between the parties to drive the supply chain towards a system-wide optimal performance (Albrecht, 2010; Cachon, 2003). Four different computational approaches (decentralized planning, integration, coordination, and bilevel optimization) to the same lot-sizing problem in a two-player supply chain are compared in Kovács et al. (2013).

2.2. Game theory

Most papers in supply chain research assume *complete information*, i.e., that the game structure is common knowledge for the players (Wu and Parlar, 2011). In realistic situations however, there is an information gap between them—typically concerning either the cost structure or the demand forecast—which justifies the application of *incomplete information* (also called asymmetric information) models. Such approaches usually necessitate Bayesian setting, where the players have some common belief about the private information of the others. The inverse lot-sizing model presented in this paper provides a similar sort of information to the underinformed player by characterizing the feasible cost parameters. The key difference between the two approaches is that we determine only the *range* of the feasible values, in contrast to the *probability distribution* computed by the Bayesian models. For further details on game theoretic models and their applications in inventory management problems, we refer to Wu and Parlar (2011).

In two-player games with incomplete information, the process of learning the private information of the other player is called *screening*. Such models are widespread in the supply chain management literature, for a recent overview see Voigt (2011). For instance, Corbett (2001) considers the case where either the setup cost or the backorder cost of the supplier is a private information. Xu et al. (2010) present a model where the supplier's cost—which is inversely proportional to the required delivery time—is only known by the supplier, which is an obstacle for the buyer in optimizing its purchasing. Wang et al. (2009) investigate situations where it is beneficial for the supplier to share its production cost information with the buyer truthfully. The two-player setting is more exhaustively investigated in Esmaeili and Zeephongsekul (2010), which also assumes that the price- and marketing-dependent demand rate is a private information of the buyer. We have studied an extended newsvendor type model in Egri and Váncza (2012), where the buyer has private information about the uncertain demand forecast, while the supplier knows the various cost factors. The suggested coordination protocol and payment scheme provide both partners the right incentive for minimizing the total cost: the buyer is interested in sharing its unbiased information on the demand forecast and its uncertainty, while the supplier's rational decision concurs with the overall optimum.

A different approach to mitigating the effects of information asymmetry and ensuring a win–win situation for the players is called *collaborative planning*. In this case the goal is not eliciting the missing information, but the cooperative iterative improvement of the supply chain plan by non-hierarchical players. For uncapacitated dynamic lot-sizing in assembly networks (Chu and Leon, 2009) present an iterative planning procedure. For the finite capacity case (Dudek and Stadtler, 2005) developed a solution. A general overview of the collaborative planning problem can be found in Stadtler (2009).

2.3. Inverse combinatorial optimization

Inverse combinatorial optimization is a relatively new field of operations research. A comprehensive survey of this topic, including the studied problem models and algorithms has been given in Heuberger (2004). Most of the previous work in the field focused on graph theoretical problems, such as the inverse shortest path problem (Burton and Toint, 1992) or the inverse center location problem (Cai et al., 1999). A generic optimization model for a class of inverse problems has been introduced in Zhang and Liu (2002), together with a Newton-type algorithm that runs in strongly polynomial time under mild conditions. In Ahuja and Orlin (2001), it is shown that the inverse of a linear programming problem (LP) under the L_1 or the L_∞ norm is also an LP, and polynomial-time algorithms are derived for the inverse problems of various classes of polynomially solvable combinatorial problems. On the other hand, extensions of these narrow-sense

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