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A model for heuristic coordination of real life distribution inventory systems with lumpy demand

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ABSTRACT

This paper presents an approximation model for optimizing reorder points in one-warehouse N-retailer inventory systems subject to highly variable lumpy demand. The motivation for this work stems from close cooperation with a supply chain management software company, Syncron International, and one of their customers, a global spare parts provider. The model heuristically coordinates the inventory system using a near optimal induced backorder cost at the central warehouse. This induced backorder cost captures the impact that a reorder point decision at the warehouse has on the retailers' costs, and decomposes the multi-echelon problem into solving $N + 1$ single-echelon problems. The decomposition framework renders a flexible model that is computationally and conceptually simple enough to be implemented in practice.

A numerical study, including real data from the case company, shows that the new model performs very well in comparison to existing methods in the literature, and offers significant improvements to the case company. With regards to the latter, the new model in general obtains realized service levels much closer to target while reducing total inventory.

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1. Introduction

Inventory control of one-warehouse N-retailer systems is an issue that has attracted significant research interest for quite some time. The multi-echelon inventory literature contains a large number of models and approaches for analyzing different aspects of this problem, see for example Axsäter (2003a) for an overview. Still there are few reported applications of these theories to real systems. One reason for this may be that most of the models in the literature are difficult to directly apply because of restrictive model assumptions and/or conceptual and computational complexities. The research reported in this paper is an attempt to remedy this by presenting a simple and flexible approximation model for optimizing reorder points in systems subject to highly variable lumpy customer demand.

The work is motivated by close collaboration with a supply chain management software company, Syncron International, and one of their customers, a global spare parts provider. Important requirements posed on the model are that it should: (i) handle reorder point policies with batch ordering, backordering, and partial order deliveries, (ii) jointly optimize and coordinate the reorder points in the system to meet target service levels for the end customers while minimizing the inventory costs, (iii) be applicable to realistic demand distributions, particularly where customer orders vary considerably in size, (iv) be able to deal with transaction data, i.e., continuous review information, (v) be computationally feasible for large systems in practice, and (vi) be conceptually simple enough to be understood by the end users.

Based on these requirements our model is characterized by continuous review installation stock (R, nQ)-policies at all locations, First-Come–First-Served allocation, complete backordering, and compound Poisson demand with general compounding distributions. Applying the (R, nQ)-policy, means that an order of nQ units is generated as soon as the inventory position (=stock on hand + outstanding orders–backorders) reaches or drops below the reorder point R, where n is the smallest integer such that the inventory position just after ordering is above R.

The approximation model we present heuristically coordinates the reorder point decisions by decomposing the multi-echelon system into solving $N + 1$ single-echelon models. The decomposition is achieved by introducing a near optimal induced backorder cost at central warehouse that captures the impact that its reorder point decision has on the retailers. The induced backorder cost is obtained from applying the results in Berling and Marklund (2006). The decomposition framework makes it possible to obtain a very flexible model that is able to meet the requirements listed above. It also allows for optimization of reorder points either with the objective to minimize expected inventory holding costs while meeting specified target fillrates, or the objective to minimize total expected holding and backorder costs for specified backorder cost rates.

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A numerical study, including real data from our case company, shows that the new model performs very well. It renders total cost solutions that are on average within 1% of the exact method in Axsäter (2000). It is superior to the approximation method in Berling and Marklund (2012) in meeting target fillrates (and thereby also to the other approximation methods from the literature that they investigated), and it offers significant improvements to the case company. In our simulation study based on real data, the fillrate on average increases from 12% *below* target with the current method, to 0.6% *above* target with our approximation model, while at the same time reducing the average holding costs by 11.8%.

Looking at the literature, there is a close relationship between our work and that of Andersson et al. (1998), Andersson and Marklund (2000), and Berling and Marklund (2006), all dealing with approximation models for minimization of expected holding and backorder costs in the type of system we consider. Assuming identical retailers and normally distributed demand, Andersson et al. (1998) first introduced the idea of decomposing the complex multi-echelon system into $N + 1$ single echelon systems by use of an induced backorder cost, β, at the central warehouse. Their approach is based on replacing the stochastic retailer lead-times with their correct averages, and applying an iterative procedure (repeatedly solving the $N + 1$single-echelon problems, and updating the reorder points, β, and the retailer lead-times) to find an optimal solution to the resulting approximation model. The obtained solution is proven to represent a lower bound to the cost minimizing solution. Andersson and Marklund (2000) generalize the method to non-identical retailers, under the assumptions of complete deliveries and normal demand. Later, Berling and Marklund (2006) investigate how the induced penalty cost depend on the system parameters and provide closed form estimates for near optimal induced backorder costs as functions of the system parameters. A numerical study illustrates that the estimated induced penalty costs are near optimal not only for the normal demand models from which they are derived, but also in the exact compound Poisson model presented in Axsäter (2000). The study also shows that the new method for estimating the induced backorder costs outperforms the alternative method proposed in Axsäter (2005), which is based on disregarding the warehouse stockout delay. These results have been an important source of inspiration for the present research. Important features that distinguish our present model from the previous is that it deals with compound Poisson demand, partial deliveries, and optimization of reorder points to meet target service levels. Last but not least, it represents a complete approximation model that is computationally feasible to implement in practice.

A closely related paper is Berling and Marklund (2012), which analyzes a similar approximation model. The main difference is that customer demand in their model is assumed to be normally distributed. An important model feature is compensation for the fact that arriving customers actually demands an integer number of units, which implies a possible undershoot of the retailers' reorder points before ordering (i.e., the inventory position may drop below the reorder point). Under the regular normal demand assumption this undershoot is disregarded, which turns out to be a major problem in the quest for reorder points that achieve target fillrates. The presented Normal demand model with undershoot compensation is computationally simple and a numerical study shows that it performs quite well. However, the same study also show that there is room for improvement for products with intermittent and highly variable (i.e., lumpy) demand. Our present model is designed to better deal with these cases, and improve the accuracy in achieving the target fillrates. This is also shown to be the case in the numerical study. We will refer to the best model alternative in Berling and Marklund (2012), in terms of fillrate attainment at low inventory holding costs, as BMN.

Our work is also related to the literature on exact analysis of continuous review one-warehouse multiple-retailer systems. Forsberg (1997) and Axsäter (1993, 1998) provide exact analysis of the same system we consider with installation-stock (R, Q) policies at all inventory locations, but for the more restrictive case of Poisson demand. Chen and Zheng (1997) also considers Poisson demand but for systems where all stock points use echelon-stock (R, Q) policies. Axsäter (1997) considers the same type of system and provides exact analysis valid also for compound Poisson demand. Axsäter (2000) is closely related to our present work as it presents a method for exact cost evaluation of precisely the same system that we study with installation-stock (R, Q) policies, and compound Poisson demand. The method is recursive and quite fast for small problems (i.e., low demand and few retailers) but it becomes computationally intractable for larger systems. It is also conceptually challenging to grasp. It is therefore not feasible to directly implement in practice, except for very small systems. The numerical study shows that our approximation model renders near optimal reorder points, which on average renders total expected costs within 1% of the minimum cost of the exact solution. Computationally and conceptually our approximation model is much simpler.

More remotely related to our work, but belonging to the same research stream of exact analysis of one-warehouse multiple retailer systems, are a number of papers focusing on more complicated warehouse ordering policies. Marklund (2002) analyzes a system with non-identical retailers, Poisson demand, (R, Q)-policies at the retailers and a service-level policy at the central warehouse. For the more restrictive case of identical retailers, Moinzadeh (2002) investigates a generalized installation-stock (R, Q) policy at the warehouse. Recently, Axsäter and Marklund (2008) derive a warehouse policy that is optimal in the class of "position based" policies, and relax the FCFS assumption used in all the exact methods mentioned above. The class of "position based" policies encompasses all the policies previously analyzed exactly.

There is of course a relationship between our work and other approximation models for continuous review one-warehouse multiple-retailer systems, particularly with non-identical retailers and batch ordering. In addition to Andersson and Marklund (2000), and Berling and Marklund (2012) mentioned above, there is a clear connection to Axsäter (2003b). The model presented in this paper deals with the same system as we do, but under the assumption of normally distributed demand. The numerical study in Berling and Marklund (2012) shows that their proposed model (BMN) is better at achieving target fillrates than the one in Axsäter (2003b). We therefore benchmark against BMN in our numerical study. In a recent paper, Gallego et al. (2007) analyze bounds, heuristics and approximations of one-warehouse continuous review multiple-retailer systems under the assumptions of Poisson demand and base-stock policies at all locations. Earlier papers that deserve mentioning, even though they are based on more restrictive assumptions, include Deuermeyer and Schwarz (1981), Moinzadeh and Lee (1986), Lee and Moinzadeh (1987a,b), and Svoronos and Zipkin (1988). The first and last of these papers also use decomposition, albeit technically quite different from ours. Schneider et al. (1995) also use a decomposition idea, which in spirit is similar to ours, for analyzing a periodic review system with continuous demand, and (s, S) policies at all installations. Examples of other more remotely related literature on periodic review models include: Federgruen and Zipkin (1984a,b,c), Jackson and Muckstadt (1989), van der Heijden et al. (1997), Cachon (1999), Cachon and Fisher (2000), Axsäter et al. (2002), Dogru (2006), Marklund and Rosling (2012), and references therein.

The remainder of this paper is organized as follows. Section 2 provides a thorough model formulation and presents the details of our approximation model. Section 3 contains the numerical study and analyzes the model performance, and Section 4 concludes.

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