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Int. J. Production Economics ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Int. J. Production Economics

journal homepage: www.elsevier.com/locate/ijpe

Impact of nested inventory allocation policies in a newsvendor setting

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ARTICLE INFO

Article history:
Received 25 September 2014
Received in revised form
16 March 2016
Accepted 15 April 2016

Keywords:
Service differentiated supply chains
Smart meters inventory management
Inventory allocation policies
Inventory rationing
Nested allocation mechanisms

ABSTRACT

We model an inventory management setting in which the decision maker first uses newsvendor model to decide on the amount of ordered perishable inventory for a fixed consumption period, based on the best available forecast of demand at the time of ordering. After a relatively long lead time, the consumption period starts and she has to assign the received inventory to two priority customer classes given the -newly updated- rate of arrival of each class. The assignment of inventory requires two simultaneous decisions: 1) the reservation quantity for the high priority class and 2) the choice of inventory allocation mechanism (Standard Nesting SN or Theft Nesting TN); to minimize the expected units short of the high priority class while minimizing the wasted inventory at the end of the fixed consumption period. We assume that some partial information about the bottom line impact of a shortage in high priority customer class compared to the other can be conjectured. For both inventory allocation mechanisms, we then calculate the monetary benefit for all feasible reserved quantities to identify the optimal reserved quantity. We derive closed form expressions for the expected number of units short in each demand class under SN and TN allocation mechanisms. We showcase the management of electricity smart meter inventory in a multi-year implementation project consisting of multiple fixed consumption periods. Numerical experiments and graphical interpretations feature the optimum allocation policy and the cost minimizing reserved quantity under such policy.

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1. Introduction

Asset managers in infrastructure companies face an increasing number of highly perishable assets due to rapid technological developments. Inventory management of such assets (e.g. smart electricity meters) in large scale implementation projects is a daunting task. In some cost benefit assessment of major European smart meter rollout projects (BER, 2007; Renner et al., 2011; Wing et al., 2009; Schrijner et al., 2008), purchasing cost of smart meter hardware and peripheral equipment such as communication and filtering can consume as much as half the project budget in these multi-billion Euro investments. Due to involvement of many municipalities, procurement of smart meter devices often follows strictly regulated tender procedures stipulating fixed delivery dates and number of units. In addition to supply inflexibility, holding cost of perishable smart meters is high due to rapid technological advancements and fast obsolescence. What complicates the problem even more is that not all consumers have the same consumption pattern and the Distribution System Operators (DSO) should consider priorities in the consumption planning as they face two competing objectives: First, the DSO is interested in priority consumption of the smart meters for high consuming customers with high variability in demand, as this demand class poses the highest risk of grid disruption and should be monitored (and consequently controlled) with highest priority. Due to the real-time two-way communication between the smart meter and the grid command center, the DSO might decide to limit (or in extreme cases, block) the consumption of such disruptive consumers for the sake of the overall grid functionality. Second, the lower priority (low consuming or high consuming but with low variability demand) customers are also interested in prompt consumption of smart meters in their premises due to potential cost savings opportunities resulted from their own corrective actions. By being better informed and in real-time, these consumers can smoothen their consumption patterns during peak periods (e.g. shift their high electricity consuming tasks such as ironing or drying to non-peak hours) to enjoy the rebate offered by the electricity suppliers (Faruqui et al., 2009). Smart meter rollout projects can take as long as a decade to complete, hence projects are broken into smaller phases (called campaigns). Due to fast changing technology of smart meters (Mark et al., 2010), the DSOs usually carry limited inventory of current technology smart meters enough for the upcoming campaign. In a study of a major

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http://dx.doi.org/10.1016/j.ijpe.2016.04.009
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Please cite this article as: Samii, A.-B., Impact of nested inventory allocation policies in a newsvendor setting. International Journal of Production Economics (2016), http://dx.doi.org/10.1016/j.ijpe.2016.04.009

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European DSO, we found out that the DSO carries enough inventory of smart meters hardware to complete a six-month campaign until the replenished newer technology meters arrive. The municipalities lined up for the future campaigns will not accept an older technology smart meter and some consumers from both priority classes opt out of smart meter consumptions due to privacy concerns. Therefore, the policy of allocating the available inventory of meters to candidate high/low priority customers should maximize demand fulfillment for both customer classes with minimum wasted (not installed and obsolete) inventory at the end of any given campaign. Since the number of consumptions as well as opt-out rates vary among municipalities, the inventory allocation policies are static on chosen policy and reserved quantity for a campaign, but dynamic between campaigns. In general, this paper studies and compares policies for inventory allocation to service differentiated customers in the absence of reliable estimates of the long term cost of stock-out. Although measuring the long term cost of unfilled demand for any demand class in the context of smart meter consumptions is extremely difficult, it may be practical to quantify the importance of one customer class to another. We assume that the decision maker is able to provide, with acceptable accuracy, an estimate of the relative impact of not fulfilling demand of higher priority class to lower class. In a similar example, Mollering and Thonemann (2008) report an interesting case in which some service parts are used in both antennas and network computers of a telecommunication network. If a part fails in an antenna, the antenna goes down. If the same part fails in the network computer, the impact is thirty fold more severe; the network computer goes down and about thirty antennas become unavailable. Analogously, we assume that some partial information regarding the bottom line impact of a smart meter shortage in one customer class compared to the other can be conjectured. Using mathematical modeling and assuming random arrival of low/high customer classes, we first identify the probability of events leading to partial fulfillment of high and low priority demand classes (i.e. stockout probabilities). We then develop closed form expressions for the expected units short of both demand classes under Standard Nesting (SN) and Theft Nesting (TN) as a function of the reserved quantity. Ultimately, the monetary benefit of reserving inventory can then be calculated for all feasible reserved quantities and the optimal reserved quantity can be identified. This study provides important insights into how decision makers can efficiently manage a product's supply chain with heterogeneous service requirements. The closed form solutions of the expected units short of the two demand classes allow us to formulate an underage cost minimization problem. Although the structure of the minimization problem is relatively simple, the complexity of the expressions for the expected units short complicates the provision of an optimal solution. Instead, we formulate the benefit of reserving an additional unit of inventory and the optimal reserved quantity will be the largest feasible reserved quantity with a positive benefit. Based on this rationale, we determine an optimality condition for the quantity reserved based on known system parameters (inventory availability and demand rates) and estimated relative financial impact of not fulfilling demand of the high compared to the low priority classes. We conclude the paper with numerical examples, which provide additional analytical insights into the choice of the optimal quantity reserved. The results obtained in this paper contribute to the existing literature in multiple ways. First, we develop a new intuitive approach for modeling this inventory reservation problem based on the relative impact of not fulfilling demand of higher priority class to lower class. Second, we provide additional formulations of expected units short of both demand classes under SN and TN that can be computed efficiently. We believe that this is an initial promising finding that should be considered in future research and potentially enables the development of efficient techniques for optimally solving this problem rather than using heuristics. Our analysis shows that, depending on the availability of smart meters inventory and the demand rates of the different customer classes, it is important for the decision maker to choose the right allocation mechanism. Although we limit our analysis to an inventory rationing problem in a single consumption period and two demand classes, we expect that our approach and our results can be utilized in a wide range of supply chain settings with multiple demand classes and differentiated service levels. The remainder of this paper is organized as following: in Section 2 we review the related literature in inventory rationing, newsvendor problem, and smart meter rollout project planning to highlight our relevant contribution. In Section 3 we provide a formal characterization of the model used in smart meter inventory allocation under SN and TN mechanisms; and consequently develop exact expressions for the high and low priority classes expected units short. The results of the numerical experiments are graphically presented in Section 4. In Section 5 we summarize our findings and point toward the future research that can be conducted based on the results of this research.

2. Literature review

In the literature on inventory theory, Deshpande et al. (2003) present a model for inventory rationing under multiple demand classes which includes setup costs, lead times, and customer backorders in a continuous time framework. They derive closed-form expressions for performance measures, such as average backorders and fill rate, for a given (Q, r, K) type threshold rationing policy and also present an algorithm for computing the optimal policy parameters. They formulate a cost minimization problem to choose policy parameters to minimize the sum of setup costs, holding costs, and customer shortage costs. Melchiors et al. (2000) also assume a (s, Q) inventory model with two demand classes. They consider a lost sales environment where low priority class demand is rejected when inventory level drops below the critical level. This assumption allows them to derive an exact expression for the expected cost, unlike the approximate results of Nahmias and Demmy (1981). Melchiors (2003) extends this work and allows a non-stationary critical level policy where critical levels depend on the elapsed time since the outstanding order is triggered. Fadiloglu and Bulut (2010a) propose a method which captures the priority clearing dynamics for continuous review inventory systems with backordering under static rationing policy. They assume two demand classes with Poisson arrivals and constant lead time; sample the continuous system at multipliers of the lead time and show that the state of the system evolves according to an embedded Markov chain. Arslan et al. (2007) develop a model for cost evaluation and optimization under the assumptions of Poisson demand, deterministic replenishment lead time and a continuous review (Q,R) policy with rationing. They analyze the service level problem, the cost minimization problem, and the service time problem. The service level problem aims to achieve a pre-specified service level for each demand class by incurring the minimum long run average inventory holding costs. In Teunter and Haneveld (2008), critical and non-critical Poisson distributed demand classes with backordering has been studied. They derive a set of formulae to determine the optimal rationing level for any possible value of the remaining time and confirm that the optimal dynamic rationing strategy outperforms all static strategies with fixed rationing levels. Fadiloglu and Bulut (2010b) propose a dynamic rationing policy for continuous review inventory systems which utilizes the information on the status of the outstanding replenishment orders. For both backordering and

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