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An inventory system with single distributor and multiple retailers: Operating scenarios and performance comparison

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ABSTRACT

We consider a single-distributor multi-retailer inventory system in six operating scenarios for a finite horizon. Five scenarios are in decentralized control and the other one is in centralized control. Approximate dynamic programming (ADP) procedures are developed to obtain system performances for scenarios in decentralized control, and a stochastic dynamic programming approach is applied to the scenario in centralized control. The efficiency and effectiveness of ADP procedures are demonstrated by numerical results. Taking the system performance in centralized control as a benchmark, system performances in decentralized control are investigated and compared for different operating scenarios. The results provide useful insights in system planning and operations.

1. Introduction

With advance of information technology, various levels of information sharing emerge in supply chains. The cooperation between Wal-Mart and Procter & Gamble is a successful case (Mason-Jones and Towill, 1997). More and more world class enterprises, e.g., Dell and Cisco, share information with their suppliers to enhance supply chain competitive edge (Zhou and Benton, 2007). Further studies upon impact of supply chain integration in practice can be found in Doyle and Snyder (1999), Vickery et al. (2003), Narasimhan and Jayaram (2007) and Zhou and Benton (2007).

Researchers have paid much attention to the value of information sharing. Lee et al. (2000) discuss a single-distributor single-retailer system in decentralized control, in which the demand process is correlated over time and the distributor accesses retailer's information to refine the forecast of demand. Cachon and Fisher (2000), Cachon (2001), Zhao and Xie (2002), Abdul-Jalbar et al. (2009), and Lee and Jeong (2010) address a decentralized control scenario for system consisting of single supplier and multiple retailers. On the other hand, operating scenarios where participators in a supply chain coordinate and collaborate through contracts are extensively investigated (Chen et al., 2001; Cachon, 2003; Wang et al., 2004; Bernstein and Federgruen, 2005). Investigation through game approaches can be referred to Esmaeili and Zeephongsekul (2010).

There exist various ways of information sharing in supply chains. We categorize all information sharing instances in single-distributor multi-retailer systems into the following six different operating scenarios, in which the first five scenarios are in decentralized control.

All-independent (*AI*, *for short*). There is no information sharing among participators except the information transmission between the distributor and the retailers via ordering. All participators of the supply chain make their decisions based on local information independently. For such scenario, installation-stock policies are discussed by Svoronos and Zipkin (1988) and Axsäter (1998).

Distributor-access-retailers (*DAR*). The distributor is allowed to access full or partial information of retailers, e.g., inventory level and ordering policy, but not a retailer can access the distributor's information. A real case of scenario DAR is that Wal-Mart opens its information to main suppliers (e.g., Procter & Gamble) and the whole system benefits from the sharing (Mason-Jones and Towill, 1997). The impact of such unilateral information sharing is widely discussed in the literature in terms of demand estimation and forecasting (Lee et al., 2000; Armony and Plambeck, 2005; Byrne and Heavey, 2006), echelon-stock policies or position-based policies (Axsäter and Rosling, 1993; Axsäter et al., 2008) and other issues (Lau et al., 2004).

Retailers-access-distributor (*RAD*). In contrast to the situation in scenario DAR, every retailer is allowed to access the distributor's information whereas the distributor cannot access retailers'. Such scenario exists in many third-party logistic systems where the information of the common warehouse is announced to all retailers. This scenario can be observed in B2B e-commerce as

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well, where all retailers can access the distributor's information via its web site. In a rationing game environment, a retailer accesses distributor's information, estimates available stock at the distributor, and may over-order to hedge against potential shortage in supply. Such inflation can cause information distortion and may low performance of the supply chain. Lee et al. (1997) state that the inflation in a rationing game environment may result in the so-called bullwhip effect and can incur enormous cost increasing.

Two-way-access (*TWA*). The information sharing is bilateral in this scenario. The distributor is allowed to access retailers' information, and every retailer is also allowed to access the distributor's. This scenario is a combination of scenarios DAR and RAD. As in scenario RAD, retailers may also over-order in a rationing game environment. The distributor faces distorted information from retailers. Two-way information sharing is a significant mechanism for Cisco to enhance supply chain planning, JIT production, and delivery practices (Zhou and Benton, 2007).

All-access (*AA*). Information is shared systemwide, i.e., all participators of the supply chain can access any other's information. The previous scenarios DAR, RAD and TWA concern vertical information sharing in supply chain, and such scenario AA takes horizontal information sharing into consideration. The incentive of horizontal information sharing in supply chain has been well discussed in the literatures, e.g., Gal-Or (1985), Li (2002), and an empirical examination in motor vehicle industry is presented by Doyle and Snyder (1999). In such scenario, with fully shared information, whether the participators operate selfishly or not may result in different performances of the supply chain. In a cooperating environment, an idea on supply chain coordination is to allow everyone to make decisions based on the information from everyone else, and many enterprise and cross-enterprise systems have been developed under this idea (Davenport and Brooks, 2004).

Centralized-control (*CC*). A "super-manager" makes centralized decisions instead of decentralized ones. Such scenario has been well discussed (Chen and Zheng, 1997; Kim et al., 2005), and it can be applied when the distributor and all retailers belong to the same enterprise. It can also be adopted under special configurations, e.g., vendor-managed inventory (VMI) (Choi et al., 2004; Bernstein et al., 2006).

Performances comparison is an important issue for supply chain integration and information sharing. However, it is the lack of knowledge on impact of various operating scenarios on supply chain performance. Only a few works can be found in the literature, in which operating policies are pre-specified. Lau et al. (2004) study a three-stage supply chain, in which each participator adopts a (R, Q) policy to control its inventory and may share information with its immediate upstream partner. Disney et al. (2008) examine impact of different coordination strategies on system performance of a two-echelon supply chain, where each echelon implements a generalized order-up-to policy.

In this paper, a single-distributor multi-retailer system is considered for a finite horizon. For generality, we do not pre-specify policies for inventory management. System performances are compared in terms of system costs for different operating scenarios. We adopt approximate dynamic programming (ADP, see Powell, 2007) to obtain system costs in the first five scenarios in decentralized control, while a stochastic dynamic programming procedure is implemented for the scenario in centralized control. According to operations of many actual systems, we consider that both inventory levels and ordering histories can be accessed as shared information, and assume that the distributor and retailers make decisions simultaneously. Recently, Qiu et al. (2007) apply a reinforcement learning approach to investigate business service modes on distribution systems which are similar as the scenarios in our paper but with different operating mechanisms and for infinite horizon. Other related works include Qiu and Zhao (2006), Zhao and Qiu (2007), and Qiu et al. (2008).

Our motivations are: (1) propose models for all different scenarios; (2) develop an ADP approach to obtain system performances; (3) provide numerical experiments to compare system performances in different scenarios. Some results can provide managerial insights into actual logistics systems.

2. Model descriptions

The inventory system consists of a single distributor and M retailers. The retailers can be non-identical. An external resource supplies goods to the distributor through which all retailers are replenished. The system is observed periodically and is operated for a finite planning horizon. A discounted cost is incurred from period to period. All lead times are assumed to be zero, i.e., ordered goods are delivered and received immediately.

The sequence of the events is as follows:

(1) At the beginning of each period, the distributor reviews its inventory level and then decides whether or not to place an order to the external resource. The retailers, respectively, review their inventory levels and then decide whether or not to place orders to the distributor.

(2) The goods from the external resource arrive at the distributor and the distributor then allocates goods to the retailers.

(3) The goods from the distributor arrive at the retailers and the retailers with received goods satisfy customer demands during the period.

The inventory is at discrete form, i.e., at unit form. The distributor always satisfies orders from retailers as far as possible. If the distributor currently possesses enough goods, it allocates them to the retailers according to their orders. Otherwise, it allocates the goods in accordance with a specified rule. There are several allocation rules, among which most commonly used rules may be proportional allocation and batch-size allocation. (Detailed descriptions for these two allocation rules will be presented later.) Unsatisfied demands at retailers, as well as unsatisfied orders at the distributor, are all lost.

Let entity $m = 0$ stand for the distributor, and entities $m=1,2,\ldots,M$ denote retailers, respectively. The following notation is used.

- t: period t in the planning horizon, $t=1,2,\ldots,T$;
- α: discounted factor, $0<\alpha\leq 1$;
- U_m: capacity of entity m ($=0,1,\ldots,M$);
- K_m: setup cost at entity m ($=0,1,\ldots,M$);
- c_m: unit purchasing price at entity m ($=0,1,\ldots,M$);
- h_m: unit holding cost for leftover goods at entity m ($=0,1,\ldots,M$);
- p_m: unit penalty cost for shortage at entity m ($=0,1,\ldots,M$);
- D_m: demand at entity m ($=0,1,\ldots,M$), during one period;
- $f_m(\xi)$: probability of $D_m=\xi$ at retailer m ($=1,2,\ldots,M$).

Use a row vector $\mathbf{U}=(U_0,U_1,\ldots,U_M)$ to simplify the presentation, and as well as $\mathbf{K}$, $\mathbf{c}$, $\mathbf{h}$, $\mathbf{p}$ and $\mathbf{D}$.

At the beginning of period t, inventory level at the distributor is x_0^t. On observing it, the distributor decides to bring its inventory level to y_0^t with $y_0^t \leq U_0$. Meanwhile, retailer m observes its inventory level x_m^t and decides to bring the inventory level to y_m^t with $y_m^t \leq U_m$. Note that the distributor has a limited capacity, hence, perhaps only part of retailers can be fully satisfied. Let z_m^t denote the actual inventory level at retailer m after receiving goods. Obviously, $z_m^t \leq y_m^t$.