Indian Institute of Management Calcutta

Working Paper Series

WPS No. 756
October 2014

Generalized joint replenishment model for multi-retailer scenario under VMI

Nishant Kumar Verma
Doctoral Student, Indian Institute of Management Calcutta
D. H. Road, Joka, P.O. Kolkata 700 104

Ashis K Chatterjee
Professor, Indian Institute of Management Calcutta
D. H. Road, Joka, P.O. Kolkata 700 104
http://facultylive.iimcal.ac.in/workingpapers

Generalized joint replenishment model for multi-retailer scenario under VMI

by

Nishant Kumar Verma[a] and Ashis K. Chatterjee[b]

[a] Doctoral Student, Indian Institute of Management Calcutta, Kolkata 700104, India

Email: nishantkv11@email.iimcal.ac.in

[b] Professor, Indian Institute of Management Calcutta, Kolkata 700104, India

Email: ac@iimcal.ac.in

Generalized joint replenishment model for multi-retailer scenario under VMI

Abstract

Vendor managed inventory is a well established supply chain coordination practice wherein the supplier is responsible for managing the inventory at the retail points. In particular, the

supply chain helps in reducing excessive inventory, tackling demand uncertainty, flexibly (Horvath, 2001; Lee, Padmanabhan & Whang, 1997). Vendor managed inventory is such a coordination mechanism, popularized by Wal-Mart and P&G in 1980's (Waller, Johnson, & Davis, 1999). Since then, it has proved to be one of the successful supply chain integration and coordination mechanism (Danese, 2006; Pohlen & Goldspy, 2003).

VMI over the time has evolved in different forms. In one of the forms the ownership of the items remain with the supplier until those are sold. This is referred to as VMI on consignment (Valentini & Zavanella, 2003; Wang, Jiang & Shen, 2004). In some other cases, supplier receives the money as soon as items are transferred to the customers(retailers). This is known as VMI (Fry, Kapuscinski & Olsen, 2001; Lee & Chu, 2005). Irrespective of the kind of form adopted by various companies, VMI in general has proved beneficial in terms of reduced inventory cost, improved customer service level, greater transparency and fill rate (Angulo, Nachtmann & Waller, 2004; Cetinkaya & Lee, 2000; Waller et al., 1999). Losses due to demand fluctuations also get reduced in the VMI environment as supplier is directly monitoring the inventory at the retailer's space thus giving it more comfort for replenishing it (Yao, Evers & Dresner, 2007). Moreover, the availability of the information helps to reduce the Bullwhip effect (Reiner & Trcka, 2004). From the retailer's perspective the benefits come from the reduced administrative cost as they are no more responsible for placing the order themselves (Aichlmayr, 2000).

With any coordination mechanism for a SC, many issues such as contract design, information sharing, competition dynamics etc. emerges simultaneously. Vendor managed inventory being a coordination mechanism, also incorporates such issues. Mathematical modelling of such issues to understand them deeply has been conducted in the VMI literature quite well over the course of time. The modelling literature of VMI, includes studies like evaluation of the time-benefit the supplier has under VMI (Kaipia, Holmström & Tanskanen, 2002), shipment coordination mechanisms (Cheung & Lee, 2002), inventory cost sharing under VMI (Nagrajan & Rajagopalan, 2008), shipment consolidation by the supplier (Cetinkaya, Tekin & Lee, 2008) etc.

Apart from the issues stated above, another area that has received researchers attention is of

Other studies under such a setting are taken up by Van der Vlist, Kuik and Verheijen (2007), Wang, Wee and Tsao (2010), Huang and Ye (2010) etc. Single supplier – multiple retailer setting have also received its share of attention in the VMI literature. Viswanathan and Piplani (2001) proposes a replenishment policy under which the supplier sets up at fixed intervals/epochs and retailers get replenished at those intervals/epochs only. Zhanga, Liang, Yu and Yu (2007) develops a model by considering supplier's production cycle as constant and retailers having different replenishment cycles. Zavanella and Zanoni (2009) studies such a VMI setting under consignment.

Some studies in the literature situate themselves in a single supplier – multiple retailer setting with additional contractual constraints such as storage limits. Darwish & Odah (2010) devises a replenishment policy wherein the retailers have equal replenishment intervals(ERI). Hariga, Gumus, Daghfous and Goyal (2013) and Verma, Chakraborty and Chatterjee (2013) generalizes their model by relaxing the assumption of ERI by allowing retailers to have unequal replenishment intervals(URI). The inherent assumption in the above papers is that the retailers are homogeneous with respect to their cycle ratios. This paper too, situates itself in a single supplier – multiple retailer VMI environment with contractual storage agreements and develops a generalized replenishment policy by taking into account the heterogeneity of the retailers. The meaning of homogeneity/heterogeneity of the retailers is dealt in detail in section 3.

2. Notations

Let i be the index for retailers, i =1,2….n, where n denotes the total number of retailers. For i^{th} retailer following notations are used :-

a_i Order cost for i^{th} retailer ($).

h_i Inventory carrying cost of i^{th} retailer ($/unit/unit time).

D_i Annual demand for the i^{th} retailer (Assumed to be deterministic in nature).

U_i Upper limit set by the retailer.

P_i Penalty imposed by i^{th} retailer for exceeding the upper limit U_i ($/unit).

X_i Quantity by which the upper limit is exceeded for i^{th} retailer.

Y_i

Let the retailers be divided into two sets viz. S_a and $S_{b.}$ S_a is defined as the set of all the retailers with their respective optimal replenishment cycle T_i being greater than or equal to the optimal setup cycle of the supplier (T). S_b, on the other hand is defined as the set of all the retailers with their respective optimal replenishment cycle T_i being less than the optimal setup cycle of the supplier (T).

S_a – Set of retailers with $T_i \geq T$

S_b – Set of retailers with $T_i < T$

Thus, in the context of single supplier – multiple retailer scenario, three cases arise as stated below :-

Case 1 : When all the retailers belong to the set S_b (Figure 1).

Case 2 : When all the retailers belong to the set S_a (Figure 2).

Case 3 : When some retailers belong to the set S_b and some to the set S_a (Figure 3).

The diagrammatic representation for each of these cases are shown below :-

Figure 1. Diagrammatic representation of case 1, where both the retailers have T_i less than T viz. T/2 and T/3.

Figure 2. Diagrammatic representation of case 2, where both the retailers have T_i greater than or equal to T viz. T and $2T$.

cycle ratio). In terms of the cases depicted above, case 1 and case 2 are a representation of homogenous retailers and case 3 is a representation of heterogeneous retailers.

In this regard replenishment policy suggested by Hariga et al.(2013) is a representation of case 1 (depicted in figure 1) and that by Verma et al.(2013) is a representation of case 2 (depicted in figure 2). Replenishment policy by Hariga et al.(2013) does not cover case 2 and vice versa for the policy developed by Verma et al.(2013). Moreover, neither of these policies cover case 3.

The generalised policy developed in this paper covers all the three cases and therefore can be seen as a generalization of URI replenishment policies under VMI context. Thus the models suggested by Hariga et al.(2013) and Verma et al.(2013) will lead to suboptimal results in the presence of heterogeneous retailers. This is summarised in the table given below :-

ERI/URI	Policy	Case1	Case2	Case3
ERI	Darwish and Odah(2010)	Sub-Optimal	Sub-Optimal	Sub-Optimal
URI	Hariga et al.(2013)	Optimal	Sub-Optimal	Sub-Optimal
URI	Verma et al.(2013)	Sub-Optimal	Optimal	Sub-Optimal
URI	Generalized model	Optimal	Optimal	Optimal

Table 1: Conceptual comparison of various replenishment policies

4. Problem statement and model development

Consider a two echelon supply chain where supplier replenishes a common item to a number of retailers under a coordinating VMI contract. Under such a VMI contract the retailers provide their respective demand information to the supplier. The supplier after receiving the demand information sets-up every T period and replenishes i^{th} retailer every T_i period. Under such a VMI environment it is optimal for the supplier to push as much inventory as possible so as to save holding and transportation cost. To avoid such behaviour by supplier, the VMI contract imposes a condition wherein supplier incurs a per unit penalty cost P_i whenever the replenishment quantity exceeds the agreed upon upper limit U_i (Fry et al., 2001; Shah & Goh, 2006).

Demands for the retailers are assumed to be deterministic in nature. Orders are replenished immediately to the retailers by the supplier i.e. zero lead time has been assumed. Also, the supplier in such a setting is assumed to have infinite capacity.

The model developed under such a VMI scenario seeks to minimize the total cost associated with this kind of two echelon supply chain. The total cost incurred by the supply chain is composed of retailer's cost and supplier's cost. Retailer's cost include ordering and inventory holding cost, whereas the supplier's cost include setup, inventory holding and penalty cost. The mathematical expressions for all the above stated components of total cost are mentioned below.

Cost components for i^{th} retailer :-

a_i / T_i	Ordering cost per unit time.
$.5 * D_i * T_i * h_i$	Inventory holding cost per unit time.

The total retailer cost TC_R is then the summation of above two components for all the retailers,

$$TC_R = \sum_i a_i / T_i + .5 * \sum_i D_i * T_i * h_i$$

Cost components for Supplier :-

A / T	Setup cost per unit time.
$.5 * h_s * \sum_i \left((m_i - 1) * D_i * T_i * b_i \right)$	Inventory holding cost per unit time.
$.5 * \sum_i \left(P_i / (T_i * D_i) \right) * X_i^2$	Total penalty cost incurred

The penalty expression for a single retailer can be visualized in figure 4 as shown below :-

6. m • I i , I

The above model is solved using Global solver toolkit of optimization software Lingo 14.0. For the illustrative purpose we consider a VMI environment involving one supplier and six retailers with the input data as shown below:-

RETAILER DATA						
RETAILER	ANNUAL DEMAND	a_i	h_i	a_i/D_ih_i	Upper limit (U_i)	Penalty P_i (per extra unit)
R1	1000	60	10	.006	109.54	4
R2	700	60	5	.01714	129.61	3
R3	3000	70	14	.001667	173.2051	2

Hariga et al.(2013)	Total cost	R1	R2	R3	R4	R5	R6	Supplier

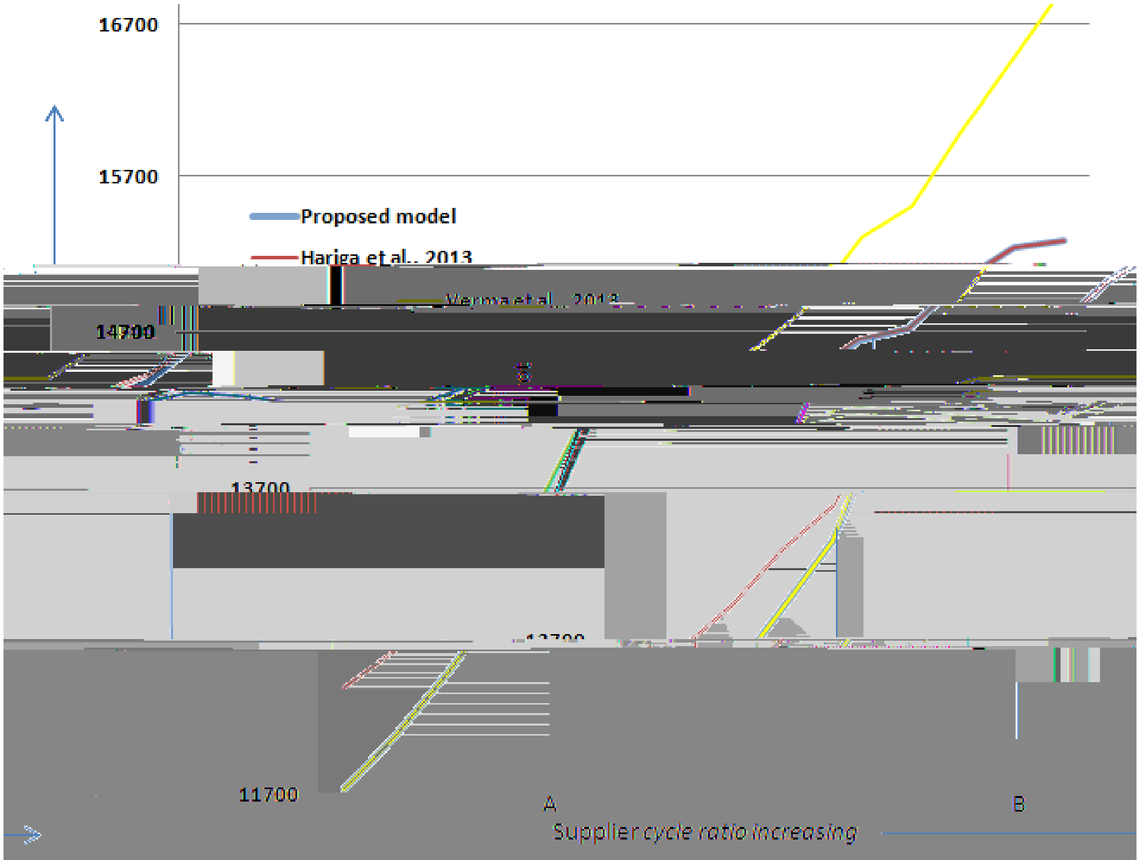

Figure 5. Total cost comparison of the three types of replenishment policies.

It has clearly come out in the graph that the proposed model has the lowest cost among the three models for all the instances. Also, below point A i.e. when the supplier's cycle ratio is too low as compared to the retailer's, model by Verma et al.(2013) performs better than the model by Hariga et al.(2013) and vice versa for the instances above point B. Moreover, the limitation of existing models in the scenarios of heterogeneous retailers has come out clearly in figure 5.

5. Conclusion

In this paper we have developed a generalized model under the contractual VMI setup for the replenishment of multiple retailers. In practice, in a multi retailer setting, retailers can be heterogeneous in nature with respect to their cycle ratio. Considering this we have tried to show, how the proposed model gives the optimum result vis a vis the existing models.

With the help of an example we have compared the existing models with the proposed model to show how the proposed model achieves the lowest total cost as compared to the other models. All the three models including the proposed model have been solved for a number of instances to clearly show how each of the models behaves under different scenarios.

The supplier in the VMI setup for multiple retailers is in advantageous position as it is the only entity with complete information. Thus, the future course of research could be to study the impact on individual retailer's cost when the supplier chooses to optimize its cost independently instead of minimizing the cost of total supply chain.

References :-

1. Aichlmayr, M. (2000). DC mart: who manages inventory in a value chain?Transportation & Distribution.

2. Angulo, A., Nachtmann, H., & Waller, M. A. (2004). Supply chain information

15.

28. Xu, L., & Beamon, B. M. (2006). Supply Chain Coordination and Cooperation Mechanisms: An Attribute-Based Approach. Journal of Supply Chain Management, 42(1), 4-12.

29. Yao, Y., Evers, P. T., & Dresner, M. E. (2007). Supply chain integration in vendor-managed inventor-7.4(u.l Supp) ree566J /T9s,60/s (De/-6a(4642 683.Tc S1 gs B 681 Tf .233c .08