INDIAN INSTITUTE OF MANAGEMENT KOZHIKODE

Working Paper

IIMK/WPS/186/QMOM/2015/22

August 2015

Analysis of Replenishment Policy Options in VMI Systems with Emission Related Cost

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Organizations are actively trying to incorporate sustainability considerations in their strategic and operational decision making. Recent studies suggest that business process redesign offers a promising avenue for meeting business goals. In this paper, we build on some recent studies that have shown that vendor managed inventory based supply chain coordination not only leads to cost savings, but also is a very useful tool in reducing greenhouse gas emissions. Both operational and emission related costs are incorporated in such models. We present different ways of structuring the replenishment policy and show that each of the policies leads to different performance outcomes. Furthermore, we also discuss how these policies can be used to cater to the strategic imperatives facing an organization. Implications for proper design of government legislation have also been discussed.

Keywords: *Coordination, VMI, consignment, emissions, environment.*

1. Introduction

Incessant industrialization has resulted in significant deterioration in the environment. Ecological considerations have now become an indispensable part of the decision making process of all entities, ranging from the government to the business organizations, and from the society (in form of NGOs etc.) to the individual (Chun and Bidanda, 2013). This paradigmatic shift has now necessitated incorporation of these perspectives in business strategy and operation. The recent impetus on triple bottom line reporting, with its focus on people, planet and profits can be attributed to this changed thinking.

Policy makers, for their part, have also been proactive in promulgating legislations and instituting other mechanisms which induce more environmentally sustainable business practices, and at the same time levy fines, taxes etc. in order to deter irresponsible firm behavior vis-à-vis the environment. There are primarily two kinds of policies that have been instituted to combat the threat of environmental degradation. The first is the 'cap and trade' system under which organizations have to adhere to an upper limit on greenhouse gas (GHG) emissions. Those who exceed their limit must buy additional permits from other organizations who might have underutilized their limit. Thus, the system imposes a cost on breaching the upper limit. The second type of policy intervention is a per unit carbon tax. Organizations thus have a monetary incentive to reduce their respective emissions. The latter system has been adopted in the US while the European Union – Emission Trading Scheme is an example of the former (Jaber et al., 2013).

Businesses too have been trying to entice customers by establishing their 'green' credentials. Pursuant to this, most of the effort in this regard has so far been focused on the development of new technologies and products or adoption of more energy-efficient processes (Tiwari et al., 2013). Researchers have also been studying the field of green supply chain management for quite some time now. Much of this literature is focused on 'closing the loop', i.e. handling product return and end of lifecycle issues. Sarkis et al. (2011) comprehensively review this stream of research.

However, some recent studies suggest that a realignment of business processes to improve coordination may offer a more effective and more sustainable way of reducing the environmental footprint and achieving cost efficiencies simultaneously (Daskin and Benjaafar, 2010). The issue of GHG emissions with respect to the lot sizing decision has received scant attention (Absi et al., 2013). Benjaafar et al. (2013) developed some simple models that illustrated how carbon emission considerations could be incorporated in operational decision making. Bonney and Jaber (2011) presented an EOQ model with environmental considerations which accounted for transportation cost and GHG emission related taxes. Several researchers then built on their work by incorporating a variety of assumptions (Hua et al., 2011; Wahab et al., 2011; Bouchery et al., 2012; Toptal et al., 2014). Ksekin and Plambeck (2011) analyzed the problem of allocating emissions across co-products from a process. Cachon (2014) studied the impact of retail store density on GHG emissions and found that an exclusive focus on minimizing the operating cost is often detrimental for the environment.

Jaber et al. (2013) investigated a two level SC with one vendor and one buyer with emission related costs. Extending their work, Zanoni et al. (2014) showed that vendor managed inventory system with consignment stock (VMI-CS) can be used to reduce the total system costs. VMI is a collaborative strategy between a buyer and a vendor to optimize the availability of products at minimal cost to the two companies (Hines at al., 2000). The responsibility of managing the replenishment decisions rests with the vendor who in turn gains access to actual end-level demand information, which is otherwise seldom available (Hariga et al., 2014). Benefits of VMI adoption that can be found in literature include a reduction in costs for the parties involved, reduction in inventory requirements, as well as a decrease in the bullwhip effect (Sari, 2008). Due to operational control, the vendor may be tempted to place extra inventory at the buyer's facility. In order to counter this kind of behavior on the part of the vendor, a slightly modified form of VMI called VMI with consignment stock has been proposed. Under this modified form, the vendor bears the financial component of the holding cost for the stock kept downstream (Ben-Daya et al., 2013) This increased investment acts as a deterrent against improper vendor behavior to the detriment of the buyer. Several aspects of VMI systems have been investigated by researchers. For detailed reviews, readers are referred to Marques et al. (2010) and Govindan (2013).

In our paper we build on studies such as Zanoni et al. (2014) that have tried to integrate operational and environmental issues inherent in a supply chain (SC). We present two alternate ways of structuring the replenishment policy for a VMI-CS system that lead to different cost and GHG emissions. We also show that the flexibility offered by these policies can be aligned to strategic goals of the company and the harmonization thus achieved can lead to significant value creation.

In the next section, we provide the problem statement. Mathematical models for the replenishment policies have been developed in section 3. Numerical analysis has been carried out in section 4. Managerial and policy implications have been discussed in section 5. In the last section, we provide some concluding remarks.

2. Problem statement

We consider a two-tier SC with a vendor who manufactures a product to meet the demand faced by a single buyer.

Assumptions:

(1) Demand rate is deterministic and is assumed to be constant over time.

(2) The production rate of the vendor is finite but is bound by upper and lower levels. Furthermore, it is assumed that the lower level of the production rate is more than the demand rate faced by the buyer. Thus, there are no backlogs in the system.

(3) Under a VMI-CS system, the vendor bears both the physical and financial components of the holding cost incurred for the stock kept at his own facility. In addition, he is also responsible for bearing the financial component of the holding cost incurred for the stock kept at the buyer's facility. Thus, the latter incurs only the physical component of the holding cost.

(4) There is no delivery lead time.

(5) The vendor and the buyer act cooperatively to maximize SC wide profits.

Notations:

D	Demand rate (units/year)
P	Production rate of the vendor (unit/year)
P_{min}	Minimum production rate (unit/year)
P_{max}	Maximum production rate (unit/year)
Q	Production batch size (units)
n	Number of delivery sub-batches in a production batch
A_v	Vendor's setup cost ($)
A_b	Buyer's ordering cost ($)
h_v^{fin}	Financial component of vendor's holding cost ($/unit/year)
h_v^{ph}	Physical storage component of vendor's holding cost ($/unit/year)
h_b^{fin}	Financial component of buyer's holding cost ($/unit/year)
h_b^{ph}	Physical storage component of buyer's holding cost ($/unit/year)
a	Emissions function's factor (tonne year^2/unit^3)
b	Emissions function's factor (tonne year/unit^2)
c	Emissions function's factor (tonne /unit)
C_t	Emissions tax ($/tonne)
C_p	Emission penalty for exceeding emission limit ($/year)
E	GHG emissions (tonne/unit)
Y	Emissions limit variable (Y=1 if the emission limit is exceeded, otherwise Y=0)

3. Model development

We consider three different ways in which the replenishment policy can be structured for the SC under consideration. Each of these policies captures the cost trade-offs inherent in the system in a different way. They differ primarily in the timing of delivery sub-batches (i.e. whether batches are transferred immediately after processing at the vendor's site or wait till the buyer's stock is exhausted) and the size of the delivery sub-batches (i.e. whether they are of uniform sizes or not). Note that there may be multiple delivery sub-batches in a given production batch for all the models.

3.1. *VMI-CS Policy 1 – Immediate delivery in sub-batches of uniform size (IDSBU)*

Zanoni et al. (2014) developed this model incorporating emission related costs in a VMI-CS system. In their model, the vendor manufactures the product and delivers it to the buyer in *n* uniform sized sub-batches. These sub-batches are transferred as soon as their processing at the vendor's facility is complete. Since the rate of production is more than the demand rate, buyer's inventory level will increase till the n^{th} delivery has been made. After that, the next delivery will reach the buyer only when his inventory is exhausted (Figure 1).

Let Q be the size of the delivery sub-batch. The, the size of the production batch will be nQ. The total production set up cost incurred by the vendor will be:

$$= \frac{DA_v}{nQ} \tag{1}$$

From the figure, the holding stock incurred for the stock kept at the vendor's site will be:

$$= \left(h_v^{fin} + h_v^{ph}\right)\left(\frac{QD}{2P}\right) \tag{2}$$

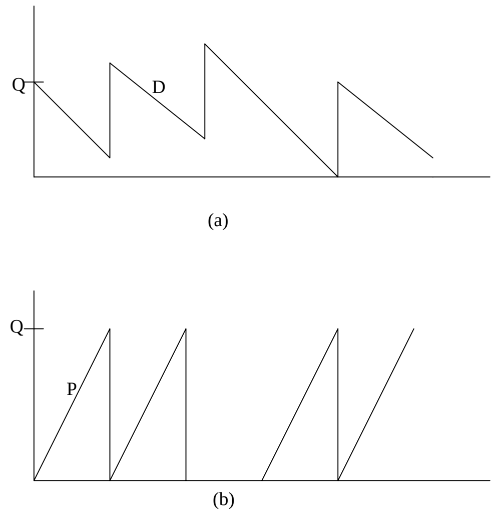

Figure 1: Inventory profile under IDSBU policy for (a) buyer (b) vendor

The second sub-batch arrives the buyer's facility at $(\frac{Q}{P})$, but its consumption will not start till the first batch is consumed at $(\frac{Q}{D})$. In turn, the third lot would have to wait even longer, as it would arrive at $2(\frac{Q}{P})$ while the time taken to consume the previous two sub-batches would be $(\frac{2Q}{D})$. Thus, the holding stock incurred corresponding to the stock at the buyer's site will be:

$$=\left[\left(h_v^{fin}+h_b^{ph}\right)\left\{n\left(\frac{1}{2}Q\frac{Q}{D}\right)+\left(\frac{Q}{D}-\frac{Q}{P}\right)Q(1+2+3+....+n-1)\right\}\left(\frac{D}{nQ}\right)\right]$$

Note that the financial component of the holding cost is charged to the vendor. Furthermore, (nQ/D) is the length of the production cycle. On simplification, the above expression can be written as:

$$=\left(h_v^{fin}+h_b^{ph}\right)\left[\frac{DQ}{P}+\frac{(P-D)nQ}{2P}-\frac{QD}{2P}\right] \quad (3)$$

Next, the total ordering cost will be:

$$=\frac{DA_b}{Q} \quad (4)$$

Next, we account for GHG emissions for the system. Bogashewsky (1995) provided the relationship between the production rate of a process and the rate of GHG (CO_2) emission as:

$$E = aP^2 - bP + c \tag{5}$$

Such convex functions of the production rate or equipment speed have been empirically validated for several production processes (TÜV Rheinland, 1987; Fandel, 1991).

Now, following Jaber et al. (2013) and Zanoni et al. (2014), we assume that there are two components of the costs associated with these GHG emissions. The first one is incurred per unit of GHG emission. The second component is a penalty that is levied in case the total emissions exceed a prescribed upper limit. Thus, the total emission related cost will be:

$$TCE = E * D * C_t + Y * C_p \tag{6}$$

The first term gives the total emission tax (charged on per unit of GHG emission) and the second term corresponds to the penalty levied in case the limit is exceeded and the binary variable Y will take the value 1 in this case. Note that this particular cost structure incorporates both the modes of emission related charges discussed in section 1.

Using the cost expressions developed thus far, cost optimization problem associated with the IDSBU policy would be:

$$\begin{aligned} TC_{IDSBU} = & \frac{DA_v}{nQ} + \frac{DA_b}{Q} + \left(h_v^{fin} + h_v^{ph}\right)\left(\frac{QD}{2P}\right) \\ & + \left(h_v^{fin} + h_b^{ph}\right)\left[\frac{DQ}{P} + \frac{(P-D)nQ}{2P} - \frac{QD}{2P}\right] \\ & + E * D * C_t + Y * C_p \\ \text{s.t.} \quad & E = aP^2 - bP + c \\ & E - E_{\lim} \le Y * M \\ & P_{\min} \le P \le P_{\max} \\ & P, Q \ge 0 \\ & Y \in \{0,1\}, M \text{ is a very large number} \end{aligned} \tag{7}$$

The optimization problem can be solved to obtain the values of decision variables (Q, P, n) and the system costs.

3.2. ***VMI-CS Policy 2 – Delayed delivery in sub-batches of uniform size (DDSBU)***

As in the previous model, the buyer gets delivery in uniform batch sizes from the vendor. However, in this case, the vendor synchronizes the system such that these deliveries reach the buyer only when the existing stock gets exhausted. Prior to that, the product is stored at the vendor's site. Thus, unlike the IDSBU policy, there is no accumulation of the inventory at the buyer's site across delivery sub-batches (Figure 2).

As before, the total production set up cost incurred by the vendor will be:

$$= \frac{DA_v}{nQ} \tag{8}$$

The total inventory for the vendor is given by the area ABCGE, as shown in the figure. Direct calculation of this area is difficult. However, following an approach similar to Pan and Yang (2002), we can write:

Area (ABCGEA) = Area (AFCDA) – Area (AFBA) – Area (EGDE)
(9)

$$\text{Area (AFCDA)} = \left\{ nQ\left(\frac{Q}{P} + (n-1)\frac{Q}{D}\right)\right\} \tag{10}$$

Note that it the product of the two sides of the rectangle AFCD. While the side CD is nQ as shown in the figure, for the side AD, we must understand the change in inventory profile. The inventory accumulation across all the retailers happens for (n-1) sub-cycles and for producing the first sub-batch, the time taken will be Q/P. Thus, the area can be written as in (10).

The area of triangle AFBA will be:

$$\text{Area (AFBA)} = \left\{ \frac{1}{2} nQ \frac{nQ}{P} \right\}$$

(11)

Next, the area EGDE can be calculated following an approach similar to that used in (3), as:

$$\text{Area (EGDE)} = \left\{ Q\frac{Q}{2}(1+2+3+\ldots n-1)\right\} \tag{12}$$

Thus, the area ABCGEA will be

$$=\left[\left\{nQ\left(\frac{Q}{P}+(n-1)\frac{Q}{D}\right)\right\}-\left\{\frac{1}{2}nQ\frac{nQ}{P}\right\}-\left\{Q\frac{Q}{2}\left(1+2+3+...n-1\right)\right\}\right] \tag{13}$$

Average inventory at the vendor can be written as:

$$=\frac{1}{\left(nQ/D\right)}\left[\left\{nQ\left(\frac{Q}{P}+(n-1)\frac{Q}{D}\right)\right\}-\left\{\frac{1}{2}nQ\frac{nQ}{P}\right\}-\left\{Q\frac{Q}{2}\left(1+2+3+...n-1\right)\right\}\right]$$

On simplification, the total inventory holding cost for the vendor will be:

$$=\left(h_v^{ph}+h_v^{fin}\right)\frac{Q}{2}\left[n\left(1-\frac{D}{P}\right)-1+\frac{2D}{P}\right] \tag{14}$$

From the inventory profile in the figure, the total holding cost associated with the buyer’s stock can be written as:

$$=\left(h_v^{fin}+h_b^{ph}\right)\frac{Q}{2} \tag{15}$$

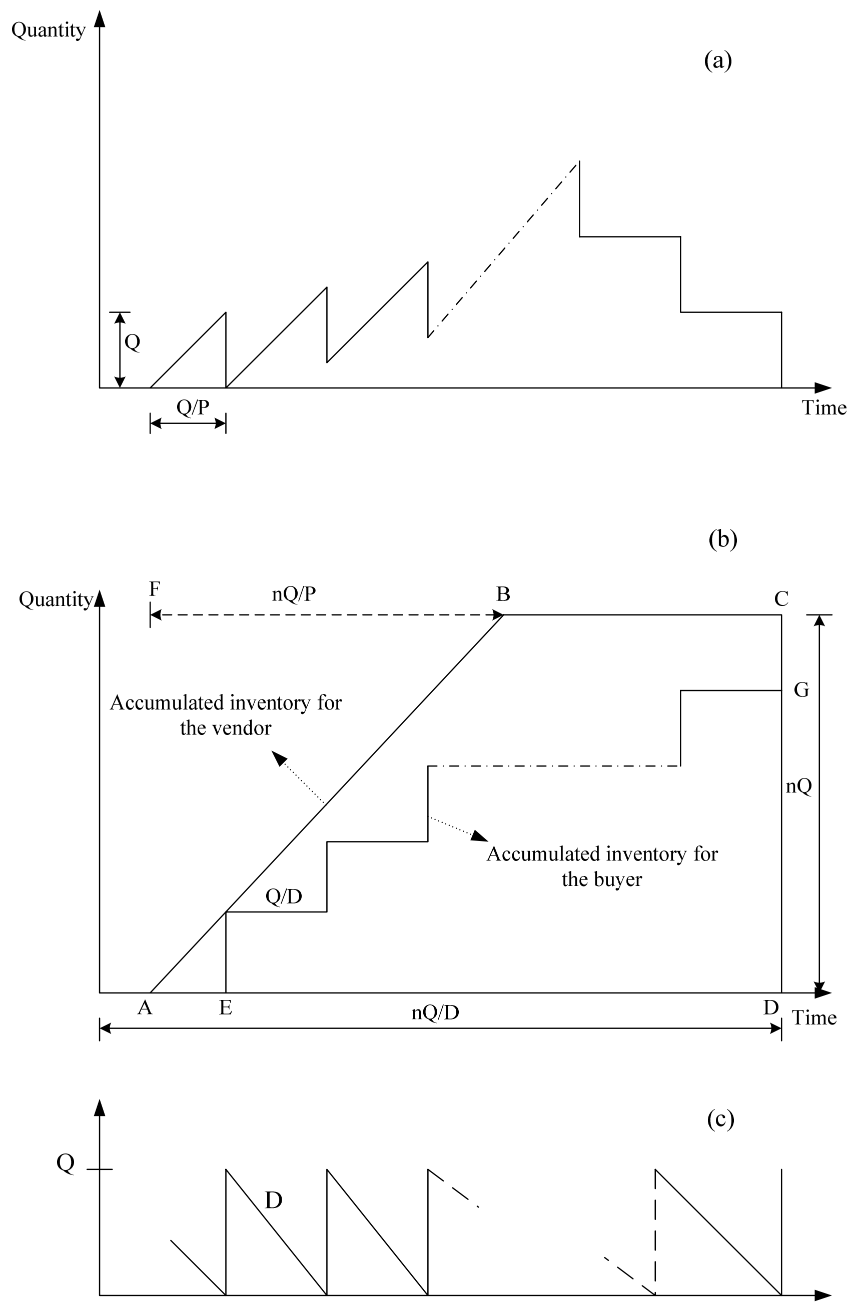

Figure 2 Inventory profile for (a) vendor, (b) system, and (c) buyer

Incorporating the order and emission related costs from (4) and (6) respectively, the cost optimization problem corresponding to the DDSBU policy would be:

$$TC_{DDSBU} = \frac{DA_v}{nQ} + \frac{DA_b}{Q} + \left(h_v^{ph} + h_v^{fin}\right)\frac{Q}{2}\left[n\left(1-\frac{D}{P}\right) - 1 + \frac{2D}{P}\right]$$
$$+\left(h_v^{fin} + h_b^{ph}\right)\frac{Q}{2} + \left(E * D * C_t + Y * C_p\right)$$

$$E = aP^2 - bP + c$$

s.t. $E - E_{\lim} \leq Y * M$ (16)

$P_{\min} \leq P \leq P_{\max}$

$P, Q \geq 0$

$Y \in \{0,1\}, M$ is a very large number

3.3. *VMI-CS Policy 3 – Immediate delivery in sub-batches of increasing size (IDSBI)*

The key difference between the IDSBU and DDSBU policies is in terms of the timing of the delivery of the sub-batches, while keeping the quantity delivered to be constant. However, under certain situations, it may be beneficial for the SC to deliver the production lots in delivery sub-batches of increasing sizes (Chatterjee and Ravi, 1991; Goyal, 1995). Essentially, by reducing the number of delivery sub-batches, this replenishment approach seeks to limit the total order cost incurred.

We take a similar approach for our VMI system. In this model, the vendor makes *n* deliveries corresponding to a given production batch to the buyer. The size of each sub-batch increases by a factor *x* (=P/D), as compared to the previous sub-batch. Let Q_k be the size of the k^{th} sub-batch from the vendor. Given that the production and consumption rates must be synchronized, we have:

$$\frac{Q_{k+1}}{P} = \frac{Q_k}{D} \tag{17}$$

If Q is the total production batch size, we can write:

$$Q = Q_1 + Q_2 + \ldots + Q_n \tag{18}$$

Since $Q_{k+1} = xQ_k$, we can simplify the above expression:

$$Q = Q_1\left[\frac{x^n - 1}{x - 1}\right] \tag{19}$$

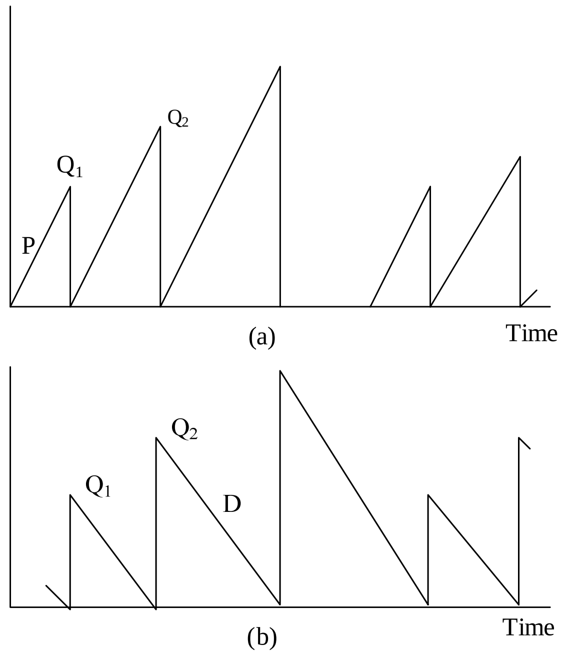

Figure 3: Inventory profile under IDSBI policy for (a) vendor, and (b) buyer

From the figure, average annual inventory at the vendor will be:

$$=\frac{D}{Q}\left[\frac{Q_1^2}{2P}+\frac{Q_2^2}{2P}+\ldots+\frac{Q_n^2}{2P}\right] \tag{20}$$

Using (17) and after some simplification, the holding cost incurred for vendor's stock will be:

$$=\left(h_v^{fin}+h_v^{ph}\right)\left(\frac{QD}{2P}\right)\left[\frac{x^{2n}-1}{x^2-1}\right]\left[\frac{x-1}{x^n-1}\right]^2$$

(21)

Average annual inventory at the buyer is given by:

$$=\frac{D}{Q}\left[\frac{Q_1^2}{2D}+\frac{Q_2^2}{2D}+\ldots+\frac{Q_n^2}{2D}\right] \tag{22}$$

After some algebra, the holding cost incurred can be written as:

$$=\left(h_v^{fin}+h_b^{ph}\right)\frac{Q}{2}\left[\frac{x^{2n}-1}{x^2-1}\right]\left[\frac{x-1}{x^n-1}\right]^2 \tag{23}$$

Adding the expression developed for the order, setup and emission related costs developed in the previously, the cost optimization problem for the IDSBI policy will be:

$$TC_{DDSBU} = \frac{DA_v}{nQ} + \frac{DA_b}{Q} + \left(h_v^{fin} + h_v^{ph}\right)\left(\frac{QD}{2P}\right)\left[\frac{x^{2n}-1}{x^2-1}\right]\left[\frac{x-1}{x^n-1}\right]^2$$

$$+\left(h_v^{fin} + h_b^{ph}\right)\frac{Q}{2}\left[\frac{x^{2n}-1}{x^2-1}\right]\left[\frac{x-1}{x^n-1}\right]^2$$

$$+\left(E * D * C_t + Y * C_p\right)$$

$$E = aP^2 - bP + c$$

$$x = P / D \qquad (24)$$

s.t. $E - E_{\lim} \leq Y * M$

$P_{\min} \leq P \leq P_{\max}$

$P, Q \geq 0$

$Y \in \{0,1\}, M$ is a very large number

4. Numerical analysis

In order to analyze the behavior of the three replenishment policies, we adapt the numerical example used in Jaber et al. (2013). The values of parameters are provided in Table 1 below. We used LINGO 13 in order to solve the optimization problems corresponding to the three replenishment policies. The solution was obtained within seconds in each instance.

Table 1. Data for the numerical example.

A_v=1200	$h_v^{fin} = 5$	$h_b^{fin} = 10$	P_{min}=1200	a=3x10^{-7}	c=1.4	C_p=4000
A_b=400	$h_v^{ph} = 55$	$h_b^{ph} = 80$	P_{max}=3000	b=0.0012	E_{lim}=220	C_t=18

We will explore the performance of the three models over a wide range of operating values. However, before that it is important to understand the change in GHG emission with change in the production rate as specified in equation (6). Figure 4 depicts the quadratic nature of the relationship. Note that the penalty would be limited on breaching the limit of 220 tonnes/year. Thus, given the relatively large penalty, the vendor would prefer to keep the production rate within the no-penalty zone between 1742 units/year and 2258 units/year.

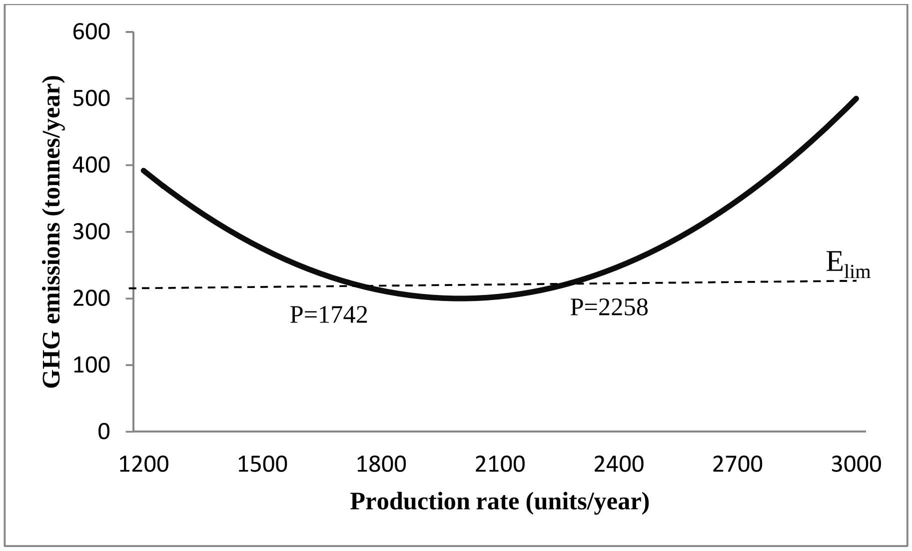

Figure 4: Change in total GHG emissions with an increase in the production rate

Next, we will vary different parameter values and check the impact for all the three policies. We will focus on both the economic as well as environmental aspects as specified by the total system cost and total GHG emission respectively.

4.1. ***Impact of change in production rate***

The change in total system cost for the three policies with the change in the production rate is shown in Figure 5. In general, the IDSBI policy gives the lowest cost, while the IDSBU policy gives the highest cost. Note that for a given production rate, all the three policies would generate the same amount of GHG emissions.

Furthermore, the operating cost (i.e. not including the emission related costs) increased with an increase in the production rate. The pattern observed in figure 5 can be accounted for keeping in mind that a production rate between 1742 units/year and 2258 units/year does not incur any emission related penalty. The other emission related cost of the tax per unit follows the pattern observed in Figure 4.

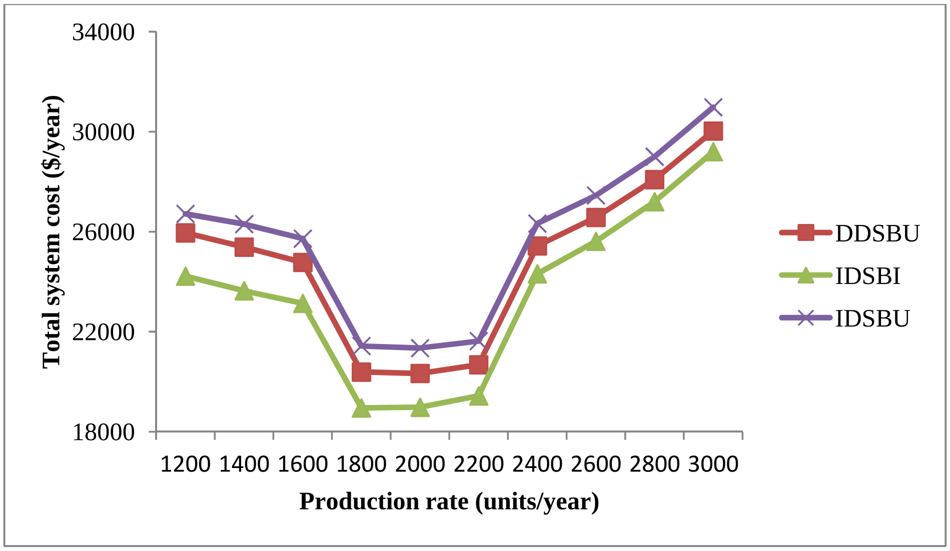

Figure 5: Impact of change in production rate on the total system cost

4.2. *Impact of change in vendor setup cost*

With an increase in the production setup cost, the vendor increased the size of the production batch. Furthermore, in order to keep the stock level at the vendor's site under check, the rate of production was also gradually decreased. However, increasing batch sizes led to an increase in the holding cost associated with retailer's stock. To counter this, the vendor increased the number of delivery sub-batches. The ISSBI policy led to the lowest cost, while the IDSBU policy led to the highest cost (Figure 6). The difference between the total system costs for the three policies increased with an increase in the setup cost. The optimal production rate under IDSBI led to the higher GHG emissions, as compared to the other two policies.

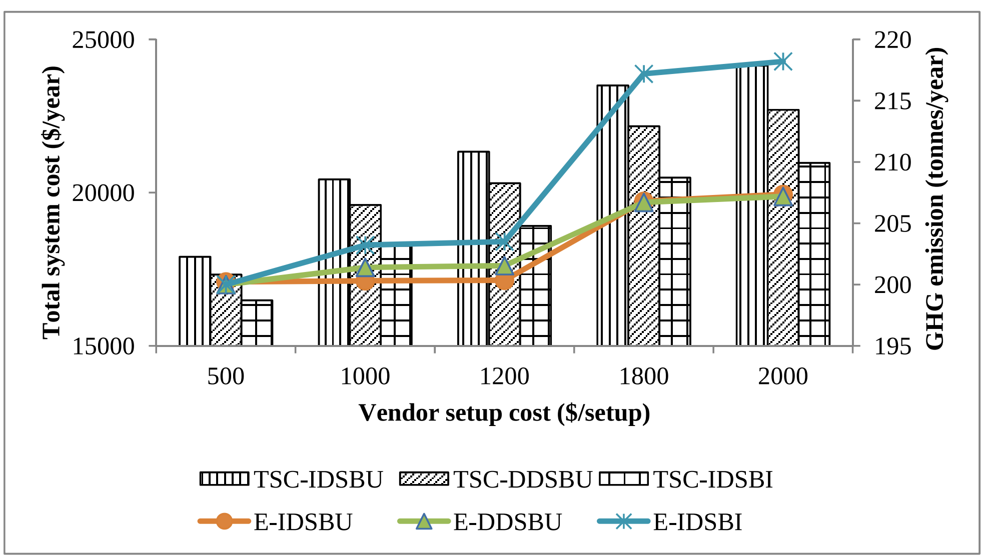

Figure 6: Impact of change in vendor setup cost on total system cost and GHG emissions

4.3. *Impact of change in buyer ordering cost*

The effect of change in this parameter on the system cost and GHG emissions is shown in Figure 7. As the ordering cost increased, the vendor reduced the number of delivery sub-batches (of larger sizes). In terms of the total system cost, the IDSBI policy consistently gave the best results followed by, in order, the DDSBU and the IDSBU policies. On the other hand, the GHG emission associated with the IDSBI policy were found to be the highest, while the other two policies gave almost similar results in this regard.

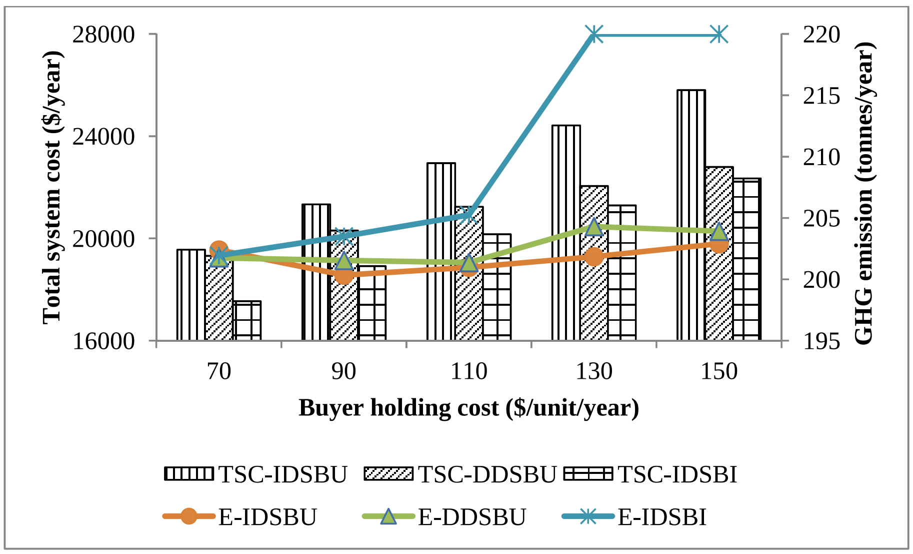

Figure 7: Impact of change in buyer ordering cost on total system cost and GHG emissions

4.4. *Impact of change in buyer holding cost*

Next, we changed the holding cost of the buyer while keeping the holding cost of the vendor constant. Note that this change was achieved by increasing the physical stock related component of the holding cost (which is to be borne by the buyer in a VMI-CS system). The trends observed are shown in Figure 8.

With an increase in the buyer holding cost, the vendor decreased the quantity shipped in a delivery sub-batch, keeping the number of sub-batches constant. As it became even costlier for the buyer to hold stock, the vendor increased the number of the delivery sub-batches. In general, the IDSBI policy led to the lowest cost. At lower values of the buyer holding cost, the IDSBU policy gave better results than the DDSBU policy. However, with increasing buyer holding cost, the latter started giving better results, so much so that at the higher values its cost implication became almost similar to that observed for the IDSBI policy. As before, the IDSBI policy led to higher total GHG emission, while the IDSBU policy led to the lowest GHG emission.

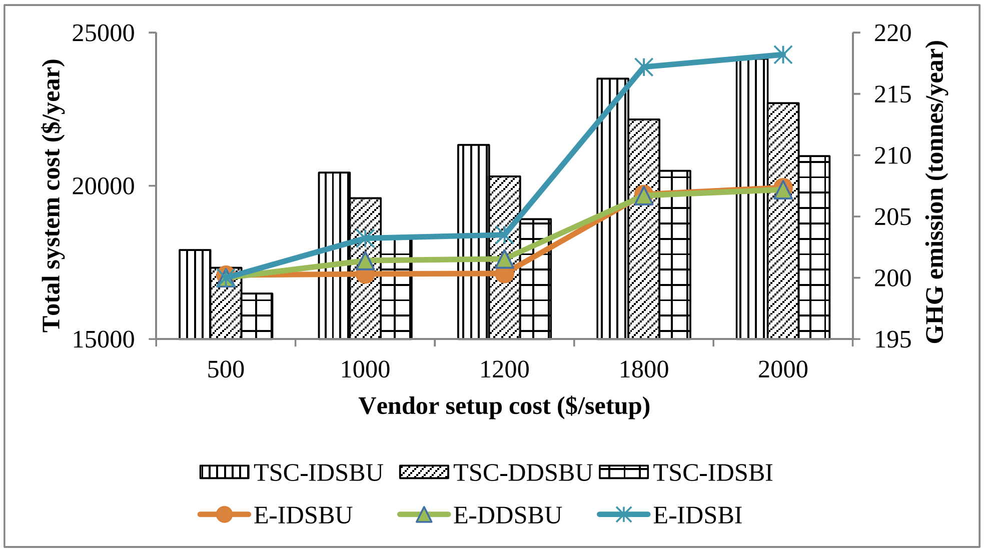

Figure 8: Impact of change in buyer holding cost on total system cost and GHG emissions

4.5. *Impact of change in emission tax*

At very low values of the emission tax, the operating costs dominate the decision making. Under all the policies, the vendor decided to operate at a production rate of 1742 units /year, which is the minimum possible value corresponding to which the total GHG emission do not incur the penalty. As before, the total system cost followed the trend IDSBU>DDSBU>IDSBI. On the other hand, GHG emission associated with the IDSBI policy were found to be the highest. With increasing emission taxes, it becomes optimal for the system to operate at higher production rates. Correspondingly, even the total system cost goes up, GHG emission come down to the minimum possible value of 220 units/year.

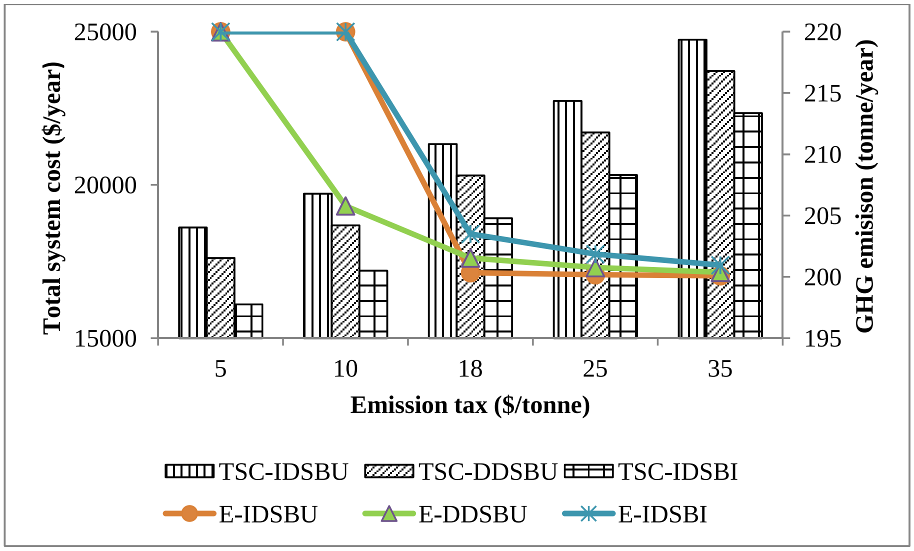

Figure 9: Impact of change in emission tax on total system cost and GHG emissions

4.6. *Impact of change in other parameters*

We also studied the impact of change in other emission related parameters, viz. emission limit and emission penalty. Since it was impossible for the SC to operate at total GHG emission lower than 200 tonnes/year (see Figure 4), if the specified limit was lower than this value, the parties had no other option than to incur the penalty. Under these circumstances, penalty effectively became an exogenously imposed cost for the SC without any material effect on the choice of the replenishment policy. It was also observed that if the emission penalty and the emission tax were taken to be quite low, the vendor operated at very low production rates which led to very high GHG emissions.

5. Discussion and managerial implications

The different models analyzed in this paper seek to capture and exploit different trade-offs present in a SC. Thus, the key difference between the IDSBU and DDSBU policies is in terms of whether the product is shipped immediately after the processing is completed. By holding the product for a longer time at the vendor's facility the DDSBU policy seeks to exploit the fact that the holding cost is often lower for the vendor (Lal and Staelin, 1984). On the other hand, the DDSBI policy seeks to limit the number of sub-batches. This policy would obviously help in circumstances in which the ordering cost (incorporating administrative, transportation and other associated expenses) is relatively higher. We found that, in general, the DDSBI policy led to the lowest cost.

However, this low cost came at the expense of more GHG emission, as both the DDSBU and IDSBU policies offered better alternatives in this regard. At the same time, it must be pointed out that the DDSBI policy (as well as the other two) did not breach the stipulated emission limit.

As shown in Zanoni *et al.* (2014), SC coordination is a more attractive proposition as compared to non-coordinated approaches, both in terms of cost as well as GHG reduction. We extend the argument further by developing different replenishment policies, each of which seeks to exploit different trade-offs inherent in the SC. Importantly, they must not be seen as merely production and logistics related decisions. In order to fully exploit the flexibility offered by these policies, the choice of a particular operating regime must be aligned to business level goals. Thus, cost alone must not be viewed as the sole determinant of policy selection as apart from cost efficiency, organizations may be desirous of focusing on responsiveness, eco-friendliness etc. Hence, within acceptable limits, an organization which prides itself on its ‘green thinking’ may decide to adopt the IDSBU policy even though it may lead to cost escalation as compared to the IDSBI policy, as the GHG emissions associated with the latter are often lower. Similarly, by lowering the number of delivery sub-batches, the IDSBI policy sacrifices a certain degree of responsiveness. Thus, for organizations focused on this aspect, the DDSBU and IDSBU policies may offer a more attractive proposition. The key point emanating from the preceding discussion is that an organization must carefully evaluate the entire choice set and choose the one which delivers the best results vis-à-vis its strategic priorities.

Finally, some our numerical analysis also provides some policy level pointers. The three emissions related parameters viz. emission limit, penalty and tax are very important levers available to the policy makers. It is imperative however that they must have fully comprehend their respective impact on decision making by business organizations. For instance, if in our case the limit was set beyond 200 tonnes/year, it was impossible for the vendor to adhere to this bound. Consequently, the vendor would just pay the penalty and pass along the cost incurred to the final consumer. Similarly, a low value of penalty may also fail to act as a proper deterrent. Thus, in line with the spirit of sustainable development, the policy maker must adopt such values that spur the business to operate in a more responsible way without jeopardizing the economic well-being of the business and/or the final consumers (Brundtland Commission, 1987).

6. Conclusions

The alternative replenishment policies developed in this paper offer managers a useful way of incorporating different strategic organizational choices in their operational decision making. We establish that VMI-CS based SC coordination offers a very attractive new avenue of aligning business operations. This alignment can be beneficial for all the stakeholders involved by reducing both the costs incurred as well as GHG emissions.

This paper can be extended in several directions. Analysis of more complex networks mimicking real-life value chains would be one such area. Mechanism design for incentive alignment to spur the organizations to adopt such multi-faceted initiatives may also be explored.

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