Improving Sustainability in a Two-level Pharmaceutical Supply Chain through Vendor-Managed Inventory System

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Abstract. In the pharmaceutical industry, regulations have been imposed on producers to green their supply chains and to minimize the impact of their leftovers in the environment. On the other hand, hospitals, as the main consumers of medications, adopt a conservative inventory control policy through keeping large quantities of drugs in stock. Such a strategy would lead to the expiration of excess inventory in the absence of patients demand. Consequently, producers are faced with governmental penalties and environmental reputation forfeit. This article aims at improving the sustainability of a pharmaceutical supply chain in a real case study. An analytical model is proposed to explore the effect of implementing a Vendor-Managed Inventory (VMI) system on minimizing the quantity of expired medications at customer zones. Results reveal that the amount of expired medications could reach zero against the current 18% expiration rate of shipped items.

Key words: Vendor-Managed Inventory, Pharmaceutical Supply Chains, Mixed-Integer Nonlinear Programming

1 Introduction

Medications, as any other perishable product, typically have a fixed shelf life set by a used-by or a sell-by date. They also contain active molecular ingredients that degrade with time even when using modern keeping conditions [1]. These particularities lead to challenges on inventory control management, by trading off stock outs and on-shelf availability against wastage due to expiry [2, 3]. Any shortage in medications delivery has furthermore a high cost in terms of preventable illness and death. Therefore, governments (such as the US) and customers (such as hospitals) might adopt a conservative inventory control policy by ordering more products to be hedged against uncertainty [4]. Given the perishable nature of medications, such a strategy would lead to the expiration of the excess inventory in the absence of patients demand.

Leaving expired medications at customer zones and disposing them improperly lead to penalties that pharmaceutical companies must pay to governments. It might also turn into a jeopardy to people’s health if being redistributed illegally in undeveloped countries. Therefore, improving the Pharmaceutical Supply Chain (PSC) sustainability effectively is essential not only to protect the environment and patients from exposing to expired medications but also to reduce the associated cost [1].

Against the current reactive practices in collecting unwanted/expired medications, we propose, in this article, a proactive approach by obstructing the entrance of excess medications to the supply chain (SC) inventories at first place by implementing one of the most widely used initiatives for perishables dubbed as Vendor-Managed Inventory (VMI) system. The customer relinquishes control of replenishment decisions and transfers financial responsibility to the pharmaceutical company. It is worth mentioning that producers are usually engaged in a such policy because of its benefits, such as alleviating the bullwhip effect [5].

Along with the aforementioned advantages, our goal in implementing a VMI system is to reduce the large quantities of expired medication at customer zones through a more realistic inventory replenishment policy. As the main contribution in this article, we propose a VMI model, from the pharmaceutical company perspective, between him and one of his customers (a hospital). The model is a nonlinear mixed-integer program (MINLP) that seeks the optimal quantity of medications that must be shipped to the hospital in each period over a planning horizon with the goal of minimizing the quantity of expired medications as well as shortage and inventory levels.
The remainder of this paper is structured as follows. A brief summary of the literature related to VMI and PSC inventory management is given in section 2. In section 3, the description of the PSC under investigation and the VMI model is provided. Numerical results and discussion of the model are presented in 4. Finally, concluding remarks and future recommendations are provided in section 5.

2 Literature Review

The first initial literature available on the perishable inventory management is chronicled by Nahmias [2], followed by Goyal and Giri [6]. The authors gave a holistic review on perishable SCs and touched briefly on applications of these models in blood bank inventory management. Several studies have focused on the inventory management of blood SCs as [7, 3, 8, 9]. An extensive review of the available literature on inventory and SC management of blood products prior to 2012 can be found in [10]. Gunpinar and Centeno [8] could reduce the wastage rates and cost of blood inventory through proposing an integer programming model from a hospital perspective over a planning horizon. Using a First-In-First-Out (FIFO) policy, Civelek et al. [9] suggested heuristic replenishment inventory models to minimize the expected total cost over an infinite time horizon for blood platelet SC. Önal et al. [11] considered an economic lot-sizing problem for perishable products, where items have deterministic expiration periods that depend on their procurement periods. Few research has been conducted on inventory management in the pharmaceutical value chain. Uthayakumar and Priyan [4] developed a two-echelon PSC inventory model to minimize the total cost of a SC that involves a pharmaceutical company and a hospital. Lee et al. [12] studied a public pharmaceutical inventory system with respect to the strategic national stockpile in the United States that requires to maintain a high minimum inventory volume at all times.

It is worth mentioning that all of the contributions reviewed above have developed inventory management models for perishable items with the goal of cost minimization. In contrary, reducing the amount of expired items and their effect on the environment have been capturing less attention.

Since the first adoption by Wal-Mart in 1980s, many articles treat VMI superiority over traditional replenishment techniques for SCs in general [13, 14, 15, 16]. For more details on VMI benefits, the reader is referred to [17]. Implementing VMI system leads suppliers to a higher replenishment frequency with smaller replenishment quantities as stated by Dong and Dresner in [18]. Consequently, VMI system implementation leads to utmost inventory cost saving without negatively impacting the overall performance of the SC or the customer service level [19, 20]. The available research focus is on grocery industry or blood banks but not on PSC. Ketzenberg and Ferguson [21] evaluated two structures in a grocery SC. The authors tested the value of information sharing or centralized control in a VMI system relative to the case when no information is shared and decision making is decentralized. Recently, Stanger [22] developed a seven-step framework for the assessment of a VMI system implementation in a blood bank in Germany.

The literature review summarized above clearly indicates the lack of application of VMI systems in PSC, an issue addressed in this article.

3 Problem statement

In this section, we provide a brief description of the current PSC structure in the company under discussion. A VMI model for a two-echelon PSC, i.e., a producer (Generic PharmaX) and a customer (hospital) is then presented.

3.1 Generic PharmaX supply chain

Generic PharmaX is a leading multinational pharmaceutical producer focusing on developing a branded pharmaceuticals business across the Middle East, North Africa, Europe, and in the United States. Based on purchasing orders received from hospitals, the producer ships his medications with respect to the regulations
in the destination countries (Figure 1). According to the producer archival data, in some countries like the United States, large amounts of the shipped medications expire in hospitals’ stock. Upon their expiry, the hospitals inform the producer about the quantities of the expired medications. **Generic PharmaX**, then, contracts with transportation providers to pick up those medications and send them to governmental disposal sites. The producer is obligated to pay fees to the government to safely dispose the wastage of medications. Currently, around 18% of branded medications at customer sites are expired and must be collected, which incurs penalties to the producer.

Against the current practice, we believe that cutting off the SKUs level at hospitals sites, without sacrificing their customer demand satisfaction rate, is helpful in improving the PSC sustainability. More precisely, reducing the inventory level can lessen the quantity of expired medications and their negative environmental impact. In addition, the governmental fees and penalties could be avoided when an efficient inventory control management would be utilized. This can be achieved by implementing a VMI system (Figure 2).

**Fig. 1:** The current PSC of **Generic PharmaX**

**Fig. 2:** The PSC under VMI system

The implementation of this type of system requires private information sharing and a certain level of trust between SC entities [23]. For this reason, only one key hospital is elected to implement VMI with **Generic PharmaX**. Besides its long-term relationship with the producer, it is chosen due to its high demand rate of medications and high level of technology and infrastructure.

Considering the case where the producer and the hospital have agreed to implement the VMI system, **Generic PharmaX** is responsible for managing the hospital inventory and creating its monthly replenishment orders. In addition, the producer communicates with the hospital to decide on a minimum amount from each medication that has to be available in the hospital stock at all times, dubbed as safety stock (SS) level. Some medications are essential because they can be life-saving, such as respiratory and cardiovascular medicines. They have to be available in the hospital stock at all times in adequate amounts. Therefore, the SS level of essential medications is higher than nonessential medications. Having an access to the on-hand level inventory is also required to enable the producer to provide on-site inventory planning.

Medications move from the producer, through a transportation provider, to the hospital site to satisfy its demand in each period of the planning horizon. The producer issues a notification of delivery to the hospital upon the shipment release in stock.

Given the perishable nature of medications, the producer checks their shelf life at the hospital site with every replenishment. Any medication that reaches to the end of its shelf life is quarantined and then shipped to governmental safe disposal sites, while unexpired medications remain at the hospital to be used in a next period.

Because of the criticality of medications, the demand of the hospital has to be fulfilled by the producer over the planning horizon. **Generic PharmaX** managing the inventory through the VMI system, he is obliged to pay monetary penalties to the hospital for any shortage in the supply. The producer could also be coerced to outsource that shortage with same or equivalent medications from another pharmaceutical company to satisfy the hospital demand.
3.2 Mathematical model for the VMI system in the PSC

In this subsection, we propose a mixed-integer nonlinear programming (MINLP) model for implementing the VMI system in the PSC described previously. The notations used are as follows:

**Notations**

**Index sets:**
- \( p \): index of medications, \( p = 1, 2, ..., P \);
- \( i \): index of medication ages (in months), \( i = 1, 2, ..., I \);
- \( t \): index of time periods (in months), \( t = 1, 2, ..., T \);

**Parameters:**
- \( \mathcal{O}_p \): unit cost of outsourced medication type \( p \) that the producer could not satisfy (\$);
- \( C D^p_t \): fees obligated by governments for each unit of medication type \( p \) disposed at their sites (\$);
- \( T R^p_t \): unit transportation cost of medication type \( p \) shipped to the hospital (\$);
- \( T S^p \): unit transportation cost of expired medication type \( p \) sent to government disposal site (\$);
- \( \pi^p \): penalty the producer pays to the hospital for each unit of shortage in the supply of medication type \( p \) (\$);
- \( h^p \): unit holding cost of medication type \( p \) at the hospital site (\$);
- \( CAP^p_t \): producer capacity of medication type \( p \) in period \( t \);
- \( d^p_t \): hospital demand of medication type \( p \) in period \( t \);
- \( SS^p_{t-1} \): minimum SS level at the hospital for medication type \( p \) in period \( t \);
- \( VI^p_{t-1} \): the inventory level of product type \( p \) of age \( i \) at the beginning of the planning horizon;
- \( M \): the upper bound on the inventory level of medications at the hospital site;

**Decision variables:**
- \( Q^p_{i,t} \): replenishment quantity of medication type \( p \) of age \( i \) shipped to the hospital in period \( t \);
- \( E^p_{i,t} \): quantity of expired medication type \( p \) sent to governmental disposal site in period \( t \);
- \( S^p_{i,t} \): shortage quantity of medication type \( p \) that is needed to be outsourced in period \( t \);
- \( v^p_{i,t} \): inventory level of medication type \( p \) of age \( i \) of period \( t \);
- \( F^p_{i,t} \): binary variable that is equal to 1 when medication type \( p \) of age \( i \) is used to satisfy the demand in period \( t \), 0 otherwise;
- \( L^p_{i,t} \): auxiliary variable associated with the medication age. It captures the number of medications type \( p \) of age \( i \) in period \( t \) that left to be used for the next period if not all medications from this age are used to satisfy the demand in the current period.

The VMI model developed encompasses equations (1)-(16).

\[
\begin{align*}
\min & \quad \sum_{p \in \mathcal{P}} \sum_{i \in \mathcal{I}} \sum_{t \in \mathcal{T}} TR^p_t Q^p_{i,t} + \sum_{p \in \mathcal{P}} \sum_{i \in \mathcal{I}} \sum_{t \in \mathcal{T}} (CD^p + TS^p)E^p_{i,t} + \\
& \quad \sum_{p \in \mathcal{P}} \sum_{i \in \mathcal{I}} \sum_{t \in \mathcal{T}} (\pi^p + \mathcal{O}_p)S^p_{i,t} + \sum_{p \in \mathcal{P}} \sum_{i \in \mathcal{I}} \sum_{t \in \mathcal{T}} h^p \cdot v^p_{i,t} \\
\text{s.t.} & \quad \sum_{i \in \mathcal{I}} Q^p_{i,t} \leq CAP^p_t, \quad \forall p \in \mathcal{P}, \quad \forall t \in \mathcal{T} \\
& \quad Q^p_{i,t} = 0, \quad \forall i \neq 1, \quad \forall p \in \mathcal{P}, \quad \forall t \in \mathcal{T} \\
& \quad F^p_{i,t} \geq F^p_{(i-1)t}, \quad \forall i \in \mathcal{I}, \quad \forall p \in \mathcal{P}, \quad \forall t \in \mathcal{T} \\
& \quad F^p_{0t} = 0, \quad \forall p \in \mathcal{P}, \quad \forall t \in \mathcal{T} \\
& \quad d^p_t = \sum_{i \in \mathcal{I}} (v^p_{(i-1)(t-1)} + Q^p_{i,t} + F^p_{i,t} - L^p_{i,t}) + S^p_{i,t}, \quad \forall p \in \mathcal{P}, \quad \forall t \in \mathcal{T} \\
& \quad d^p_t - \sum_{i \in \mathcal{I}} (v^p_{(i-1)(t-1)} + Q^p_{i,t}) \leq S^p_{i,t}, \quad \forall p \in \mathcal{P}, \quad \forall t \in \mathcal{T} \\
& \quad v^p_{i,(0)} = VI^p_{i,(0)}, \quad \forall p \in \mathcal{P}, \quad \forall i \in \mathcal{I}
\end{align*}
\]
The model has been formulated from the producer’s perspective. The objective function (1) seeks to minimize the producer costs which involve shipping cost from the producer site to the hospital site; expired medication costs which incorporate the safe disposal fees for expired medication at government sites and the transportation cost from the hospital to the safe disposal sites; the shortage costs that consist of the penalty paid by the producer to the hospital for unsatisfied demand and the cost of satisfying that demand from another pharmaceutical producer; and the holding cost of medication at the hospital site. The objective function is constrained by the capacity of the producer as shown in equation (2). The medications from all ages shipped to the hospital in period \( t \) cannot exceed the capacity of the producer in that period. Also, medication shipped to the hospital should always be fresh, i.e., only medications of age 1 are shipped to the hospital, as shown in constraint (3). The FIFO policy used by the hospital is depicted in constraint (4). Constraint (5) stats that no medication of age zero is used to satisfy the demand. Constraint (6) requires demand to be satisfied, otherwise a shortage occurs. In fact, \( L_{it}^p \) captures the number of medications type \( p \) of age \( i \) left in stock for the next period when at least one item from that age is absorbed from inventory in period \( t \). Otherwise, it would be equal to zero and \( S_{it}^p \) would take a positive value. Constraint (7) with constraint (6) capture the number of unsatisfied demand by the producer. The inventory from different ages available at the beginning of the planning horizon is shown in constraint (8). Moreover, there are no medications of age zero in the inventory at the hospital site, as shown in constraint (9). Constraint (10) assures that the amount of medication type \( p \) of age \( i \) left in period \( t \) do not exceed the number of the available medication of the same age in that period. Constraint (11) expresses the inventory update of medication type \( p \) of age \( i \) at the end of period \( t \). It simply indicates that medication type \( p \) of age \( i \) has been used to satisfy the demand, in which case if medication of a younger age has also been used to satisfy the demand, no more medications of age \( i \) will be left in stock. Otherwise, the leftover inventory of age \( i \) would be equal to \( \tilde{L}_{it} \) calculated in constraint (6). Constraint (12) depicts the SS level for each medication. Constraint (13) captures the number of expired medications in stock that has to be sent to the governmental safe disposal site. Finally, domain constraints are provided in equations (14)-(16).

### 4 Results and implementation insights

#### 4.1 Case data and parameters

The parameters of the model were obtained through communication with the head of the SC department in Generic PharmaX. The lifetime of medicines usually varies from 24 to 36 months, therefore 24 months were considered for the medications age. Medication shipped to the hospital is always fresh of 1 month age. If the medication is kept unused, it would be of 2 month age in the next period. In addition, 36 months is considered as the planning horizon.

The criticality of medications was considered in calculating the SS level as follows. For essential medications, the level was set as 5% of the hospital monthly demand for that medication (i.e., deterministic demand). Otherwise, 2.5% of the demand was used. Furthermore, to test the effect of SS level on model (1)-(16), two different SS levels were generated and compared with the basic case. They are dubbed by low-SS
and high-SS. Table 1 summarizes the SS levels as a percentage of the hospital demand for both essential and nonessential medications.

The capacity of the producer assigned for the hospital has a direct impact on medication quantities shipped to the hospital. Therefore, two levels of allocated capacity were issued and compared with the basic case to test the effect on the model; namely Low-Capacity and High-Capacity as provided in table 2.

<table>
<thead>
<tr>
<th>Case</th>
<th>Essential medications (%)</th>
<th>Nonessential medications (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic case</td>
<td>5</td>
<td>2.5</td>
</tr>
<tr>
<td>Low-SS</td>
<td>2.5</td>
<td>1.25</td>
</tr>
<tr>
<td>High-SS</td>
<td>10</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 1: SS levels as a percentage of the hospital demand (%)

To analyze the effect of freshness assumption on the expired medication quantities, another case named as Freshness was considered. In this case, we compare the basic case with a case where the producer can ship medications with any age not only fresh ones.

The model described in subsection 3.2 was first linearized and then solved by using IBM ILOG CPLEX 12.3.

### 4.2 Numerical results

The linearized form of the model described by (1)-(16) was solved separately for each case using the parameters mentioned in subsection 4.1.

Table 3 summarizes the results for the basic case. The objective function value, as the total cost of the PSC, is given in the second row. It can be concluded that shipping, holding, and shortage costs represent 34%, 33%, and 32% of the total cost, respectively. The expired medication cost is zero since the expired medication quantity at the hospital site is zero.

<table>
<thead>
<tr>
<th>Total cost</th>
<th>($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objective function value</td>
<td>722,698</td>
</tr>
<tr>
<td>Shipping cost</td>
<td>251,210</td>
</tr>
<tr>
<td>Holding costs</td>
<td>237,238</td>
</tr>
<tr>
<td>Shortage costs</td>
<td>234,245</td>
</tr>
<tr>
<td>Expired medication costs</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total medication quantities (unit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shipping quantities</td>
</tr>
<tr>
<td>Shortage quantities</td>
</tr>
<tr>
<td>Expired medication quantities</td>
</tr>
</tbody>
</table>

Table 3: Solution results for the basic case

As expounded in subsection 3.1, the percentage of expired branded medications is currently 18% of the shipped items to the hospital. Implementing a VMI system, in contrary, eliminates the medication expiration, as provided in table 3.

Figure 3 depicts the comparison between the basic case and two SS levels. As the SS level is decreased to the Low-SS, the total PSC cost decreases by 19%. Same behavior was noted for the holding and shortage costs. This comes at no surprise, since reducing the SS level reduces the total medication shortage and holding quantities by 16% and 43%, respectively, as provided in table 4. By the same token, increasing the SS level to the High-SS increases the total PSC cost by 20%, the medication holding quantities by 30%, and the shortage quantities by 15%. Given the significant impact of this constraint, the producer is instigated to review SS levels with the hospital and update them periodically.
As anticipated, reducing the producer capacity assigned for the hospital to the Low-Capacity increases the objective value by 92% since the outsourcing process is very expensive, besides the penalties provoked. On the other hand, increasing the producer capacity to High-Capacity could fully satisfy the hospital demand and ship more medications as summarized in figure 4 and table 5. Therefore, the producer is advised to boost his capacity assigned for this customer by 1.5 times the basic case capacity to avoid expensive outsourcing and penalty cost, while ensuring greater service level. The producer also receives more information on the hospital demand patterns that aids him in better planning his own inventories. The expired medication quantities under VMI is zero for all cases.

Regarding the freshness assumption in shipping medication to the hospital, the results indicate that shipping aged medications has low impact on the objective function and other costs. However, it increases the expired medication quantities by 545 unit (which is 0.18% of the shipped medications) as shown in table 6. To improve his PSC sustainability, the producer is therefore recommend to only ship fresh medications to the hospital.

<table>
<thead>
<tr>
<th>Basic case</th>
<th>Low-SS</th>
<th>High-SS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Holding quantities</td>
<td>11,236</td>
<td>6,392</td>
</tr>
<tr>
<td>Shortage quantities</td>
<td>3,995</td>
<td>3,354</td>
</tr>
</tbody>
</table>

Table 4: Effect of SS level on medication quantities

<table>
<thead>
<tr>
<th>Basic case</th>
<th>Low-Capacity</th>
<th>High-Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shipped quantities</td>
<td>304,421</td>
<td>153,294</td>
</tr>
<tr>
<td>Shortage quantities</td>
<td>3,995</td>
<td>136,362</td>
</tr>
<tr>
<td>Expired quantities</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 5: Effect of allocated capacities on medication quantities

<table>
<thead>
<tr>
<th>Basic case</th>
<th>Freshness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity of shipped medications</td>
<td>304,421</td>
</tr>
<tr>
<td>Quantity of expired medication</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 6: Effect of medications age shipped on the PSC medication quantities

To conclude, implementing a VMI system could reduce the expired medication percentage from 18% of shipped medications in the current status to 0% for most of the cases. Allowing aged medications being delivered would, on the other hand, lead to a certain expired medication level to collect (i.e., 0.18% from the shipped medications). Therefore, it could certainly be profitable for the producer to implement the VMI system with his key customer while shipping fresh medications. The capacity level allocated to this hospital should be reviewed to avoid high outsourcing and penalty costs.

5 Conclusions and implications

In this article, a VMI model is proposed for the PSC that seeks the optimal quantity of medications that must be shipped to the hospital in each period over a planning horizon to minimize medication shortage and...
the amount of expired medications. Our experimental results on a real pharmaceutical company reveal the importance of adopting VMI system by eliminating the expired medication against the current status.

A sensitivity analysis also illustrated the effect of SS level, producer capacity, and medication freshness on the inventory control management. From the results, we conclude that implementing a VMI system could help the producer to improve the PSC sustainability and to avoid the expired medications at the hospital site. On the other hand, the producer is recommended to increase his capacity also assigned to the hospital demand to fully satisfy the demand. The SS level has significant impact on the PSC total cost.

For future work, considering more medication types and more than a hospital can be suitable. Also, VMI partnership being sometimes more beneficial for one entity over other entities, research on methods to manage benefits sharing among PSC entities would be of practical value.

References