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Abstract.. In the pharmaceutical industry, leftover medications that have not been properly disposed not only damage the environment but also might turn into a peril to people's health if being redistributed illegally in undeveloped countries. In contrary, if they are returned to the pharmaceutical producer before their expiry dates, they can be sold at subsidized prices or donated in such countries. In this research, we explore the role of providing incentives to customers in order to facilitate leftover returns and improve the sustainability for a real pharmaceutical reverse supply chain (RSC). Moreover, this research investigates the effect of having a proper coordination method between a producer of medications and third-party logistics (3PL) companies, responsible for collecting unwanted medications from customer zones. Finally, a technique is also proposed to share the RSC's saving among the producer and the 3PL companies. The experimental results on a real case study indicate that introducing incentives to customers could decrease the amount of uncollected medications from 18% up to 6.5%. Furthermore, having a proper coordination with 3PL companies could guarantee a full medication recovery.

Keywords. Reverse supply chain, pharmaceutical industry, coordination incentives.

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1. Introduction

The pharmaceutical industry has witnessed significant changes in recent years. New regulations have been imposed by governments for tackling the recovery of unwanted/expired medications at different customer zones [18]. Hospitals and pharmacies, as the main consumers of medications, are faced with uncertain and fluctuating demand. Since the shortage of certain medications might lead to severe consequences for patients, customers might adopt a conservative inventory control policy through keeping large quantities of drugs in stock. Given the perishable nature of medications, such a strategy would lead to the expiration of excess inventory in the absence of patients demand. In contrary, if unwanted medications are returned to the producer prior to the end of their shelf-lives, they can be either sold in subsidiary markets or donated in developing and undeveloped countries. This humanitarian aid could improve the quality of health care in such communities. Accordingly, improving the reverse supply chain (RSC) is one way to gain and maintain strategic advantages in this industry.

Medications recovery process is complex in the sense that information about available amounts of leftovers, the willingness of customers to return medications, and the cost associated with the collection and disposal processes are not always known by the producer [26]. The paucity of such information could be indeed the result of the lack of trust and coordination between producers, customers, and 3PL companies. Moreover, the direct and leakage effects of information sharing discourage companies from collaboration [20]. Hence an efficient decision-making process in such RSCs is bound to fail unless a coherent coordination mechanism is utilized [21].

While many studies have investigated the impact of coordination on forward supply chain networks [16, 23], the literature is scant on the benefits of coordination in RSC networks. The available literature is limited to the profitable RSCs, such as the electronics recovery networks [28, 14]. This is due to the possibility of reusing the precious metals in such networks. On the other hand, knowing the complexity of the pharmaceutical RSC, little attention has been addressed for the coordination of this specific value chain. The negligible salvage value of the expired medications has also encumbered the investment in this RSC.

In this research, we investigate the use of coordination methods to ensure full medication recovery while sharing the savings fairly between members of a pharmaceutical RSC. The current structure of this pharmaceutical RSC involves the producer, the 3PL companies, and the RSC customers. We can observe that hospitals and pharmacies, as the RSC customers, keep medications to expire at their sites; then, they inform the producer about the quantity of the expired medications. Because it is a non profitable activity, the producer is not motivated to collect the expired medications by herself. Instead, she contracts with one or more 3PL companies to collect the expired items at customer zones by offering non-negotiable collecting fees. Thereafter, 3PL companies collect the medications and ship them to one of the governmental safe disposal sites. Consequently, the producer pays disposal fees to the government for those shipped items.

It is worth mentioning that depending on the collecting fees offered by the producer, 3PL companies might only collect a percentage of the available leftovers according to their own profit margins. If we look at the archival data of the pharmaceutical producer under investigation, we can notice that the collecting fees that are paid currently to 3PL companies are insufficient. In other words, about 20% to 40% of the available unwanted medications remain uncollected. Leaving expired medications at customer zones and disposing them improperly (e.g., thrown away in water resources), lead to penalties that must be paid by the producer to the government. Furthermore, this puts company's reputation in the market in peril due to the negative environmental footprint of her products. Therefore, new strategies have to be implemented to ensure the RSC effectiveness and to reduce the negative environmental impacts.

Against the current reactive approach in collecting unwanted medications, in this article, we propose a proactive approach. It involves offering incentives to customers to encourage them to return those medications that have high stock levels and less demand before their expiry date. By involving customers in the recovery process, medications could be collected in a sufficient time to expiry date. Hence, they could be donated or sold in subsidiary markets. The idea is to have more efficient and sustainable RSC by involving customers in the recovery process [25]. In other words, these alternative reduces the risk of medical traces in groundwater by decreasing the quantity of medications that are landfilled while ensuring humanitarian aid. Besides, producers can earn revenue by selling the unexpired medications in subsidiary markets and benefit from tax deductions after donating them to developing countries.

To achieve this, we propose two coordination schemes between the pharmaceutical producer, the 3PL companies, and the customers. They have been modeled by the aid of nonlinear mathematical programming to reflect the decision-making process of the pharmaceutical RSC under study. While the first model is mainly focused on producer-customer coordination, the second one incorporates a negotiation mechanism to the first model in order to motivate 3PL companies to collect the total amount of leftover medications at customer zones. Finally, in order to reward the 3PL coordination efforts, we propose a procedure for sharing the expected savings in the enhanced RSC. To the best of our knowledge, this study is the first contribution to the literature that develops a coordination mechanism among all entities of RSC (i.e., customer, producer, and 3PL companies) in the pharmaceutical industry.

Our experimental results on a real case study reveal the importance of ensuring customers' coordination in increasing the return volume up to 6.5% while creating extra revenue/tax deduction for the producer. Furthermore, by implementing the proposed negotiation mechanism with 3PL companies, all leftovers can be collected at customer zones, hence no more penalties will be paid to the government. The cost of such coordination for the company would incorporate the incentive paid to customers, increased collection fees, as well as a portion of the savings that would have to be paid to 3PL companies. In return, adopting sustainable practices, such as the safe disposal of expired medications and regulated redistribution of unexpired ones to developing countries, is expected to improve the company's image in the market. Furthermore, the proposed producer-customer coordination has financial benefits for the producer as opposed to the current practice where the disposal of expired medications has no cash return.

This paper is structured as follows. A brief summary of the literature related to RSC coordination is given in section 2. In section 3, the description of the case study context and two different coordination models are proposed. Numerical results for each model are presented in 4. Finally, concluding remarks and future recommendations are provided in section 5.

2. Literature Review

With the imposed environmental regulations, a stream of research has been focused on involving the recovery process in supply chain practices [4]. For example, detailed reviews on RSC models can be found in [1, 2]. Knowing that supply chains inherently involve multiple independent decision-makers, profitable solutions for every member are complicated and seldom to be obtained unless a proper coordination mechanism is utilized. A coordination mechanism can be used to conquer the anti-trust problems, loss of control, the uncertainty about local policies, the variability of a returned product quality, etc [3].

Camarinha-Motas et al. [7] reviewed the key concepts, classifications, and some applications related to supply chain coordination. Kanda et al. [16] presented a holistic review of the available literature prior to 2008 on the supply chain coordination. According to the authors, coordination mechanisms for supply chains can be achieved through (1) supply chain contracts, (2) information technology, (3) information sharing, or (4) joint decision making. Many papers in the available literature on coordination mechanisms deal with forward supply chains and focus on coordinative contracts, such as revenue-sharing [6, 13, 31], buyback contracts [22], and quantity discounts [5]. In particular, if we look at the revenue-sharing techniques investigated, Cachon and Lariviere [6] studied the effect of revenue-sharing on the supply chain performance. They highlighted the limitations of revenue-sharing contract, such as the administrative burden it imposes on supply chain entities. Cao et al. [8] implemented a revenue-sharing contract to coordinate a decentralized supply chain for one manufacturer and multiple retailers. Giannoccaro and Pontrandolfo [13] proposed another revenue-sharing contract to coordinate a three-stage model. By tuning the contract parameters, they could achieve supply chain's efficiency and improve the profits of all the entities. Recently, Du et al. [9] studied a two-echelon supply chain coordinated by a credit payment and a wholesale price discount offer. Their results lead to the determination of the retail price and the quantity to order by a buyer, as well as the wholesale discount for the supplier.

A part of the literature also considers negotiation as a coordination method. For example, Dudek and Stadtler [11, 10] proposed negotiation models for two independent supply chain partners. Their results stated that using coordinative mechanisms could improve the overall performance of a forward supply chain. Jung et al. [15] proposed a negotiation process for a distributor and a manufacturer. The coordination was directed by the distributor. They aimed at finding a feasible plan for supply quantities from the manufacturer to the distributor with a minimum amount of information revelation to partners.

As aforementioned, the coordination in RSC is troublesome due to the uncertain quality of the returns, the associated costs, the volume of returns, etc [1]. Therefore, the relevant literature on coordination in RSC is very recent and limited to few of the coordination mechanisms already implemented for the forward supply chains, such as revenue-sharing contracts.

Due to the profitability of recovery practices in electronics industry, the majority of articles on RSC coordination are focused on this industry. Very recently, Govindan and Popiuc [14] investigated two and three-echelon RSCs for the personal computer industry. They coordinated the network through the implementation of revenue-sharing contracts. Moreover, the authors suggested discounts to the RSC customers to return obsolete units. Their results stated that RSC performance and total profit could be improved through revenue-sharing and customer incentives contracts. Kulshreshthaa and Sarangib [17] investigated the effect of offering deposit-refund scheme to promote the return and reuse of product packages. The refund is deducted from a deposit that is added to the price of the product and is known at the time of purchase. More precisely, the company chooses a price for a product and offers a refund for the same product at the time of purchasing. Walther et al. [28] developed a decentralized negotiation model to enable allocating product recovery tasks to recycling companies in the electronic industry. Their negotiation model enables the generation of contracts between the RSC entities which consist of masses to collect and recycle, as well as transfer prices to pay.

In contrary, due to the particularities of the pharmaceutical RSC, such as the null salvage value of medication recovery and the associated costs, the available literature on this RSC is mainly limited to theoretical frameworks for such supply chains. For example, Kumar et al. [18] proposed a framework to state each party's responsibility in the pharmaceutical RSC. Xie and Breen [30] designed a green pharmaceutical supply chain model to reduce preventable pharmaceutical waste. The study revealed that the RSC practices are hard to implement in the pharmaceutical industry since returned medications cannot be reused or resold.

Lately, Weraikat et al. [29] proposed a negotiation mechanism in order to coordinate the recovery process between a producer and 3PL companies in the pharmaceutical RSC. They also proposed a mechanism for sharing the savings of such coordination among RSC entities. However, their approach is based on the current situation of the industry where all leftover medications are remained at customer zones to expire. Therefore, in this article, we propose involving customers in the coordination process of the RSC and encouraging them to participate in the process. By including customers in the recovery process, the producer could collect more of the unexpired medications, then donate or sell them in subsidiary markets.

3. Pharmaceutical RSC coordination models

In this section, we first provide a brief description of the current RSC structure in the pharmaceutical company under discussion, *Generic PharmaX*; then we provide the producer-customer and producer-customer-3PL coordination models developed for better coordinating the RSC and ensuring full medication recovery.

As aforementioned, hospitals and pharmacies keep the medications to expire at their sites, then they inform the producer about the quantities available. Since the collecting process is not one of the core functions for *Generic PharmaX*, she contracts with 3PL companies to pick up the leftover medications at customer zones. In turn, 3PL companies send the medications to the governmental disposal sites. Consequently, the producer needs to pay fees to the government for the disposed medications. Moreover, she is obligated to pay penalties for uncollected medications at customer zones. Figure 1 visualizes the current RSC practices in *Generic PharmaX*.

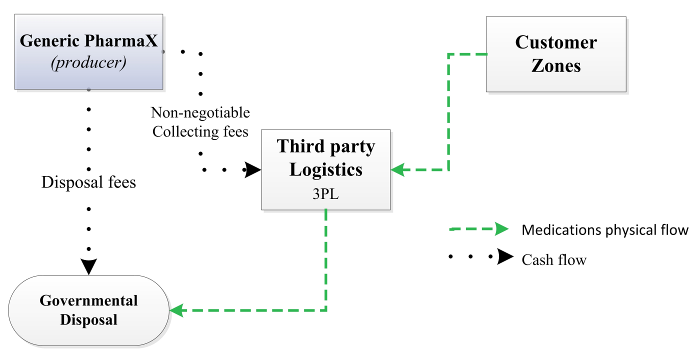

Figure 1: The current RSC of *Generic PharmaX*

3.1. Producer-customer coordination scheme

According to *Generic PharmaX*, there are always some amounts of medication at customer zones that are at risk of being expired due to low demand. If such medications are collected at a sufficient time before the expiry date, they can be resold in subsidiary markets or be donated. In the latter case, the producer can benefit from tax deductions while the former option creates revenue for the company.

In the first coordination model, we suggest to pay incentives to customers in order to encourage them to collaborate and to return unwanted medications that have not yet reached their expiry dates. The suggested incentives are offered with respect to shelf-life of the collected medications. The following categories are considered for classifying the unwanted medications:

1. **Category A** represents the medications that have a shelf-life of two years or more. The producer can resell these medications in a subsidiary market at a selling price less than the price of a new medication;
2. **Category B** represents the medications that have less than two years and more than a year shelf-life. The producer can donate these medications to developing countries and hence, benefit from tax deductions;
3. **Category C** represents medications with the expiry date of less than or equal to one year from the collecting date. In this case, the medication is safely disposed at one of the governmental sites.

Knowing that there are always chances to use the unexpired medications, it is a recondite judgment for customers to think about these medications as unwanted products. Hence, customers might be averse to give back the medications that are from categories A and B. Therefore, to reflect the reality, we introduce customer willingnesses to return medications from these two categories. We define customer willingness as the ratio of the incentive that the producer offers to customers over an incentive threshold (denoted as d^{max}) that is imposed by the customer. If the producer could provide that threshold, the customers would return the total available amounts of that category, i.e., the customer willingness to return would be 1. It is noteworthy that many factors affect the value of the customer incentive threshold such as the criticality of that medication, its price, and the demand. Nonetheless, the producer cannot pay incentives to customers greater than products prices in subsidiary markets for medications in category A or the amounts of tax deduction for returning medications in category B. Hence, customer willingness will always take a value less than or equal to 1.On the other hand, sorting and keeping track of the unexpired medications involve extra cost for the customers. Therefore, they request a minimum value for the incentives offered in order to collaborate and return part of such medications. This lower bound is denoted as d^{min} for both categories.

The proposed producer-customer coordination model is shown in figure 2. The figure illustrates that the producer offers incentives to customers for medications in categories A and B. Furthermore, the producer contracts with the 3PL companies to collect the medications, where collecting fees are non-negotiable. The 3PL companies collect and sort the medications

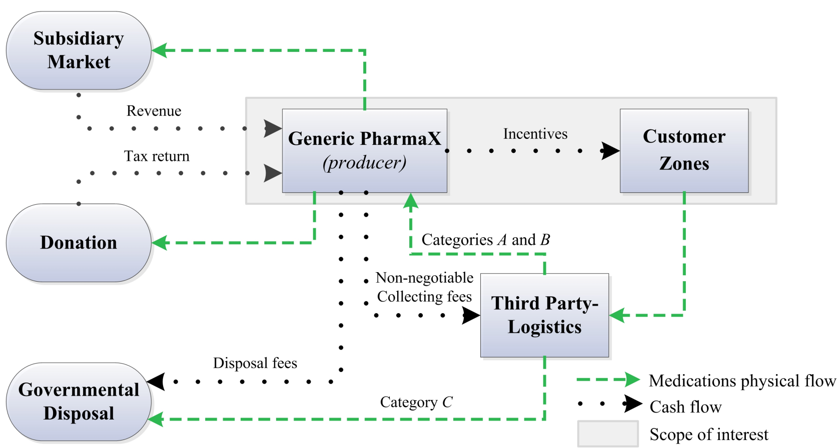

Figure 2: A producer-customer coordination RSC

with respect to expiry-dates. Medications from category C are sent directly to governmental disposal sites, where the rest of the medications are sent to the producer. The producer sells medications of category A in subsidiary markets and donates the medications from category B to some developing countries.

3.1.1. Producer-customer coordination model

In what follows, we provide the nonlinear mathematical programming model proposed in this article, in order to formulate the producer-customer coordination scheme in the pharmaceutical RSC under discussion.

Notations

Index sets:

i: index of medications, $i \in I$;

k: index of customers, $k \in K$;

j: index of 3PL companies, $j \in J$;

The producers' parameters:

P_i: the selling price of a medication type i at a subsidiary market (\$);

TX_i: the monetary deductive value from the producer's tax if she donates a unit of medication type i (\$);

CD_i: the obligatory disposal fees by governments for each unit of medication type i sent to governmental disposal sinks (\$);

M_i: the transportation cost of shipping a unit of medication type i to a subsidiary market (\$);

α: the available percentage of medications in category A;

β: the available percentage of medications in category B;

γ: the available percentage of medications in category C;

ϕ_i: the penalties enforced by governments for each unit of uncollected medication type i (\$);

A_{ik}: total mass of medication type i that is potentially available to be collected at customer zone k;

The customers' parameters:

dm_i^{max}: the threshold of incentive that a customer requests in order to return all of the medication type i in category A (\$);

dd_i^{max}: the threshold of incentive that a customer requests in order to return all of the medication type i in category B (\$);

dm_i^{min}: the minimum incentive a customer requests in order to collaborate and return a medication type i in category A (\$);

dd_i^{min}: the minimum incentive customers requests in order to collaborate and return a medication type i in category B (\$);

The 3PL companies' parameters

S_{ij}: collecting and sorting costs incurred by 3PL company j for each unit of medication type i (\$);

TS_{ij}: unit transportation cost of medication type i from 3PL company j to safe disposal sites (\$);

TC_{ij}: unit transportation cost of medication type i from 3PL company j to the producer (\$);

D_j: collecting and sorting capacity of 3PL company j (\$)

Decision variables:

dm_i: the incentive the producer offers to customers for returned medication type i in category A (\$);

dd_i: the incentive the producer offers to customers for returned medication type i in category B (\$);

Qm_{ikj}: the collected amount of medications type i from category A by 3PL company j at customer zone k;

Qd_{ikj}: the collected amount of medications type i from category B by 3PL company j at customer zone k;

Qs_{ikj}: the collected amount of medications type i from category C by 3PL company j at customer zone k;

$QE_{M_{ik}}$: the uncollected amount of medications type i from category A at customer zones k;

$QE_{D_{ik}}$: the uncollected amount of medications type i from category B at customer zones k;

$QE_{S_{ik}}$: the uncollected amount of medications type i from category C at customer zones k;

ω_{m_i}: customers' willingness to return medications of type i from category A expressed as ratio of the incentive value offered by the producer to the customer incentive thresholds ($\omega_{m_i} = dm_i/dm_i^{max}$, where $0 \leq \omega_{m_i} \leq 1$);

ω_{d_i}: customers' willingness to return medications of type i from category B expressed as ratio of the incentive value offered by the producer to the customer incentive thresholds

($\omega_{d_i} = dd_i/dd_i^{max}$, where $0 \leq \omega_{d_i} \leq 1$).

The nonlinear mathematical model that represents the producer-customer coordination scheme is provided in equations (1)-(12) as follows.

The objective function is shown in equation (1). It represents the profit of the RSC determined as the revenues minus the costs and denoted as Z_{RSC}. The revenue involves the revenue of selling the returned medications at subsidiary markets and the monetary tax deduction after donating collected medications. The costs include the disposal fees paid to the government, the transportation cost to the subsidiary market, the incentives paid to customers, the penalties paid to the government for the uncollected amounts of categories B and C, the collecting and sorting costs, transportation costs to the governmental disposal, and transportation costs to the producer.

$$\begin{aligned} Maximize\ \ Z_{RSC} = &\sum_{i\in I}\sum_{j\in J}\sum_{k\in K} P_i.Qm_{ikj} + \sum_{i\in I}\sum_{j\in J}\sum_{k\in K} TX_i.Qd_{ikj} - \sum_{i\in I}\sum_{j\in J}\sum_{k\in K} CD_i.Qs_{ikj} \\ &- \sum_{i\in I}\sum_{j\in J}\sum_{k\in K} M_i.(Qm_{ikj} + Qd_{ikj}) - \sum_{i\in I}\sum_{j\in J}\sum_{k\in K} dm_i.Qm_{ikj} - \sum_{i\in I}\sum_{j\in J}\sum_{k\in K} dd_i.Qd_{ikj} \\ &- \sum_{i\in I}\sum_{k\in K} \phi_i * (QE_{D_{ik}} + QE_{S_{ik}}) - \sum_{i\in I}\sum_{j\in J}\sum_{k\in K} S_{ij}.(Qm_{ikj} + Qs_{ikj} + Qd_{ikj}) \\ &- \sum_{i\in I}\sum_{j\in J}\sum_{k\in K} TS_{ij}.Qs_{ikj} - \sum_{i\in I}\sum_{j\in J}\sum_{k\in K} TC_{ij}.(Qm_{ikj} + Qd_{ikj}) \end{aligned} \tag{1}$$

The objective function is constrained by the amounts of medications that are potentially available at customer zones to be collected. The available amounts at customer zones incorporate medications from all categories (equation 2).

$$A_{ik} = \sum_{j\in J}(Qm_{ikj} + Qd_{ikj} + Qs_{ikj}) + QE_{M_{ik}} + QE_{D_{ik}} + QE_{S_{ik}}, \quad \forall i \in I, \quad \forall k \in K \tag{2}$$

As mentioned earlier, the quantities of collected medications from category A are affected by the willingness of customers to collaborate and by the available amounts from that category (constraint 3). Moreover, medications from the same category are either collected or uncollected as depicted in constraint (4).

$$\sum_{j \in J} Qm_{ikj} \quad \leq \omega_{m_i}.\alpha.A_{ik}, \qquad \forall i \in I, \quad \forall k \in K \tag{3}$$

$$\alpha.A_{ik} = \sum_{j \in J} Qm_{ikj} + QE_{M_{ik}}, \qquad \forall i \in I, \quad \forall k \in K \tag{4}$$

By the same token, the collected medications from category B are affected by the willingness of customers to collaborate and by the available amounts from that category (constraint 5). Constraint (6) reflects the fact that the available amounts from category B can be collected or uncollected.

$$\sum_{j \in J} Qd_{ikj} \quad \leq \omega_{d_i}.\beta.A_{ik}, \qquad \forall i \in I, \quad \forall k \in K \tag{5}$$

$$\beta.A_{ik} = \sum_{j \in J} Qd_{ikj} + QE_{D_{ik}}, \qquad \forall i \in I, \quad \forall k \in K \tag{6}$$

For category C medications, constraint (7) expresses the fact that the collected amounts from this category cannot exceed the available medications from the same category. Constraint (8) reflects possible options for the available amounts from category C, i.e., to be collected or uncollected.

$$\sum_{j \in J} Qs_{ikj} \quad \leq \gamma.A_{ik}, \qquad \forall i \in I, \quad \forall k \in K \tag{7}$$

$$\gamma.A_{ik} = \sum_{j \in J} QS_{ikj} + QE_{S_{ik}}, \qquad \forall i \in I, \quad \forall k \in K \tag{8}$$

The customer incentive thresholds for the medications from categories A and B are given in constraints (9) and (10).

$$dm_i^{min} \leq dm_i \leq dm_i^{max}, \qquad \forall i \in I \tag{9}$$

$$dd_i^{min} \leq dd_i \leq dd_i^{max}, \qquad \forall i \in I \tag{10}$$

Constraint (11) indicates that the collected medications from all categories by each 3PL company cannot exceed its capacity.

$$\sum_{i \in I} \sum_{k \in K} S_{ij}.(Qm_{ikj} + Qs_{ikj} + Qd_{ikj}) \leq D_j, \qquad \forall j \in J \tag{11}$$

Finally, domain constraints are provided in (12).

$$dm_i, dd_i, Qm_{ikj}, Qd_{ikj}, Qs_{ikj}, QE_{M_{ik}}, QE_{D_{ik}}, QE_{S_{ik}} \geq 0, \qquad \forall j \in J \tag{12}$$

3.2. Producer-customer-3PL coordination scheme

In the producer-customer coordination scheme, provided in 3.1, offering incentives to customers might be enough to motivate them to inform the producer regarding the amounts of available unwanted/unexpired medications. However, it does not necessarily guarantee the complete collection of such leftovers by 3PL companies due to the non-negotiable collecting fees offered by the producer. In order to solve this issue, a negotiation mechanism between the producer and 3PL companies is proposed.

Figure 3 visualizes the producer-customer-3PL coordination scheme. In order to motivate the 3PL companies to collect all of the available leftover medications at customer zones, we propose that the producer negotiates with the 3PL companies over contracts' parameters, i.e., collecting fees offered by the producer and the quantities that must be collected by 3PL companies. Once the producer and 3PL companies reach to a contract all agree on, the 3PL companies pick up the medications from the three different categories.

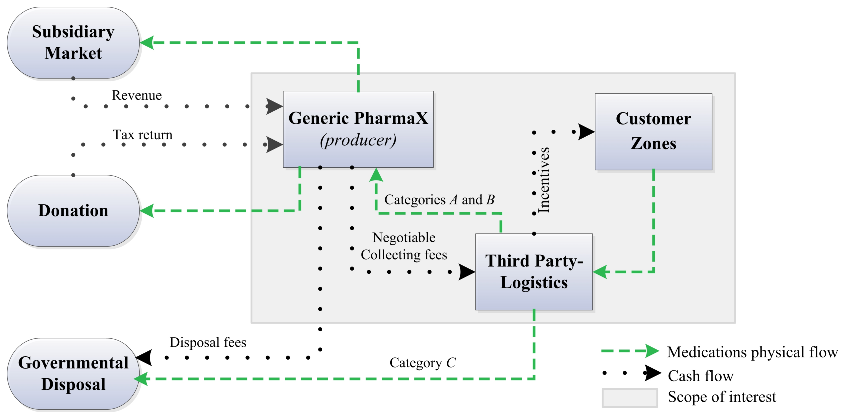

Figure 3: Producer-customer-3PL coordination RSC

This negotiation mechanism is summarized in figure 4. The producer leads the negotiation process and offers collecting fees to 3PL companies. We assume that the producer delegates the responsibility of offering incentives to customers to 3PLs. In other words, part of the collecting fees that are offered by the producer must be paid to customers as incentive in order to return medications from categories A and B. This assumption is essential in order to represent the proposed negotiation mechanism as a mathematical model. After receiving contract parameters, each 3PL company determines the incentive that must be offered to customers as well as the quantities that can be collected from all categories with respect to its capacity and profit margins. Afterwards, the producer will be informed regarding 3PLs decisions. It is evident that if the incentives offered to customers are not attractive enough, only part of medications from categories A and B might be returned to 3PLs. In turn, the producer checks the total amount collected from all 3PL companies. If not all of the available medications are collected, the producer will revise the contract parameters. As summarized in figure 4, the offers and reactions are exchanged until both parties agreed upon customer incentives as well as collecting fees such that all available medications are collected by 3PL companies. In what follows, this negotiation process is mathematically represented by the aid of Lagrangian relaxation method.

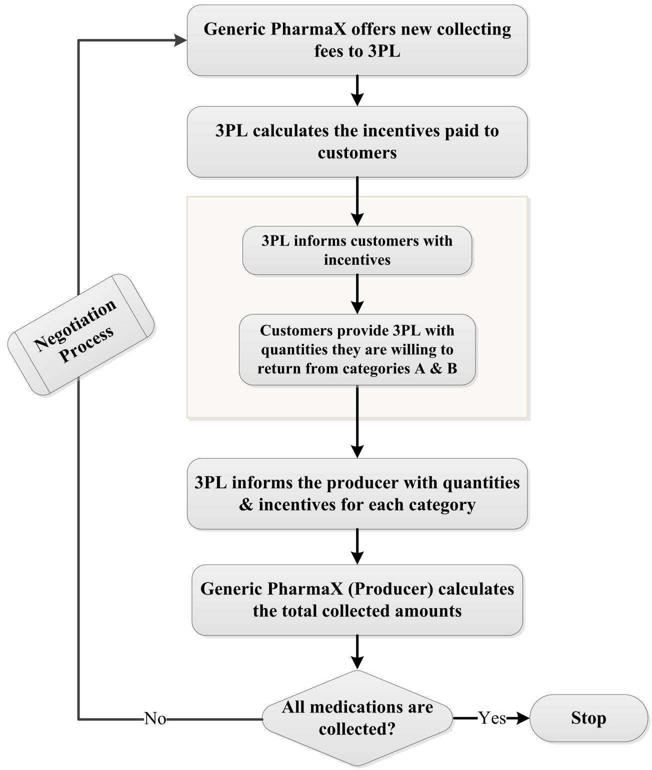

Figure 4: The negotiation approach in the RSC

3.2.1. *Producer-customer-3PL coordination model*

In order to mathematically represent the above mentioned negotiation process, the RSC coordination model (1)-(12) must be decomposed into "producer" and "3PLs" sub-models. Inspired by [29], this decomposition can be implemented by the aid of Lagrangian relaxation method [12, 27]. More specifically, by relaxing constraints (2) to (8) that link the producer decisions to 3PL ones from the model (1)-(12) and by penalizing their violation in the objective function with the aid of Lagrangian multipliers, we obtain a RSC model that only involves 3PLs information and decisions. On the other hand, the producer will only need to verify the satisfaction of relaxed constraints (2)-(8) that correspond to the collection of all available medications at customer zones. In the case of violation of such constraints, penalties would be calculated and new collecting fees would be offered to 3PL companies accordingly. In what follows, we provide mathematical models corresponding to the producer-customer-3PL coordination scheme. In this negotiation model, the following notations are used in addition to those provided in 3.1.

Producer-customer-3PL coordination model extra notations

π^m_{ik}: Lagrangian penalties corresponding to the uncollected mass unit of medication type i in category A at customer zones k (\$);

π^d_{ik}: Lagrangian penalties corresponding to the uncollected mass unit of medication type i in category B at customer zones k (\$);

π^s_{ik}: Lagrangian penalties corresponding to the uncollected mass unit of medication type i in category B at customer zones k (\$);

ϵ_{ik}: collecting fees paid by the producer to 3PL companies to collect the medication type i in category A at customer zones k (\$);

ζ_{ik}: collecting fees paid by the producer to 3PL companies to collect the medication type i in category B at customer zones k (\$);

η_{ik}: collecting fees paid by the producer to 3PL companies to collect the medication type i in category C at customer zones k (\$);

Z^{LR}_C: the objective function of the RSC Lagrangian relaxation model;

Z_{3PL}: the objective function of a 3PL company Lagrangian relaxation model.

As mentioned earlier, in order to extract the "3PLs" sub-models from model (1)-(12), we relax constraints (2) to (8) and penalize their violation in the objective function with the Lagrangian multipliers (π^m_{ik}, π^d_{ik}, π^s_{ik}). Consequently, the RSC coordination model can be formulated as (13) subject to constraints (9) to (11).

$$
\begin{aligned}
Maximize\ Z_C^{LR} = & \sum_{i\in I}\sum_{j\in J}\sum_{k\in K}(P_i - M_i - dm_i - \pi_{ik}^m - S_{ij} - TC_{ij}).Qm_{ikj} \\
& + \sum_{i\in I}\sum_{j\in J}\sum_{k\in K}(TX_i - M_i - dd_i + \phi_i - \pi_{ik}^d - S_{ij} - TC_{ij}).Qd_{ikj} \\
& + \sum_{i\in I}\sum_{j\in J}\sum_{k\in K}(-CD_i + \phi_i - \pi_{ik}^s - S_{ij} - TS_{ij}).Qs_{ikj} \\
& + \sum_{i\in I}\sum_{k\in K}\pi_{ik}^m.\omega_{m_i}.\alpha A_{ik} - \sum_{i\in I}\sum_{k\in K}(\phi_i - \omega_{d_i}.\pi_{ik}^d).\beta A_{ik} - \sum_{i\in I}\sum_{k\in K}(\phi_i - \pi_{ik}^c).\gamma A_{ik}
\end{aligned} \tag{13}
$$

After reformulationg the objective function (equation (13)) and the replacement of (1) $P_i - M_i - \pi_{ik}^m = \epsilon_{ik}$, (2) $TX_i - M_i + \phi_i - \pi_{ik}^d = \zeta_{ik}$, and (3) $-CD_i - \phi_i - \pi_{ik}^s = \eta_{ik}$, we obtain model (14) with respect to constraints (9) to (11), which correspond to 3PL companies decision model.

$$
\begin{aligned}
Maximize\ Z_C^{LR} = & \sum_{i\in I}\sum_{j\in J}\sum_{k\in K}(\epsilon_{ik} - dm_i - S_{ij} - TC_{ij}).Qm_{ikj} + \sum_{i\in I}\sum_{j\in J}\sum_{k\in K}(\zeta_{ik} - dd_i - \\
& S_{ij} - TC_{ij}).Qd_{ikj} + \sum_{i\in I}\sum_{j\in J}\sum_{k\in K}(\eta_{ik} - S_{ij} - TS_{ij}).Qs_{ikj} + \sum_{i\in I}\sum_{k\in K}\pi_{ik}^m.\omega_{m_i}.\alpha A_{ik} \\
& - \sum_{i\in I}\sum_{k\in K}(\phi_i - \omega_{d_i}.\pi_{ik}^d).\beta A_{ik} - \sum_{i\in I}\sum_{k\in K}(\phi_i - \pi_{ik}^c).\gamma A_{ik}
\end{aligned} \tag{14}
$$

Next, a separate model is extracted from (14) for each 3PL company, as shown in (15)-(19).

$$
\begin{aligned}
Maximize\ Z_{3PL} = & \sum_{i\in I}\sum_{k\in K}(\epsilon_{ik} - dm_i - S_{ij} - TC_{ij}).Qm_{ikj} + \sum_{i\in I}\sum_{k\in K}(\zeta_{ik} - dd_i - \\
& S_{ij} - TC_{ij}).Qd_{ikj} + \sum_{i\in I}\sum_{k\in K}(\eta_{ik} - S_{ij} - TS_{ij}).Qs_{ikj}
\end{aligned} \tag{15}
$$

Subject to:

$$\sum_{i \in I} \sum_{k \in K} S_{ij}.(Qm_{ikj} + Qs_{ikj} + Qd_{ikj}) \leq D_j \tag{16}$$

$$dm_i^{min} \leq dm_i \leq dm_i^{max} \qquad \forall i \in I \tag{17}$$

$$dd_i^{min} \leq dd_i \leq dd_i^{max} \qquad \forall i \in I \tag{18}$$

$$Qm_{ikj}, Qd_{ikj}, Qs_{ikj}, dm_i, dd_i \geq 0 \tag{19}$$

The negotiation process starts with initializing contract parameters by the producer, i.e., the values of the Lagrangian multipliers (π_{ik}^m, π_{ik}^d, π_{ik}^s), as well as the values of the collecting fees (ϵ_{ik}, ζ_{ik}, η_{ik}). In addition to that, the producer informs the 3PL companies with these values. Each 3PL company solves model (15)-(19) and obtains the customers incentives for categories A and B. Next, the amounts of medications that can be collected and the incentives values that are offered to customers are presented to the producer. Afterwards, the producer checks constraints (2)-(8) to make sure that all available medications have been collected. If some leftovers are still uncollected, the producer revises those parameters and informs 3PL companies, as visualized in figure 4. This process is repeated until all medications are collected or constraints, i.e., (2)-(8) are satisfied.

As we are using a Lagrangian relaxation approach, a sub-gradient procedure is utilized in order to update contract parameters (Lagrangian multipliers). For example, in the RSC coordination model (Z_C^{LR}), let $\pi_{ik}^{m^t}$ be the value of π_{ik}^m at iteration t and $\sum_{j \in J} Qm_{ikj}^t$ be the optimal value of $\sum_{j \in J} Qm_{ikj}$ at the same iteration. Then

$$g^t_{\pi^m_{ik}} = \sum_{j \in J} Qm^t_{ikj} - \omega_{m_i}.\alpha.A_{ik} \qquad \forall i \in I, \quad \forall k \in K \tag{20}$$

equation (20) represents the sub-gradient function of the corresponding relaxed constraint (constraint (3)) at $\pi^{m^t}_{ik}$. In other words, $g^t_{\pi^m_{ik}}$ is the violation of the relaxed constraint in iteration t. As long as the relaxed constraint is unsatisfied, the new Lagrangian multiplier (π^m_{ik}) is calculated as follows:

$$\pi^{m^{t+1}}_{ik} = max(0, \pi^{m^t}_{ik} + \mu_t.g^t_{\pi^m_{ik}}) \tag{21}$$

where μ_t is a positive scalar step size at iteration t and is calculated as $\mu_t = b/t||g||$, b is a scalar quantity and $||g||$ is the Euclidean norm of the sub-gradient function.

Finally, we add constraints (22)-(24) to each 3PL company model (15)-(19) in order to ensure that the maximum collected medication from each category is less than or equal to that maximum limit for each category.

$$Qm_{ikj} \leq Qm^{max}_{ikj} \quad \forall i, k, j \tag{22}$$

$$Qd_{ikj} \leq Qd^{max}_{ikj} \quad \forall i, k, j \tag{23}$$

$$Qs_{ikj} \leq Qs^{max}_{ikj} \quad \forall i, k, j \tag{24}$$

3.3. RSC coordination efforts reward methodology

In order to encourage the 3PL companies to invest in the negotiation process while supporting the coordination effort, the producer is willing to share the monetary savings from penalties used to be paid to government for uncollected medications at customer zones. Inspired by two recent articles [19, 29], sharing the savings is proposed based on the investment of RSC entities (i.e., the producer and 3PL companies) in the coordination model as follows.

1. Calculate the investment value (R) of the RSC entities in the negotiation model. This can be calculated as the difference between the profit value of each RSC entity in the producer-customer-3PL coordination model and the current situation.

2. Then, normalize the investment value (R) as follows:

$$R_{3PL}^{nor} = \frac{R_{3PL}}{R_{3PL} + R_{Producer}} \quad and \quad R_{Producer}^{nor} = \frac{R_{Producer}}{R_{3PL} + R_{Producer}}$$

3. Calculate the share of each RSC entity from the savings (S) as:

$$S_{3PL} = Saving.R_{3PL}^{nor} \quad and \quad S_{Producer} = Saving.R_{Producer}^{nor},$$

   where $Saving$ represents penalties the producer could save if all the expired medications at customer zones are collected.

4. Numerical results and discussion

In the following, we extend the current RSC practices of *Generic PharmaX* to fit the models proposed in section 3. First, we describe the producer-customer coordination model results. Second, the results for the producer-customer-3PL coordination models are presented. Afterwards, we compare the results of both models. Finally, the reward of coordination efforts is provided.

Parameters corresponding to the two proposed models such as different costs and fees were obtained through communication with the head of $GenericPharmaX$ supply chain department. After refining the data, four 3PL companies and four customers were selected among the largest collectors and customers. Twenty types of medications among the most important products were also selected from the producer records.

4.1. Producer-customer coordination model results

In this section, we provide the results of implementing the producer-customer coordination model on the case study described above. Also, we investigate the impact of the percentage of available medications from each category and the customer incentive thresholds on the performance of RSC by the aid of design of experiments (DOE) [24].

For this purpose, three factors were considered in the experimentation, i.e., (1) the percentage of available medications from each category at customer zones, (2) the customer incentive threshold for category A, and (3) the customer incentive threshold for category B. Moreover, the most important key performance indicators (response variables) for the producer incorporate the objective function value of model (1)-(12) (RSC profit), the amount of uncollected medications from category C, and the customer willingness values for categories A and B.

Factor level combinations in the designed experiments are depicted in figure 5. According to the producer, the most likely ratio for the available medications from each category at customer zones is (10:20:70), i.e., 10% of the available amounts at customer zones are from category A, 20% are from category B, and 70% are from category C. The customer incentive thresholds are considered as 50%, 70%, 100% of the medication prices in secondary markets and tax deduction amounts for medications in categories A and B, respectively. The smallest incentive value required by the customers to inform the producer about the available medications in categories A and B (d^{min}) is considered as 20% of medication prices in subsidiary markets and tax deduction amounts. Afterwards, model (1)-(12) was solved (by *Cplex*) for 27 iterations and the results are provided in table 1.

Minitab 16 was used to analyze the relationships between percentages of available medication as well as the customer incentive thresholds and the RSC profit. The results reveal that the

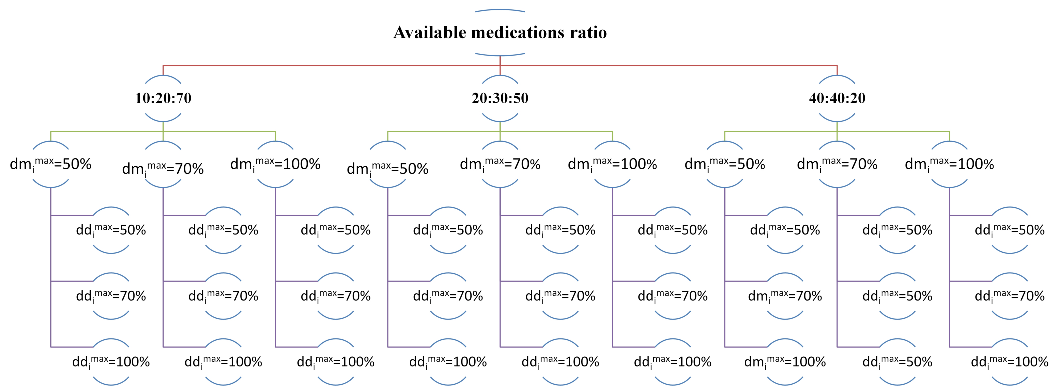

Figure 5: Factor level combinations for producer-customer coordination model

Table 1: Some of the producer-customer coordination model results

d^{max}	**Category A= 50%**			Category A = **50%**			Category A =**50%**		
d^{max}	Category B = 50%			Category B = 70%			Category B = 100%		
AMR^*	**10:20:70**	**20:30:50**	**40:40:20**	**10:20:70**	**20:30:50**	**40:40:20**	**10:20:70**	**20:30:50**	**40:40:20**
Objective value ($)	**49,928.49**	**123,181.77**	**257,670.21**	**44,553.46**	**115,119.21**	**246,920.14**	**38,955.08**	**106,721.64**	**235,723.39**
QE_M (kg)	80.14	143.78	287.55	80.13881	143.7774	287.55405	80.14	143.78	287.55
QE_D (kg)	0.00	0.00	0.00	164.2571	246.38577	328.51429	1,242.83	1,864.24	2,485.66
QE_S (kg)	1,647.75	0.00	0.00	1,647.75	0.00	0.00	1,647.75	0.00	0.00
ω_m	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97
ω_d	1.00	1.00	1.00	0.98	0.98	0.98	0.84	0.84	0.84
d^{max}	**Category A = 70%**			**Category A = 70%**			**Category A= 70%**		
d^{max}	Category B = 50%			Category B = 70%			Category B = 100%		
AMR^*	**10:20:70**	**20:30:50**	**40:40:20**	**10:20:70**	**20:30:50**	**40:40:20**	**10:20:70**	**20:30:50**	**40:40:20**
Objective value ($)	**32,309.30**	**87,653.25**	**186,613.18**	**26,934.26**	**79,590.69**	**175,863.11**	**21,335.89**	**71,193.13**	**164,666.36**
QE_M (kg)	744.67	1,477.56	2,955.11	744.67	1,477.56	2,955.11	744.67	1,477.56	2,955.11
QE_D (kg)	0.00	0.00	0.00	164.26	246.39	328.51	1,242.83	1,864.24	2,485.66
QE_S (kg)	1,577.52	0.00	0.00	1,577.52	0.00	0.00	1,577.52	0.00	0.00
ω_m	0.70	0.70	0.70	0.69	0.69	0.70	0.69	0.70	0.70
ω_d	1.00	1.00	1.00	0.97	0.97	0.97	0.84	0.84	0.84
d^{max}	**Category A = 100%**			**Category A = 100%**			**Category A = 100%**		
d^{max}	Category B = 50%			Category B = 70%			Category B = 100%		
AMR^*	**10:20:70**	**20:30:50**	**40:40:20**	**10:20:70**	**20:30:50**	**40:40:20**	**10:20:70**	**20:30:50**	**40:40:20**
Objective value ($)	**19,094.73**	**61,006.87**	**133,320.41**	**13,719.69**	**52,944.31**	**122,570.33**	**8,121.32**	**44,546.74**	**111,373.58**
QE_M (kg)	1,242.98	2,477.89	4,955.78	1,242.98	2,477.89	4,955.78	1,242.98	2,477.89	4,955.78
QE_D (kg)	0.00	0.00	0.00	164.26	246.39	328.51	1,242.83	1,864.24	2,485.66
QE_S (kg)	1,524.77	0.00	0.00	1,524.77	0.00	0.00	1,524.77	0.00	0.00
ω_m	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49
ω_d	1.00	1.00	1.00	0.97	0.97	0.97	0.84	0.84	0.84

AMR^*: Available Medication Ratio

percentage of available medications from each category and the customer incentive threshold for category A have significant impact on the objective function value (profit). Also, the results display that the customer incentive threshold for category B has no significant impact on the profit (i.e., medications donated to developing countries). The reason can be due to small tax deduction amounts that the government is willing to offer to the producer for donating medications. Nevertheless, such humanitarian aids would improve the producer's image in the market. Same results were obtained from the main effect plot, as shown in figure 6. Moreover, from the interaction analysis between factors, we conclude that for a low level medication ratio of category A (i.e., 10%), there is a slight negative effect of the customer incentive threshold on the profit.

We first discuss the impact of medication ratio and customer incentive thresholds on the RSC profit. As it can be observed in table 1, the profit, as the first response in the analysis, increases when the percentage of available medications from category C decreases (i.e., medications safely disposed at government sites). For example, considering the case of 50% for customer incentive thresholds, when 20% of available medications are from category C, the objective function value is higher than the case where the percentage is 50% or 70% for the same category. This is mainly due to negligible salvage value of returned medications in category C. In contrary, since returned medications in category A can be sold at subsidiary markets, higher percentages of category A increases the RSC profit. On the other hand, our results reveal that the customer incentive threshold of medications in category A has a negative impact on profit. The reason is that higher incentive thresholds indicate customer reluctance in returning medications. Hence, the producer needs to increase the incentives offered to customers in order to increase their willingness to return such medications. The latter has a negative impact on the profitability of the RSC.

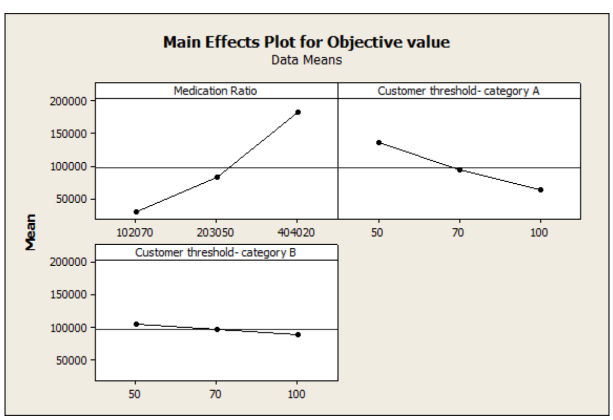

Figure 6: The main effects plot for the objective function- $Minitab$

Next, we look at the impact of the aforementioned factors on the amount of the uncollected medication from category C, $QE_{S_{ik}}$. Considering the most realistic case for percentage of available medications (i.e., 10:20:70), it can be said that regardless the customer incentive threshold, the available medications from category C are not completely collected, i.e., $QE_s \neq 0$. In other words, introducing customer incentives is not enough to ensure a full recovery when the majority of the available medications are from category C, as also highlighted in table 1. In contrary, the offered incentives have been adequate for the recovery of all medications for the other percentages of available medications (i.e., 20:30:50 and 40:40:20). However, knowing that the current average total uncollected amounts is equal to $4,292$ units, it can be said that introducing customer incentives could reduce that amount by up to $1,524.77$ units, i.e., 11.5% reduction. Hence it can be concluded that the percentage of available medications from each category has a negative significant impact on the uncollected medications from category C. However, the customer incentive threshold for category A has a slight significant impact on the uncollected medications from category C. This comes at no surprise, since the recovery process is less profitable in the presence of higher amounts of medications in category C no matter the value of customer willingness to return medications in category A is. Moreover, the results state that the customer incentive threshold for category B is insignificant, as shown in figure 7.

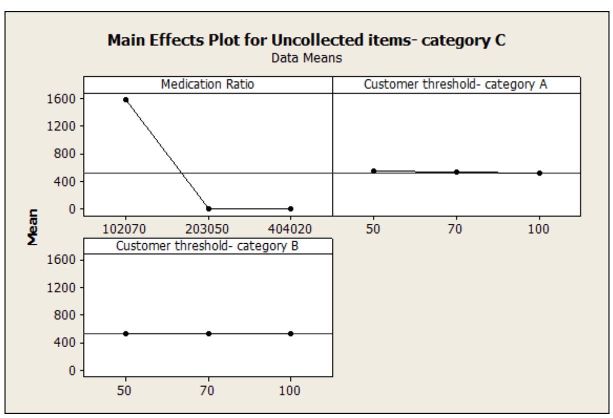

Figure 7: The main effects plot for the uncollected medication in category C- $Minitab$

Finally, we analyze the impact of medication ratio and incentive thresholds on customer willingness on returning those medications. As it can be observed in table 1, increasing the customer incentive thresholds has a negative impact on the willingness values and on the uncollected medications from different categories. This means that the producer is not willing to offer incentives more than certain limits to make the RSC more profitable. Recall that the customer willingness is $\omega = d/d^{max}$, where d is the incentives offered by the producer and d^{max} is the customer threshold. For example, consider the case of 50% customer incentives, the average willingness of category A is about 0.97 and 1.00 for category B. In other words, the producer is willing to pay this threshold (which is equal to 50% of medication prices in subsidiary markets). On the other hand, raising the customer incentive thresholds of category A to 100% results in willingness values of 0.49 for the same category. This is because the producer is not willing to pay more than 50% of the medications prices as incentives. Furthermore, the uncollected amounts from categories A and B are higher when the willingness values decreases, as illustrated in table 1.

4.2. Producer-customer-3PL coordination model results

As demonstrated in section 4.1, introducing incentives to customers per se is not enough to ensure complete collection of medications at customer zones. This is more obvious when the majority of those medications are from category C, as shown in table 1. The producer has to motivate the 3PL companies to go and pick up the medications at customer zones. Because the current collecting fees are imposed by the producer, the 3PL companies could be willing to collect more medications if the collecting fees would rather reflect their effort.

Therefore, the negotiation model proposed in section 3.2 is implemented to optimize the collecting fees as well as the amounts of collected medications by 3PL companies. In this section, we consider the most realistic ratio of available medications (i. e. 10 : 20 : 70) for the producer-customer-3PL coordination model. Figure 8 demonstrates factor level combinations used to validate the producer-customer-3PL coordination model.

We first investigate the impact of customer incentive threshold on the 3PLs' profit. As it can

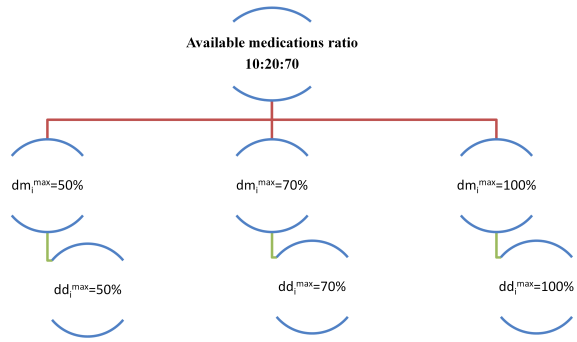

Figure 8: Factor level combinations for for producer-customer-3PL coordination model

be observed in table 2, higher customer incentive thresholds decreases the 3PL companies profits. The reason is that in the case of high incentive threshold, it is not profitable for 3PL companies to offer incentives close to that threshold. Hence, the amount of returned medications in category A would decrease due to lower customer willingness (table 2). Also,

Table 2: Some of the producer-customer-3PL coordination model results

d^{max} d^{max}	**Category A= 50%** Category B = 50%	**Category A = 70%** Category B = 70%	**Category A =100%** Category B = 100%
3PL 1 Objective value ($)	**46,367**	**44,173**	**42,568**
3PL 2 Objective value ($)	**52,505**	**54,282**	**50,426**
3PL 3 Objective value ($)	**68,807**	**68,366**	**63,414**
3PL 4 Objective value ($)	**58,689**	**60,076**	**58,387**
QE_M (kg)	0	0	0
QE_D (kg)	0	0	0
QE_S (kg)	0	0	0
ω_m	0.20	0.20	0.20
ω_d	0.40	0.40	0.20

the third 3PL company could gain the best profit in all cases. The reason can be due to high collecting capacity as well as low transportation cost of this company.

Finally, we analyze the impact of incentive threshold on customer willingness. As depicted in table 2, although in this coordination scheme, customer willingness to return medications in categories A and B is reduced comparing to the former coordination model (section 4.1), our results indicate that all available medications that the customer is willing to returns are collected by 3PL companies. Hence, in this case the producer would avoid paying penalties to government for uncollected leftover medications at customer zones.

4.3. Comparison between producer-customer and producer-customer-3PL models

According to the case data, *Generic PharmaX* currently fails to collect 18% of leftover medications at customer zones. Hence, she incurs legislative penalties. As our results indicate, by introducing customer incentives, the uncollected medications could be reduced up to 6.5%. Moreover, implementing the negotiation approach between the producer and 3PL companies, in addition to the customer incentives, lessens the percentage of the uncollected amounts to zero.

Table 3 summarizes the results for the percentage of uncollected medications as well as the RSC profit at the percentage of 10:20:70 over all categories and the worst case regarding customer willingness to return medications in categories A and B (i.e., 100%). The results for the other customer incentive thresholds are provided in the *Appendix*. As stated earlier, proposing customer incentives reduces the penalties paid for the uncollected medications. Yet, the incentives could not assure a complete leftover medication recovery. With the aid of the negotiation process proposed in section 3.2, not only the penalty could be eliminated, but also the overall RSC profit (equation 13) could be increased.

Table 3: The averages of the uncollected medications and penalties for each model

Coordination Model	Customer incentives	Producer-3PL negotiation	Average percentage of uncollected medications	RSC objective function (\$1000)	Penalties (\$1000)
Current situation	×	×	18%	-	93,000
Producer-customer *	✓	×	6.5%	8,121.32	9,991
Producer-customer-3PL *	✓	✓	0%	102,431.02	0

* The given values are for the case of 10:20:70 at 100% customer incentive thresholds for categories A and B

To implement the negotiation process, collaboration efforts are required from 3PL companies. Therefore, in the following section we present a technique to reward their efforts with respect to their investment in the customer-producer-3PL coordination scheme.

4.4. Sharing RSC coordination savings

The producer-customer-3PL coordination model for the customer incentive threshold of 100% enhances the profit of each 3PL company, as shown in table 4. The results for the other customer incentive thresholds are visualized in figure 9 and figure 10. At the same time, the producer could avoid huge penalties paid to governments by collecting all leftover medications at customer zones. Nevertheless, the 3PL companies have to invest time and efforts in the negotiation process. Therefore, the *Generic PharmaX* is willing to share a part of the expected savings with the 3PL companies.

Table 4: Profit improvement with producer-customer-3PL coordination model (in $1,000)

	Producer-customer-3PL coordination*	Current situation	The difference
3PL 1	42,568.21	39,842.57	2,725.57
3PL 2	50,426.21	47,200.82	3,225.39
3PL 3	63,414.32	58,590.18	4,824.14
3PL 4	58,387.44	52,379.16	6,008.28
Producer	-9,967.10	-17,915.13	7,948.03

* The given values are for the case of 10:20:70 at 100% customer incentive thresholds for categories A and B

Using the technique proposed in section 3.3, figures 9 and 10 visualize the expected share of the savings between the producer and 3PL companies considering different customer incentive thresholds of categories A and B. For example, the corresponding results to 50%-50% represent the RSC entities saving shares for the case of 50% customer incentive thresholds for categories A and B, respectively. It can be seen that the expected share of the savings for each 3PL company varies with respect to its capacity to collect the available medications at customer zones. The highest saving shares for 3PL companies are obtained at 70% customer incentive thresholds for categories A and B.

On the other hand, the best expected share for the producer is when the customer incentive thresholds are set at 50% for both categories A and B. In this case, the collecting fees paid by the producer to 3PL companies are higher than the customer incentives paid by 3PL companies to customers for returning medications in category A.

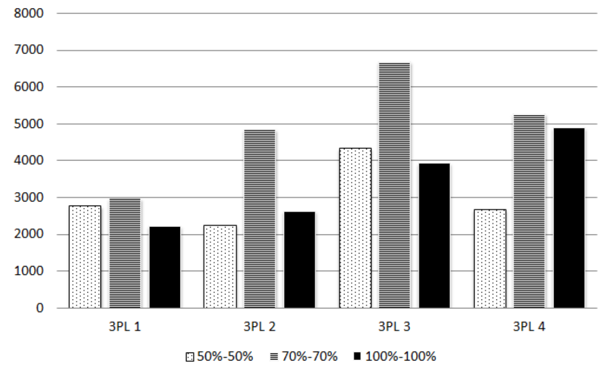

Figure 9: Saving shares for 3PL companies at different customer incentive thresholds ($1,000)

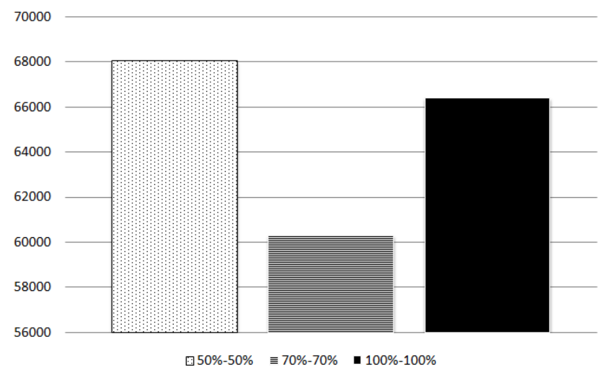

Figure 10: Saving shares for the producer at different customer incentive thresholds ($1,000)

To conclude, in one hand, 3PL companies would gain the maximum saving shares when the customer incentive thresholds are set at 70% for both categories A and B. In other words, 3PL companies need to negotiate with the customers for those thresholds to obtain higher saving shares. On the other hand, the producer would gain more saving shares when the customer incentive thresholds are set at 50%. However, any threshold value could improve the producer sustainable image, in the sense that she would not have to pay penalties to the government for uncollected medications at customer zones.

5. Conclusion

Governments' regulation on the pharmaceutical industry and customers attention to sustainable practices all play a crucial role in changing the RSC practices in this industry.

Hence, pharmaceutical companies have to be proactive in addressing the growing needs for improving their RSC performance.

This article proposed analytical models to support its objectives related to improving RSC performance in this industry. First, an analytical model based on customer incentives was proposed to encourage the RSC customers to return unexpired medications. Second, another model was proposed to motivate 3PL companies and customers to collaborate in the recovery process. Finally, the proposed models were implemented for the real pharmaceutical company, *Generic PharmaX*.

The results demonstrated the improvement of the collected amounts of medications by introducing incentives to customers. Furthermore, by implementing the negotiation model between the producer and 3PL companies, in addition to customers incentives, all the available medications are collected. Knowing that the negotiation process requires the commitment of RSC entities, such as cost and time investment, a technique for sharing the savings was also provided to reward the investment of the RSC entities.

This study is the first to direct attention for involving customers in the recovery process of the pharmaceutical products. With providing incentives, customers are motivated to return medications prior to their expiry dates. Hence, the producer can resell or donate the returned medications in subsidiary markets and gain monetary profits. In addition to the financial benefits, the producer would be step ahead of her competitors in implementing sustainable RSC practices. In particular, selling the medications instead of disposing them reduces the environmental harmful incineration process.

Future research would investigate the role of implementing a vendor-managed inventory system at customer zones (i.e., hospitals and pharmacies) on reducing the amount of effort required for collection and disposition of leftover medications. The idea is to reduce the amount of medications that reach their expiry dates. Cost/benefit implication of this coordination mechanism in addition to efforts required by supply chain entities in pharmaceutical industry would be worth being investigated.

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Appendix

Table A1: The averages of the uncollected medications and penalties for each model- customer incentive threshold = 50% for categories A and B

Coordination Model	Customer incentives	Producer-3PL negotiation	Average percentage of uncollected medications	RSC objective function ($1000)	Penalties ($1000)
Current situation	×	×	18%	-	93,000
Producer-customer	✓	×	6.8%	49,928.49	5,861.8
Producer-customer-3PL	✓	✓	0%	117,383.80	0

Table A2: The averages of the uncollected medications and penalties for each model- customer incentive threshold = 70% for categories A and B

Coordination Model	Customer incentives	Producer-3PL negotiation	Average percentage of uncollected medications	RSC objective function ($1000)	Penalties ($1000)
Current situation	×	×	18%	-	93,000
Producer-customer	✓	×	6.6%	26,934.26	5,602.59
Producer-customer-3PL	✓	✓	0%	111,438.16	0