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Sustainable Pharmaceutical Reverse Supply Chain with Customer Incentives

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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). The experimental results on a real case study indicate that some incentives are more significant than others on the amount of the medications collected. Moreover, introducing incentives to customers could decrease the amount of the uncollected medications from 18% up to 6.5%.**
***Keywords-* Sustainability; Reverse Supply Chain; Pharmaceutical Industry; Incentives; Nonlinear Mathematical Programming**

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 [Kumar et al., 2009]. 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 products, and the cost associated with the collection and disposal processes are not always known by the producer [Sbihi and Eglese, 2007]. 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 [Li, 2002]. Hence decision-making in such RSCs is bound to fail unless a coherent coordination mechanism is utilized [Lin and Ho, 2014].

While many studies have investigated the impact of coordination on forward supply chain networks [Kanda et al., 2008; Oliveira et al., 2013], the literature is scant on the benefits of coordination in RSC networks. The available literature is limited to the profitable RSCs, such as the electronic networks [Walther et al., 2008; Govindan and Popiuc, 2014]. 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.

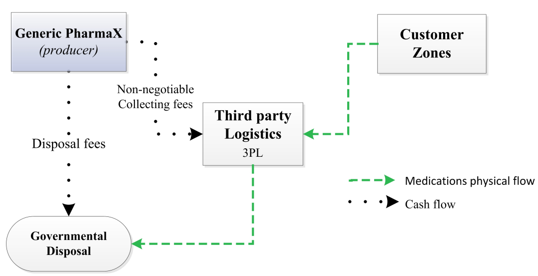

Figure 1: The current RSC of *Generic PharmaX*

In this research, we investigate a real pharmaceutical RSC shown in figure 1. 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 historical 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 [Sarkis, 2003]. 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 a coordination scheme between the pharmaceutical producer and the customers. The model has been modeled by the aid of nonlinear mathematical programming to reflect the decision-making process of the pharmaceutical RSC under study. The model is mainly focused on producer-customer coordination. 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 while creating extra revenue/tax deduction for the producer. 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.

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 the coordination model are proposed. Numerical results 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 [Blackburn et al., 2004]. For example, detailed reviews on RSC models can be found in Akcali et al. [2009] and Aras et al. [2010]. Knowing that supply chain inherently involves 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 [Bahinipati et al., 2009].

Camarinha-Matos et al. [2009] reviewed the key concepts, classifications, and some applications related to supply chain coordination. Kanda et al. [2008] 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 the coordination mechanisms deal with forward supply chains and focus on the coordinative contracts, such as revenue-sharing [Cachon and Lariviere, 2005; Giannoccaro and Pontrandolfo, 2004; Xu et al., 2012], buyback contract [Liu et al., 2014], and quantity discounts [Cachon, 2003].

Another mechanism highlighted by the authors concerns the negotiation process. For example, Dudek and Stadtler [2005, 2007] proposed negotiation models for two independent supply chain partners. Their results stated that using coordinative mechanisms could improve the overall performance of the forward supply chain.

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 [2014] 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. Kulshreshtha and Sarangi [2001] 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.

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. [2009] proposed a framework to state each party's responsibility in the pharmaceutical RSC. Xie and Breen [2012] designed a green pharmaceutical supply chain model to reduce preventable pharmaceutical waste and to dispose inevitable waste. The study revealed that the RSC practices are hard to be implemented in the pharmaceutical industry since returned medications cannot be reused or resold.

Lately, Weraikat et al. [2015] 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 involving 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 coordination model developed for better coordinating the RSC.

As aforementioned, hospitals and pharmacies keep the medications to expire at their sites, then they inform the producer about the available quantities. 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*.

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 this 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 products in a subsidiary market at a selling price less than the price of a new product;
2. **Category B** represents the medications that have less than two years and more than a year shelf-life. The producer can donate these products 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 product 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 is 1. It is noteworthy that many factors affect the value of the customer incentive threshold such as the criticality of that product, its price, and the demand. Nonetheless, the producer cannot pay incentives to customers greater than products prices in subsidized 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 some of the 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 only if the collected medications are from category A or category B. Furthermore, the producer contracts with the 3PL companies to collect the products, where collecting fees are non-negotiable. The

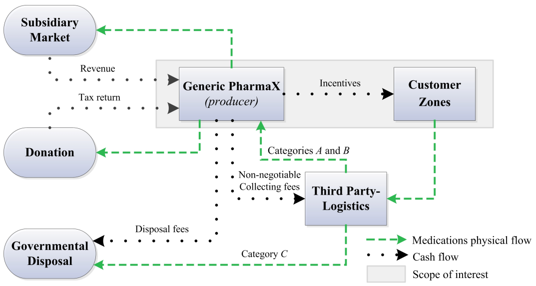

Figure 2: A producer-customer coordination RSC

3PL companies collect and sort the medications 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.

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 products, $i \in I$;
k: index of customers, $k \in K$;
j: index of 3PL companies, $j \in J$;

The producer's 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 product type i sent to governmental disposal sink (\$);
M_i: the transportation cost of shipping a unit of product 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}: mass of medication type i that has to be collected at customer 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 product 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 function of the incentive value offered by the producer on the threshold of the incentive requested by the customer ($\omega_{m_i} = dm_i/dm_i^{max}$, 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 function of the incentive value offered by the producer on the threshold of the incentive requested by the customer ($\omega_{d_i} = dd_i/dd_i^{max}$, 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.

Maximize

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

The objective function is shown in equation (1). It represents the profit of the RSC determined as the expected revenues minus the expected 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 governments, 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.

The objective function is constrained by the available amounts of medications that have to be collected at customer zones (A_{ik}). The available amounts at customer zones incorporate medications from all categories (equation 2).

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

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

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

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

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

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

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

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.

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

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

The thresholds of incentives for the medications from category A and category B, requested by customers to collaborate, 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.

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

Finally, domain constraints are provided in (12).

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

4 Producer-customer coordination model results

As mentioned earlier, the producer will offer incentives to encourage customers to collaborate and return the medications. The value of the incentives offered are affected mainly by two parameters; the percentage of available medications from categories A and B at customer zones and the customer incentive thresholds. Regarding that the percentage of available medications is unknown by the producer, it becomes interesting to investigate what could be the incentive to offer regarding the percentage of available medications in each category and the customer incentive threshold.

In this study, we use design of experiments (DOE) [Park, 2007] to determine the impact of the percentage of available medications from each category and the customer incentive thresholds on the performance of RSC. In our experiments, three factors were considered, 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) to the producer incorporate the objective function value of model (1)-(12) (RSC profit), the amount of the uncollected medication from category C, and the willingness values for category A and category B.

Through the help of the producer, three levels were defined for each factor mentioned above, as depicted in figure 3. 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 medications prices in secondary markets and tax deduction amounts for medications in category A and B, respectively. Figure 3 visualizes all the instances studied for the producer-customer coordination scheme. The value of the smallest incentive that customer requires to inform the producer about the available medications in categories A and B (d^{min}) is considered as 20% of medications prices in subsidiary markets and tax deduction amounts.

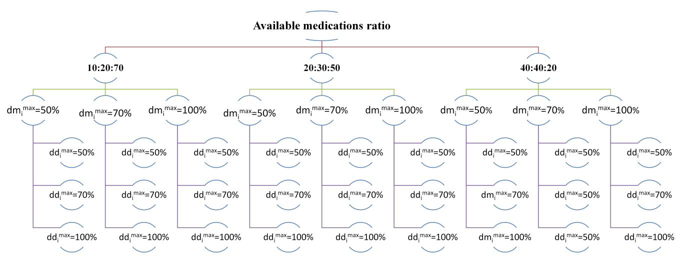

Figure 3: The studied instances for producer-customer coordination model

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 results of the DOE. The results reveal that the percentage of available medica-

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 ($)	**49,928.49**	**123,181.77**	**257,670.21**	**44,553.46**	**115,119.21**	**246,920.14**	**38,955.08**	**106,721.64**	**235,723.39**
QE_M	80.14	143.78	287.55	80.13881	143.7774	287.55405	80.14	143.78	287.55
QE_D	0.00	0.00	0.00	164.2571	246.38577	328.51429	1,242.83	1,864.24	2,485.66
QE_S	1,647.75	0.00	0.00	1,647.75	0.00	0.00	1,647.75	0.00	0.00
ω_m	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97
ω_d	1.00	1.00	1.00	0.98	0.98	0.98	0.84	0.84	0.84
d^{max}	**Category A = 70%**			**Category A = 70%**			**Category A= 70%**		
d^{max}	Category B = 50%			Category B = 70%			Category B = 100%		
AMR^*	**10:20:70**	**20:30:50**	**40:40:20**	**10:20:70**	**20:30:50**	**40:40:20**	**10:20:70**	**20:30:50**	**40:40:20**
Objective value ($)	**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	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	0.00	0.00	0.00	164.26	246.39	328.51	1,242.83	1,864.24	2,485.66
QE_S	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	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	0.00	0.00	0.00	164.26	246.39	328.51	1,242.83	1,864.24	2,485.66
QE_S	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

tions 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 incentives threshold for category B has no significant impact on the profit. 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 4. Moreover, from the interaction analysis between factors, we conclude that at low level medication ratio of category A (i.e., 10%), there is a slight negative effect of the customer incentive threshold on the profit.

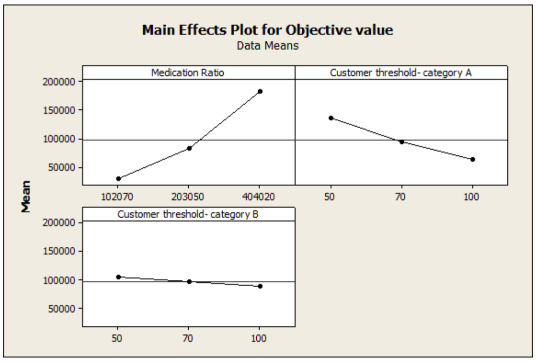

Figure 4: The main effects plot for the objective function-*Minitab*

As it can be observed in table 1, the profit increases when the percentage of available medications from category C decreases. 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 offer higher incentives to customers in order to increase their willingness to return such medications. The latter has a negative impact on the profitability of the RSC.

Since the expired uncollected medications (category C) not only have negative impacts on the green image of the producer but also cause legislative penalties, the second response studied is 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.

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. However, for the most realistic case, introducing customer incentives could reduce the total uncollected medications in category C from 18% up to 6.5%, as shown

Table 2: The averages of the uncollected medications in category C and penalties for the case of 10:20:70 medications ratio

Customer incentive thresholds	Customer incentives	Percentage of uncollected medications in category C	RSC objective function ($1000)	Penalties ($1000)
Current situation-no incentives	$\times$	18%	-	93,000
50% for categories A and B	✓	6.8%	49,928.49	5,861.8
70% for categories A and B	✓	6.6%	26,934.26	5,602.6
100% for categories A and B	✓	6.5%	8,121.32	9,991

in table 2.

Moreover, the results state that the customer incentives thresholds for category B are insignificant, as shown in figure 5.

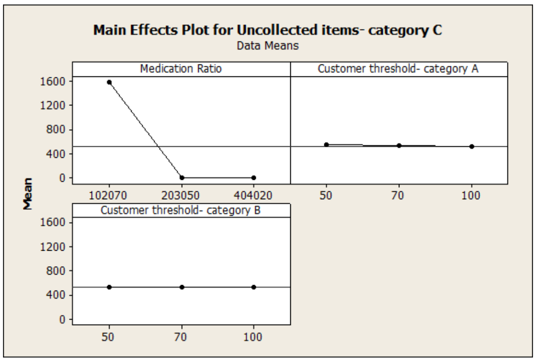

Figure 5: The main effects plot for the uncollected medication in category C- *Minitab*

The customer willingness values are also presented 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 subsidized 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.

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. Since the profitability of the return medication is almost negligible, the recovery process is challenging for this industry.

This article proposed analytical model 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. Then, the proposed model was implemented for the real pharmaceutical company, *Generic PharmaX*. The results verified the importance of incentives in improving the sustainability of the RSC performance. Also, the results demonstrated the improvement of the collected amounts of medications by introducing incentives to customers up to 6.5%. However, in some cases the incentives were not sufficient to guarantee a full recovery for all leftover medications.

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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