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Framework for stochastic returns management in a closed-loop supply chain

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Abstract

The ways of improving the performance of a supply chain through effectively and efficiently closing the loop have received considerable attention both from academic researchers and industry practitioners over the past two decades. This paper proposes a Closed-Loop Supply Chain (CLSC) model with independent third-party reverse logistics Provider (3PRLP) for returns processing. Realistically, product demand is generated by a stochastic process and a fraction of the units that are initially sold are returned by consumers for a full refund in every period. We model the forward flow interaction between the supplier, the retailer and 3PRLP by a widely accepted control policy that is lot size-reorder point inventory policy, which is detailed by the Markov process. We utilize a queuing network to capture reverse flow activities of the 3PRLP, which consists of customer decision delay and each of the 3PRLP activities. We characterize the expected profits for both firms and derive the effects of key parameters through a set of numerical examples. The results of the optimization analysis indicate that both firms' benefits from processing returns increase with an increasing returns rate. This is due to fact that the retailer captures more profits through selling processed returns at the price of new product. The 3PRLP unambiguously earns more profit from processing the returns since fees from processing returns are sole source of revenue. Furthermore, the directions of effects of changes in the holding cost are similar for both the retailer and 3PRLP. However, the magnitude of effects of the same parameter is quite opposite. Interestingly, the retailer's profit appears to be more sensitive to the holding cost than that of the 3PRLP's profit.

Keywords: Reverse Supply Chain, Closed-Loop Supply Chain, Consumer Returns Management, Supply Chain Management, Queuing Theory

1. Introduction

In today's highly competitive global markets, supply chain operations are impacted by multiple stakeholders. These stakeholders include customers, who are both environmentally and cost conscious in their buying behaviour, and governmental and regulatory agencies that levie environmental mandates. As a result, companies are placing increased attention on both the environmental and economic performance of their supply chains (Birkel & Müller, 2021). This has led many retailers and manufacturers to re-examine the return flow of products in order to maximize product recovery value (cite needed here). According to the National Retail Federation reports, the total volume of returns surged from $260.5 billion (about 8% of total sales) in 2015 (NRF Report, 2015) to $369 billion (about 10% of the total sales) in 2018 (NRF Report, 2018). The scope of products returns suggests that there is significant economic opportunity in maximizing product recovery in the reverse channel of a supply chain.

There are many reasons why customers return products. In many cases, the return is a result of the product's failure to meet the expectations of consumers in terms of quality, product attributes related to model and size specifications, or perceived obsolesce. Variety buying behavior by customers where several items are initially purchased with the intention of keeping only the one best liked item is also a significance source of returned items. Such returns are especially apparent in online shopping where customers do not get to see physical product before their making purchase decisions. Customer service policies of retailers which make the acceptance of returns effortless (e.g., no questions asked, no receipts necessary and no time limits) further contribute to product returns. For example, Amazon.com will provide a full refund of the product price within 30 days of purchase and pays all shipping costs. Wholesaler giant Costco offers a no time limit returns policy on most of the non-perishable products which allows customers to return any time. Furthermore, the fact that returns can be made via mail without physical travel physical by the consumer makes the return process more anonymous and effortless. In fact, many firms recognize that there is a competitive advantage to offering customers an effortless and seamless returns experience (Zhang et al., 2019; Chen et al., 2018; Terry, 2014). Lastly, the rise of online sales relative to traditional brick-and-mortar sales further contributes to higher levels of returned products thus placing an increased load on the reserve supply chain tasked with processing the returns return (Ofek et al., 2011).

In the business literature the terms reverse logistics (RL) and closed-loop supply chain (CLSC) are often used interchangeably. According to American Reverse Logistics Executive Council, reverse logistics (RL) can be viewed as the process of planning, implementing, and controlling the efficient, cost-effective flow of raw materials, in-process inventory, finished goods and related information, from the point of consumption back to the point of origin, for the purpose of recapturing their value or proper disposal (Rogers & Tibben-Lembke, 1998). A more recent definition of CLSC has been stated by Guide and Van Wassenhove (2009) "as the design, control, and operation of a system to maximize value creation over the entire life cycle of a product with dynamic recovery of value from different types and volumes of returns over time".

The main drivers for CLSC design are the volume of returns, the marginal value of time and the quality of returned product (Guide & Van Wassenhove, 2009). Given the fact that volume of returns is increasing, it should be clear that most of the product returns, especially consumer returns, are not waste. However, if the CLSC is hindered by slow handling and recovery processes, the recoupable value from the returns is greatly diminished. Products that have been rarely used are best reintroduced market as quickly as possible in order to maximize the recovery value.

Although the simplicity of returning a product for consumers is a competitive advantage at the front-end, the returns handling that CLSC should integrate is often complex to operate at the back-end. This complexity is compounded by the substantial uncertainties regarding the timing, volume and condition of the returned items (Serrato et al., 2007). The variability in characteristics and policies associated with each return indicates one of many possible outcomes when processing a returned item. For instance, the item may be returned to the OEM, transferred to another store, repackaged, repaired, liquidated, disassembled or reused. Returns management requires different processes and technologies, capabilities and expertise than forward operations (Terry, 2014; Greve & Davis, 2012). Thus, firms with an effective forward logistics capability may not be able to operate a productive reverse operation for processing returns.

Consequently, given the time sensitivity of returns process and complexities of designing and managing the reverse logistics function in a supply chain, many firms have adopted a strategy to outsource the reverse logistics function to a third-party reverse logistics provider (3PRLP). In fact, most Fortune 1000 retailers and consumer goods manufactures outsource part or all of their reverse logistics functions. Moreover, this trend is expected to grow globally over next 20 years (Greve, 2014). Especially most of the well-known retail chains and manufactures such as Walmart, Dell, Target, HP, Unilever, Pfizer and The Home Depot with well-established and developed forward logistics channels outsource their RL (Greve, 2014). The main reason for outsourcing RL is that RL is not considered to be a core competency of the firm (Terry, 2014; Serrato et al., 2007). By outsourcing its RL to a 3PRLP a firm can focus on doing what they do best i.e., producing and selling. Outsourcing to a 3PRLP also allows a firm to gain a state-of-the-art RL program immediately thereby avoiding the capital investment and start up delay required to implement an in-house RL program. Most 3PRLPs have existing facilities that can be leveraged depending on the situation or will open facilities in the best locations to minimize processing costs. When 3PRLPs provide RL service, the costs of the entire infrastructure required, building facility, software and equipment can be consolidated to their price (Terry, 2014; Serrato et al., 2007). Additionally, most of the 3PRLP contracts include some form of price per item cap that makes budgeting and planning easy for the outsourcing firm. Finally, since the 3PRLPs are focused on the processing returns, they can provide cutting-edge analysis and recommendations for an integrated and effective CLSC design.

This paper considers a CLSC where there is no distinction between a new product and a returned product once the returned product has undergone a series of RL processing activities to repair and repackage the product for reuse. Moreover, we consider that the returns processing activities are outsourced to a 3PRLP. The model developed herein can be extended to both consumer returns that are merely used and are resalable after processing, and end-of-use returns for which the user no longer has utility left for. We model the CLSC where 3PRLP operates independently while coordinating activities with the retailer. We propose a model that gives detailed analysis of 3PRLP activities, which can be specific to product or firm. Although there are studies that consider outsourcing of RL functions to 3PRLP, their modelling approaches are different. For example, models that evaluate when it is appropriate to outsource RL have been proposed but these models do not detail the processes of the RL (Tanai et al., 2021; Wang et al., 2021; Atasu et al., 2013; Serrato et al., 2007; Savaskan & Van Wassenhove, 2006; Savaskan et al., 2004). Our model assumes that the RL functions are already outsourced to a 3PRLP and optimizes the RL operations from the 3PRLP's point of view. We believe to the best of our knowledge, that the model herein represents the first quantitative examination of the detailed processes of RL by 3PRLP.

The main objective is to investigate how customers return decisions and RL choices affect the forward channel decision and how the parties in the forward and reverse channels interact to process returns. For this, we consider a two-echelon CLSC, which consists of a supplier, a retailer and a 3PRLP who operates independently from the supplier and the retailer. In particular, we address the following research questions:

1. How are the inventory policy and total expected profits/costs of the retailer affected by the percentage of demand that is returned?
2. Given the stochastic returns, how does the 3PRLP allocate its labor into different types of processes that require different skills?

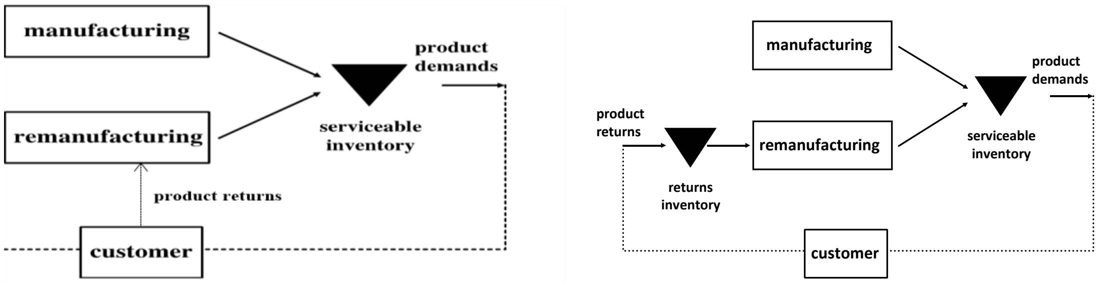
The framework presents a CLSC where demand is stochastic. A fraction of the units that are initially sold are returned by the consumers for a full refund in every period. We model the forward flow interaction between the supplier, the retailer and 3PRLP by a widely accepted control policy that is lot size-reorder point inventory policy, which is detailed by the Markov process. We further propose a queuing network to capture reverse flow activities of the 3PRLP, which consists of customer decision delay and each of the 3PRLP activities. We characterize the expected profits for both firms and derive the effects of key parameters using a set of numerical examples. The results generated through the model's optimization of the set of numerical examples indicate that both firms' profits increase with an increasing returns rate. This is due to fact that the retailer captures more profits through selling processed returns at the price of new product. The 3PRLP unambiguously earns more profit from increasing product returns since the fee from processing returns is sole source of revenue. Furthermore, the directions of effects of changes in the holding cost are similar for both the retailer and 3PRLP. However, the magnitude of effects of the same parameter are quite opposite. Interestingly, the retailer's profit appears to be more sensitive to the holding cost than that of the 3PRLP's profit.

The remainder of the paper is organized as follows. In Section 2, we discuss the related literature and highlight contributions. In Section 3 we propose Stochastic CLSC with 3PRLP model that details the reprocessing activities of the 3PRLP based on the retailer's operational decisions. In Section 4, we illustrate sensitivity of the model with numerical analysis and provide important managerial insights. In Section 5 we discuss possible extensions and present concluding remarks.

2. Literature Review

Most of the current literature on returns management is in the context of manufacturing and remanufacturing. These studies focus generally on technical aspect of RL that minimizes the average cost of inventory. From the retailer's inventory management point of view, our work is primarily related to the inventory and production planning streams of research in the CLSC area. We highlight that studies in inventory planning represent majority of research in CLSC and we acknowledge that many authors have provided excellent contributions to this theme. We shall discuss studies only related to our study. To provide more details about current literature, we direct readers to three recent literature review articles on CLSC. First, Akçalı and Çetinkaya (2011) review existing quantitative literature on inventory and production planning for CLSC systems up to year 2009. Next, Govindan et al. (2015) review RL and CLSC models published between years 2007 and 2013. Recently, Shekarian (2020) reviews factors influencing the CLSC's.

Stochastic inventory control approaches that integrate returns are generally classified into to single-level versus two-level inventory structures. These are illustrated in Figure 1. We summarize studies of single-level inventory structures in Table 1 and two-level inventory structures in Table 2. As one can notice from these tables, most of the studies emphasize on the cost minimization. Conversely, we emphasize on value recovery by maximizing profit function. This approach puts more strategic lens on the overall supply chain regarding changes in parameters. Furthermore, most of the studies assume returns to be independent from the demand. However, we model returns as a fraction of demand and do not explicitly assume independence of returns.



(a) Single-level inventory **(b) Two-level inventory**

Figure 1: Inventory structures

Article	Remarks	Demand & Return	Objective
Heyman (1977)	Continuous review model. No order lead-time.	Independent continuous RV for demand and return.	Cost minimization
Cohen et al. (1980)	Single period newsvendor model. No lead-time for ordering. Excess demand is lost.	Demand and returns are continuous iid.	Cost minimization
Muckstadt and Isaac (1981)	Considers fixed order costs and non-zero procurement and repair lead-times. The values of the control parameters are determined via an approximation of the net inventory distribution.	Independent Poisson demand and return processes.	Cost minimization
Toktay et al. (2000)	CLSC model using queuing networks approach. Base-stock policy.	Independent Poisson demand and return processes.	Cost minimization
Fleischmann et al. (2002)	Extension of Muckstadt and Isaac (1981) with closed form analytical solution.	Independent Poisson demand and return processes.	Cost minimization
Mostard and Teunter (2006)	Analyze a newsboy problem with resalable return.	Demand is continuous RV. Return is a fraction of demand.	Profit maximization
Guide et al. (2006)	Evaluate alternative reverse supply chain designs using network flow models capturing the effects of delays on costs and revenues.	Demand is Poisson. Return is fraction of demand.	Profit maximization
Karaer and Lee (2009)	CLSC model for single period newsboy problem. Quantify the value of information visibility on the reverse supply chain using RFID.	Demand and returns are continuous iid.	Cost minimization
Alinovi et al. (2011)	Formulate stochastic EOQ model under discrete time domain.	Demand is continuous RV. Return is a fraction of demand.	Cost minimization
Fu et al. (2019)	Study of a periodic-review manufacturing /remanufacturing inventory system for a perishable product with a fixed lifetime by focusing on a lifetime of two periods.	Demand is continuous RV. Return is a fraction of demand.	Profit maximization

Table 1: Single-level inventory articles

Our work is closely related to first line of research i.e. one-level inventory models. Specifically, we advance our CLSC model using inventory control approach studied by Muckstadt and Isaac (1981) and Fleischmann et al. (2002). Then, we detail the RL activities of 3PRLP using a queuing network. This approach differs from the studies that use queuing networks in two ways. First, while we use queuing network for RL activities only, others use queuing network for the entire supply chain (Guide et al., 2006; Toktay et al., 2000). Second, in our RL modeling we do not necessarily implement any specific inventory control policy in order to analyze economic performance. The costs processing of returns depends on the number of labor and items in each queue node.

Article	**Remarks**	**Demand & Return**	**Objective**
Inderfurth - 1997	A fixed deterministic lead-time for remanufacturing as well as manufacturing. Simultaneous procurement, remanufacturing and disposal decisions.	Demand and return are continuous RVs. Dependent demand and return.	Cost minimization
van der Laan and Salomon - 1997	A PULL strategy had been investigated. Disposal policy when the system inventories become too high. Non-zero manufacturing and remanufacturing lead-times.	Demand and return are Poisson processes. Dependent demands and returns.	Cost minimization
van der Laan et al. (1999)	Examines both PUSH and PULL strategies	Demands and returns are continuous RVs. Dependent demand and return.	Cost minimization
Teunter and Vlachos (2002)	Average cost is discounted to the beginning of time. Extend van der Laan and Salomon -1997	Independent Poisson demands and returns.	Cost minimization
van der Laan and Teunter (2006)	A heuristical approach for remanufacturing. Multiple types of policies are analyzed. Generalizes PUSH and PULL strategies.	Independent Poisson demands and returns.	Cost minimization
Behret and Korugan (2009)	Simulation approach using queue nodes for each process of the remanufacturing	Demand is Poisson. Return is fraction of demand.	Cost minimization
Shi et al. (2011)	Study the production-planning problem for a multi-product closed loop system.	Independent continuous demands and returns.	Profit maximization
Vercraene et al. (2014)	Coordination framework for manufacturing, remanufacturing and returns using a queuing control framework.	Independent Poisson demand and returns.	Cost minimization
Sun et al. - 2018	Introduction of quality grading to the lot scheduling model with returns.	Discrete demand and returns	Cost minimization
Devoto et al. (2021)	Extension of economic lot-sizing application where incoming returns are classified into pre-determined quality categories.	Discrete demand. Return is fraction of demand.	Cost minimization

Table 2: Two-level inventory articles

Studies that explicitly model the 3PRLP or RL activities are summarized in Table 3. Most of these articles address the interaction between the manufacturer and the retailer. They analyze the problem of choosing appropriate reverse channel structures (centralized vs. decentralized) using various collection cost functions (linear vs. non-linear) under different types of economic environments (monopoly vs. competitive) (see for examples Tanai and Dechenaux, 2021; Atasu et al., 2013; Savaskan and Van Wassenhove, 2006; Savaskan et al., 2004). On the contrary, we focus on the decentralized CLSC where RL activities are outsourced to 3PRLP. Furthermore, our analysis is based on activities of the 3PRLP, which contains collection activity as well. Other studies evaluate the decision process of when it is appropriate to outsource the RL activities (for example see Serrato et al., 2007). Our modeling is different from this line of research in that we assume RL activities are already outsourced to 3PRLP.

Article	Remarks	Objective
Savaskan et al. (2004)	Address the problem of choosing the appropriate reverse channel structure for the collection of used products from customers. Game theory approach.	Profit maximization
Savaskan and Van Wassenhove (2006)	Extends the findings of Savaskan et al. (2004) work to a competitive retailing environment.	Profit maximization
Serrato et al. (2007)	A Markov decision model to evaluate outsourcing in reverse logistics.	Cost minimization
Efendigil et al. (2008)	A 3PRLP selection in the presence of vagueness. A two phase model based on artificial neural networks and fuzzy logic.	Performance maximization
Atasu et al. (2013)	Analysis of the impact of collection cost structure on the optimal reverse channel choice of manufacturers.	Profit maximization
Tanai and Dechenaux (2021)	Coordination between the retailer and the 3PRLP according to Nash bargaining	Profit maximization

Table 3: 3PRLP articles

3. Model Development

In this section we present a stochastic CLSC with 3PRLP model. The product flow starts at the top echelon, where the supplier directly supplies to the retailer who is at the bottom echelon. Further product flows continue from the retailer to the customer. However, the flow of products does not stop upon their distribution to retailers as well as from retailer to the customers. Beside typical forward channel of the products from supplier to the customers, there is reverse channel of the products those being returned to the market. Hence, the proposed CLSC model consists of a supplier, a retailer and a 3PRLP who operates independently from the supplier and the retailer. The generic product flow of proposed CLSC is illustrated in Figure 2. The 3PRLP is involved with RL activities, which are initiated by the customers' decision to return a purchased item.

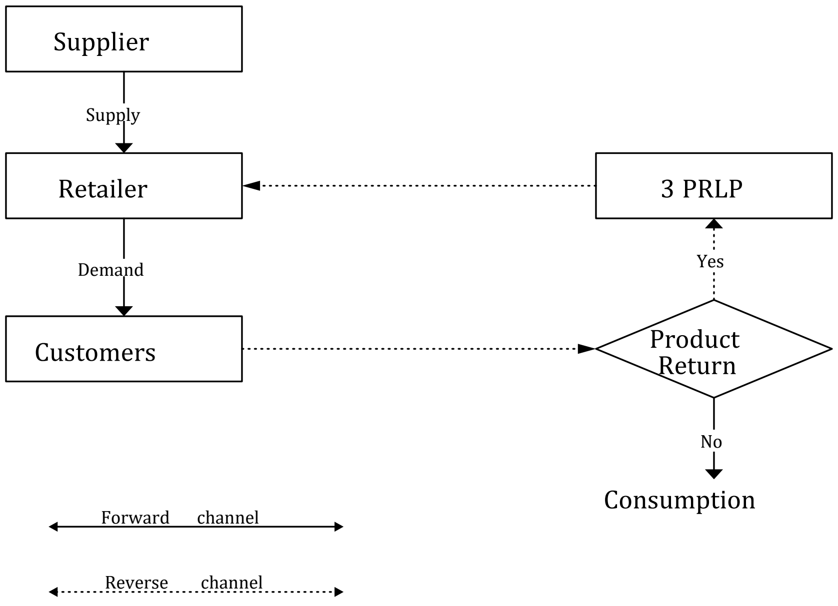


Figure 2: Product flow

During each period, after a delay customers decide whether to keep the product or return it to the retailer. We call this delay as customers decision delay and note that this delay is commonly dictated by the return policy of the product. By deciding to return the items, customers implicitly activate the return process. As a result, a certain proportion of demand is returned each period. The reverse channel activities can be described as follows. The returned items are collected by the 3PRLP or customers can bring the items to either retailer or 3PRLP location. Once collection, the 3PRLP internally processes the items in its facility and send them back to the retailer in same as new conditions. There are different types of activities ranging from collection to sorting to repair and to repackaging. We note that processing of returns by the 3PRLP is specific to a particular item, and that the processing activities can be modified or generalized to more different kinds of RL functions.

For each type of activity, the 3PRLP employs workers with different skill sets and labor and capital requirements. For instance, the low skilled workers in sorting and repackaging activity are paid less than the highly skilled technicians in repair activities due to their skill and allowance through OEMs. Therefore, the fee charged, and wage given by the 3PRLP is based on the activity that each return undergone. Furthermore, the processing times at each activity also differ. The 3PRLP tasked with processing the returns, either sends the item back to the retailer or disposes the item

The forward flow interaction between the supplier, the retailer and 3PRLP is governed by a widely accepted control policy that is lot size-reorder point inventory policy. We note that this policy is detailed by the Markov process. The backward flow or RL activities by 3PRLP is modeled as a queuing network, which consists of customer decision delay and each of the 3PRLP activities. We summarize the notation for the model in Table 4. In section 3.1 we describe the lot size-reorder point model for the retailer and in section 3.2 we construct the queuing model for the 3PRLP to process the returns.

Retailer and forward flow	
Notation	**Description**
λ	Demand rate per unit time
τ	Fraction of demand that is returned per unit time
γ	3PRLP's processed returns supply rate per unit time
c	Unit cost to purchase an item ($)
p	Unit selling price ($)
a	Fixed cost to place an order ($)
b	Penalty cost for one unit backordered per unit time ($)
h	Cost to hold one unit in inventory per unit time ($)
r	Reorder point units
Q	Order size units
LT	Supplier lead time (constant)
3PRLP and reverse flow	
α_i	Percentage of returns that undergone through activity i per unit time
$1/\mu_d$	Customers mean decision delay to whether return the item
$1/\mu_i$	Mean processing time at activity i per unit time
k_i	Number of workers in activity i per unit time
f_i	Fee ($) charged from the retailer per unit return that undergone in activity i per unit time
w_i	Wage ($) per worker in activity i per unit time
h_i	Holding/storing cost of one unit at each activity i per unit time

Table 4: Notation for Stochastic CLSC with 3PRLP Model

3.1 Retailer and forward flow

The retailer's demand per period follows a Poisson process with mean λ and is satisfied from on-hand inventory. Any unsatisfied demand is backordered. Product returns represent τ percentage of total demand. Hence, the input in each period for the RL activity follows a Poisson process with mean $\tau\lambda$. We assume that returned products serviced by the 3PRLP emerge are as good as new items and are indistinguishable from the new items being made available to customers by the supplier. Without loss of generality, let γ be the mean rate of items serviced by the 3PRLP that are sent back to retailer each period. Thus, as illustrated in Figure 2, the retailer has two sources of product replenishment. The first source is products received from the supplier in the forward channel of the supply chain; the second source is products that have undergone processing by the 3PRLP in the reverse channel of the supply chain. The first one is the supplier with a constant lead-time LT. The second source is the 3PRLP, which supplies returns as good as new items according to Poisson process with a mean rate of γ units per period. This is, in fact, not an explicit assumption, it is because Poisson input process of a queue imposes that output process is also Poisson (see Section 3.2 for derivation of γ). The retailer's inventory structure is illustrated in Figure 3.

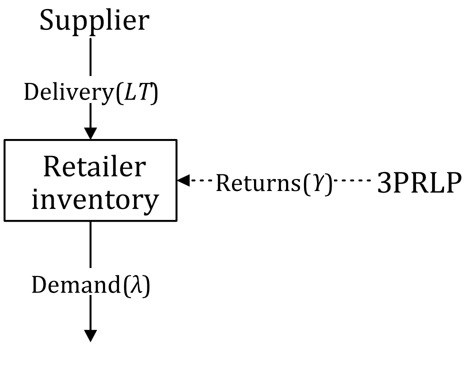


Figure 3: Retailer's inventory

The inventory cost factors include: the backorder cost b (per item per unit time), the holding cost h (per item per unit time) and the fixed order cost a (per order). We assume that the net inventory is continuously reviewed and that an (r, Q) inventory control policy is applied. On-hand inventory cannot be used to define the reorder point, since when a heavy demand occurs during some periods and a large number of backorders were incurred, then arrival of outstanding orders can never bring the on-hand inventory back to the reorder point. Therefore, the inventory position is a suitable level to apply control policy for defining reorder point. In other words, it is true that a heavy demand and a significant number of backorders during some periods cause substantial number order placement. In this case, a reorder point in terms of inventory position will be crossed multiple times whereas a reorder point in terms of on-hand inventory may not be crossed at all (for more details see Hadley and Whitin, 1963).

Ultimately, to analyze the system, we are interested in the average number of on-hand inventory and average backorders. Since the lead times are constant and are not generated by Poisson process; we cannot describe transitions between the on-hand inventory states. Instead, we formulate a continuous-time Markov process for the inventory position. The advantage of this approach is that the supplier lead-time does not enter into the computation of steady-state probabilities. Hence a demand decreases the inventory position by one item; the arrival of a returned item from the 3PRLP increases the inventory position by one unit. Suppose when in a state $r + 1$ and a demand occurs, the system moves from state $r + 1$ to state $r + Q$ since the demand triggers the placement of the order. Note that unlike traditional inventory models, the state space is unbounded above. This is due to returns that are being supplied continuously according to Poisson process. The inventory position state transition diagram is depicted in Figure 4.

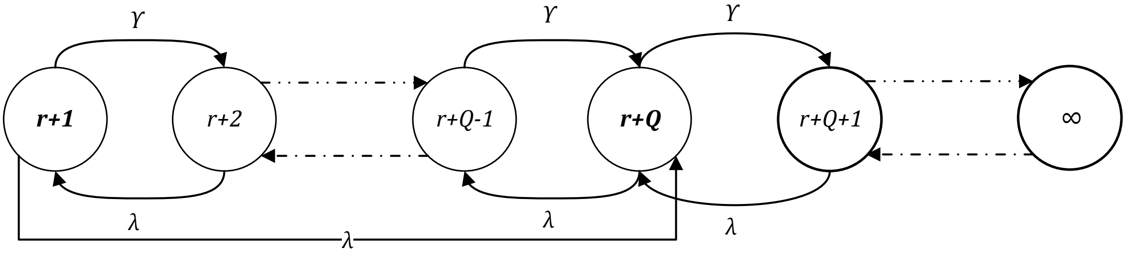


Figure 4: Inventory position transition diagram

Let IP(t) be an inventory position at time t. Then we can write down the balance equations (transition rates) for this case as,

$$\lim_{(\Delta_t \to 0)} \mathrm{P\,r}[\mathrm{IP}(t+\Delta_t) = k \mid \mathrm{IP}(t) = j] = \begin{cases} \lambda \text{ for } k = j-1, j \geq r+2 \\ \lambda \text{ for } k = r+Q, j = r+1 \\ \gamma \text{ for } k = j+1, j \geq r+1 \end{cases} \quad (1)$$

For $0 \leq \frac{\gamma}{\lambda} < 1$ the inventory position is ergodic and using balance equations, the steady-state distribution can be derived (see Fleischmann et al., 2002; Muckstadt & Isaac, 1981). Next, following Fleischmann et al. (2002), we can write down the distribution of net demand during the lead-time $D(t - LT, t)$ as $D(LT)$ since, it is independent of t. It follows that

$$Pr[D(LT) = n] = exp\big(-LT(\lambda+\gamma)\big)\,(LT\lambda)^n \textstyle\sum_{y=0}^{\infty} \frac{LT^{2y}(\lambda\gamma)^y}{y!(y+n)!}. \quad (2)$$

Furthermore $E[D(LT)] = LT(\lambda - \gamma)$ and $Var[D(LT)] = LT(\lambda + \gamma)$.

We now have all the preconditions for expected inventory cost function. Denote $IC_{RE}(r, Q)$ be the expected inventory cost per unit time in a steady-state. This function can be written as,

$$\begin{aligned} IC_{RE}(r,Q) &= \frac{a(\lambda-\gamma)}{Q} + \sum_{l=r+1}^{\infty} \eta(l)G(l) \\ &= \frac{1}{Q}\left[a(\lambda-\gamma) + \sum_{l=1}^{Q}(1-\rho^l)G(r+l) + (\gamma^{-Q}-1)\sum_{l=Q+1}^{\infty}\gamma^l(r+l)\right] \\ &= \frac{1}{Q}\left[a(\lambda-\gamma) + \sum_{k=s+1}^{s+Q} H(k)\right] \end{aligned} \quad (3)$$

Where $H(k) = (1-\rho)\sum_{l=0}^{\infty}\rho^l G(k+l)$, which is convex in k and $G(l)$ is the sum of average holding and backorder costs at the inventory position $_l$:

$$\begin{aligned} G(l) &= (h+b)\sum_{j=-\infty}^{l-1}(l-j)d_j + b(E[D(LT)] - l) \\ &= (h+b)\sum_{j=-\infty}^{l-1}\sum_{t=-\infty}^{j} d_j + b(E[D(LT)] - l). \end{aligned} \quad (4)$$

Furthermore, we now define the expected total cost for the retailer. Let $TC_{RE}(\cdot)$ be the expected total cost of retailer that is sum of expected inventory cost, purchase cost and the total fee paid to 3PRLP to process returns. Hence, assuming there are n number of activities in reverse flow (see section 3.2 for details)

$$TC_{RE}(\cdot) = IC_{RE}(r, Q) + (\lambda - \gamma)c + \sum_{i=0}^{n} f_i\, \alpha_i \tau \lambda. \tag{5}$$

Finally, let $\Pi_{RE}(\cdot)$ be the expected profit per unit time for the retailer such that,

$$\Pi_{RE}(\cdot) = (1 - \tau)\lambda p + \gamma p - \left[IC_{RE}(r, Q) + (\lambda - \gamma)c + \sum_{i=0}^{n} f_i\, \alpha_i \tau \lambda \right]. \tag{6}$$

The optimization problem for the retailer is to maximize the expected profit defined in (6). Note that for a given set of cost parameters, the maximization problem above becomes minimization of expected inventory cost. Hence objective is to find non-negative integer pair (r^*, Q^*) that minimizes the expected inventory cost. The optimal solutions (r^*, Q^*) that minimize (3) can be found in a using complete enumeration (for details see Fleischmann et al., 2002; Muckstadt and Isaac, 1981). However, it is worth to mention that the implications of change in those parameters may not be reflected if only cost minimization model is adopted. The rationale here is that maximizing the profit or value for the entire supply chain.

Another cost component incurred by the retailer that we have not discussed this section is the fee paid $(f_{3P}^{(i)})$ to 3PRLP to process returns in each activity i. At the same time, this fee turns out to be the only source of revenue for the 3PRLP. Hence, we discuss this cost in next section 3.2 in detail since it does not affect the optimization problem for retailer in (6). In other words, fees paid to process returns do not influence reorder point or ordering quantities. This is intuitive such that the fee is exogenous and hence there is no influence of fee to the expected inventory cost.

3.2 3PRLP and reverse flow

In this section we use a queuing network to model the reverse flow of products in the CLSC. As discussed in model description, we assume that after a delay, τ fraction of the demand is returned during each period. Furthermore, we assume that the RL is independently managed by the 3PRLP who assumes all managerial responsibility for the return product flow. An example of a RL models with some sequential activities by the 3PRLP is illustrated in Figure 5.

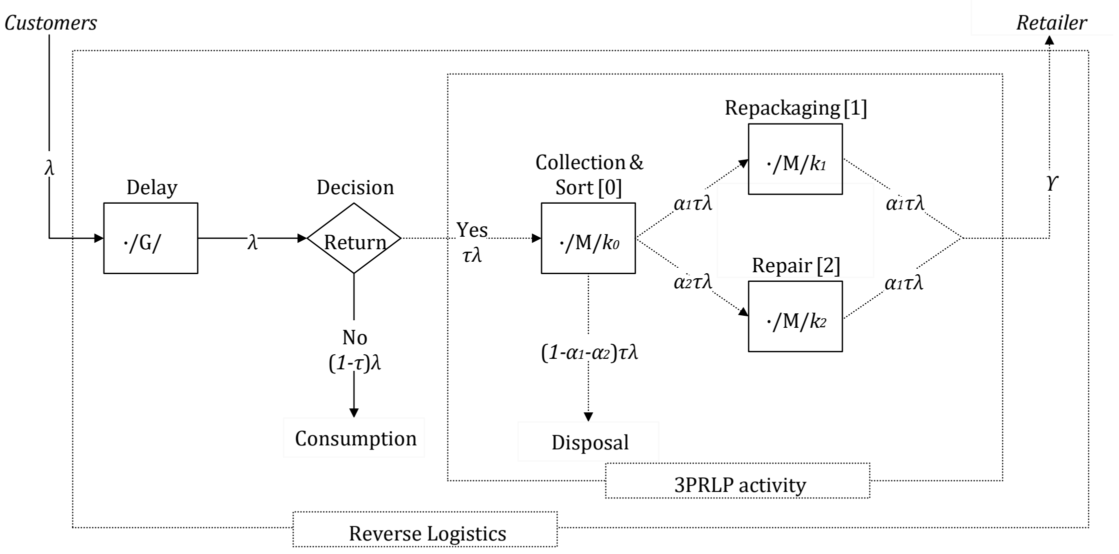


Figure 5: Reverse flow

Details of product flow in the RL are as follows. After purchasing an item, the customer may keep the item or return the item to the 3PRLP who is acting as the agent of the retailer. The time required by the customer to decide whether to keep or return the item is represented in the model as the customers' decision delay node and is modeled as an infinite-server queue with a general service time distribution with mean delay time equal to equal $1 / \mu_d$. Toktay et al. (2000) also assumes the infinite-server queue with general service time distribution used to model customer return delays. Now if the customer decides not to return the item, then that item exists and never comes back to the system.

Hence, $1 - \tau$ portion of the demand exits the system each period which makes remaining $\tau\lambda$ as the input for the 3PRLP activities.

To keep track of input and output processes of 3PRLP activities we note following theorems. According to Mirasol (1963), the output process of infinite server queues with general service time is Poisson when the input is Poisson. In the same way, based on Burke (1956), the output process of multi-server queue is also Poisson, and it is known as Burke's theorem. As indicated in above example in Figure 5, since the output of customers' decision delay is the input for the 3PRLP's first activity i.e. collection/sort node, it means 3PRLP receives returns according to Poisson process with mean $\tau\lambda$. Moreover, based on above theorems, we can establish that all the input and output processes of 3PRLP activities are according to Poisson process.

To exploit the tractability of the product-form queuing network theory (Baskett et al., 1975; Jackson, 1963), we assume that queues designated for the 3PRLP activities have exponential service times. Hence, the performance of the RL processing depends on the four service time distributions only through their means. Furthermore, we model each activity of the 3PRLP as a multi-server queue. Also note that splitting a Poisson process using a Bernoulli switch is Poisson as well as merging multiple independent Poisson processes results in a Poisson process with a rate equal to the sum of individual rates (Ross, 1997). Hence, we have established that all the input and output processes of the 3PRLP activities are Poisson processes. Now let αi be the fraction of return that is gone through activity i. This means $1 - \sum_i \alpha_i$ fraction of returns is disposed. Consequently, after processing all the returns, the 3PRLP replenishes items back to the retailer according to Poisson process with mean $\sum_i \alpha_i \tau\lambda$. In other words, each period $\sum_i \alpha_i \tau$ fraction of the demand is processed and sent back to the retailer by the 3PRLP. Also, we note that $\sum_i \alpha_i \tau\lambda$ corresponds to γ in previous section 3.1.

As mentioned above, we model each of 3PRLP activity as a multi-server queue to detail the activity (such that processing rate, number of workers in each department, average processing rates etc.) and derive economic performance based on these details. Therefore, each activity $i = 1..n$ has k_i workers and the service time for each worker is independently and identically distributed exponential service-time distribution with mean $1/\mu_i$. Moreover, the 3PRLP charges a fee f_i per item processed from the retailer and pays wage w_i for every item processed, which both a fee and wages are specific to a particular activity. Furthermore, a fee charged, an wage paid as well as a cost incurred to hold an item are specific such that an activity i's costs can be different from j's. For instance, a repair activity might incur highest fee and wage due to the technical skills of an employee such that he/she is a certified technician in repair department and hence should be paid higher than a worker operating in collection or sorting department. Now, we derive the expected total profit for the 3PRLP. So as to achieve this expression, we formulate the steady-state probability that there are no returns in the 3PRLP activity i such that,

$$Pr\left[N^{(i)}(t) = 0\right] = \left[\frac{z_i^{k_i}}{k_i!\,(1-\delta_i)} + \sum_{j=0}^{k_i-1} \frac{z_i^n}{j!}\right]^{-1} \quad for\ i = 0..2 \tag{7}$$

where $z_i = \begin{cases} \tau\lambda/\mu_i & if\ i = 0 \\ \alpha_i\tau\lambda/\mu_i & otherwise \end{cases}$ and $\delta_i = \frac{z_i}{k_i}$.

Note that the condition for the existence of a steady-state solution for each activity is $\delta_i < 1$ (for details see Gross et al., 2013). That is, the mean input rate for any 3PRLP activity must be less than the mean maximum potential processing rate of that activity. Next, we derive the expected number of returns in each activity. Denote $L_i(k_i)$ as the expected number of returns in activity i and,

$$L_i(k_i) = z_i^{k_i} + \frac{z_i^{k_i}\delta_i}{k_i!\,(1-\delta_i)^2} Pr\left[N^{(i)}(t) = 0\right]. \tag{8}$$

Note that the derivation of (8) is straightforward result of Little's formula for multi-server queues and can be found in most of queuing textbooks such as Gross et al. (2013).

We now construct expected total cost for the 3PRLP, once we have the expression for expected number of returns in each activity. As discussed above, we define a cost structure that considers two different operational cost factors, the wage provided to workers as well as the expected storage costs for returns incurred in each of the activities. Hence, the expected total cost for 3PRLP is sum of wages and storage costs incurred in every activity. That is for activities $i = 0..n$, the total expected cost is

$$TC_{3P}(\cdot) = \sum_{i=0}^{n} (h_i L_i(k_i) + w_i k_i). \tag{9}$$

Finally, the expected total profit for the 3PRLP is the difference of total fees collected from the retailer and the total expected cost expressed in (9):

$$\Pi_{3P}(k_i) = \sum_{i=0}^{n}[f_i \alpha_i \tau \lambda - (h_i L_i(k_i) + w_i k_i)] \tag{10}$$

We are interested in an optimization problem for the 3PRLP that is to obtain number of workers in each activity (integer values k_i^*), which maximizes the expected profit defined in (10). The total revenue specified in the first part of (10) does not depend on the number of workers employed by the 3PRLP but it depends on the number of returns that are processed by the 3PRLP. This is intuitively appealing since the retailer does not have any influence on the 3PRLP's internal decision making. Hence, the retailer should only incur costs according to number of returns processed by the 3PRLP. By the same token, the 3PRLP does not control the flow of returns $\tau\lambda$ to its processing facility, which implies that its total revenue on the returns is fixed. Therefore, given this fixed revenue, the 3PRLP will try to maximize its profit by determining the optimal number of workers to staff in its returns processing activities.

Due to the complexity of optimizing (10), closed form solutions for optimal number of labors for each activity of the 3PRLP are intractable. However, Proposition 1 ascertains that the optimal number of workers required to staff each process can be determined by complete enumeration.

Proposition 1 We can observe that from total cost function in (9), cost of wage, $w_i k_i$, for any activity i is increasing in k_i, while $L_i(k_i)$ is decreasing in k_i. Hence, the expected profit in an activity i is a concave function in number of workers k_i since revenue for each activity is not a function of k_i. Furthermore, the maximum total expected profit can be achieved by summing all individual activity profits since each activity is independent.

As noted earlier, both total profit functions for the retailer and the 3PRLP are highly non-linear and this complexity limits the ability to obtain closed form solutions of the decision variables. Therefore, in the next section, we conduct numerically analyze the model to derive solutions and illustrate the impacts of the key parameters on the decision variables.

4. Numerical Analysis

In this section we conduct set of 18 numerical examples to demonstrate the model developed in Sections 3.1 and 3.2. Rather than analyzing the complete set all the parameters, for simplicity and tracking purposes, we limit the number of processing activities for the 3PRLP to $i = 1$. That is, one could speculate that the 3PRLP firm is only responsible for repackaging the returned items and hence these items can be sold at the same price of new item. Furthermore, we vary the returns rate and the inventory holding costs for both the retailer and the 3PRLP but fix other parameters. We consider values for the returns rate ranging from $\tau = 0.1$ to $\tau = 0.6$. Note that we do not consider values greater than 0.6 since returns rates higher than 60 percent are uncommon in practice. We vary unit holding cost ranging from \$2.5 to \$7.5 in order to illustrate the firm specific impacts. The parameters values used in the numerical example are summarized in Table 5.

Retailer and forward flow		
Notation	**Description**	**Values**
λ	Demand	20
τ	Fraction of demand that is returned	0.1, 0.2, 0.3, 0.4, 0.5, 0.6
c	Unit cost to purchase an item	\$25
p	Unit selling price	\$40
a	Fixed cost to place an order	\$400
b	Penalty cost for one unit backordered	\$100
h	Cost to hold one unit in inventory	\$2.5, \$5, \$7.5
LT	Supplier lead time (constant)	10
3PRLP and reverse flow		
α_1	Percentage of returns that undergone through sorting	1
$1/\mu_1$	Mean processing time at sorting	1
f_1	Fee (\$) charged to sort per unit return	\$20
w_1	Wage (\$) per worker at sorting	\$2.5
h_1	Holding cost of per unit at sorting	\$2.5, \$5, \$7.5

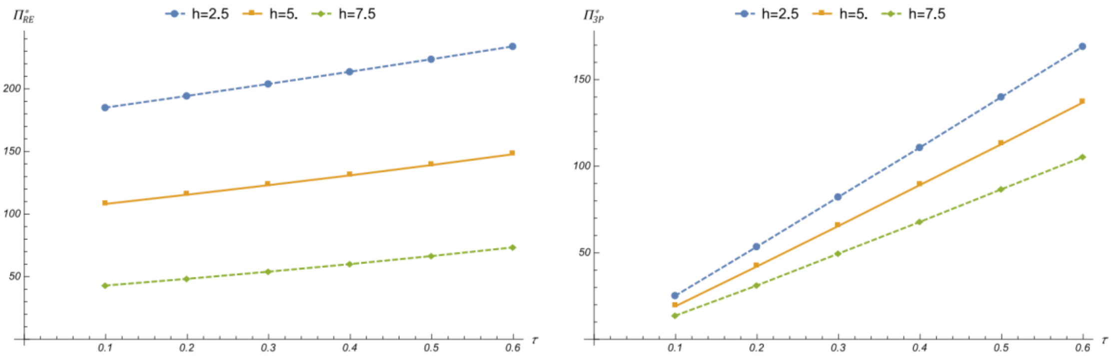
Table 5: Parameter values

The results of optimization based above parameters are presented in Table 6. We discuss the results for each firm separately. For the retailer, as the amount of flow for processed returns increases, both reorder point units r^* and order size units Q^* decrease. This result is expected since the processed returns are considered as the second source for the retailer and are sold at the undifferentiated price. Therefore, the retailer's overall profit improves when returns rate increases as the more goods can be sold at a new product price. Furthermore, as expected the inventory holding cost has a negative impact on the overall retailer profit. It is crucial to we note that the retailer's profit is affected more excessively with changes in the inventory holding cost from the case of 3PRLP's profit. This is due to the fact that retailer's inventory cost defined in (3) is sensitive to the changes in holding cost. These results are depicted in panel A of Figure 6.

The directions of effects of changes in both the returns rate and the holding cost are similar for the 3PRLP. However, the magnitude of effects is quite opposite from the case of retailer. In other words, even though the returns rate has positive effect on the 3PRLP's profit, it is quite significant than the effect of decreasing holding cost. This is because the effect of changes in τ is direct to the 3PRLP's profit function in 10 whereas the effect of changes in h_1 is subdued by the average number of returns being processed. To put simply, the amount returned items is always higher or equal to amount of returns to be processed at the 3PRLP's facility.

Holding cost ($h = h_1$)	Return rate (τ)	Optimum inventory policy (r^*Q^*)		Retailer's profit (Π_{RE}^*)	No. of workers (k_1^*)	3PRLP's profit (Π_{3P}^*)
$2.5	0.1	31	199	$185.08	3	$25.28
	0.2	30	180	$194.42	6	$53.58
	0.3	29	162	$204.00	8	$82.32
	0.4	28	143	$213.74	10	$110.91
	0.5	26	124	$223.73	13	$140.12
	0.6	24	106	$233.99	15	$169.31
$5	0.1	24	196	$108.15	4	$19.13
	0.2	24	177	$115.51	6	$42.15
	0.3	23	158	$123.10	9	$65.54
	0.4	22	139	$130.95	11	$89.23
	0.5	20	121	$139.20	14	$112.82
	0.6	19	102	$147.81	16	$136.93
$7.5	0.1	21	193	$42.95	4	$13.70
	0.2	21	174	$48.30	7	$31.15
	0.3	20	156	$54.02	9	$49.56
	0.4	19	137	$60.07	12	$67.90
	0.5	19	118	$66.51	14	$86.74
	0.6	18	99	$73.42	16	$105.40

Table 6: Results for optimum values and profits



(a) Retailer's Profit (b) 3PRLP's Profit

Figure 6: Returns rate vs. holding cost

5. Conclusion

In this paper we present a CLSC model where demand is generated by a stochastic process. A fraction of the units that are initially sold are returned by the consumers for a full refund in every period. The retailer may then contract out the services of a 3PRLP that has the capability of bringing the returned products back to their original condition (these processed returns are then "like new"). The processed returns are sold again at the full price.

We model the forward flow interaction between the supplier, the retailer and 3PRLP by a widely accepted control policy that is lot size-reorder point inventory policy, which is detailed by the Markov process. We further propose a queuing network to capture backward flow activities of the 3PRLP, which consists of customer decision delay and each of the 3PRLP activities. We characterize the expected profits for both firms and derive the effects of key parameters through set of numerical examples. We note that due to intractability of deriving closed form solutions to decision variables, we relied on running numerical examples.

The results of numerical experiments conducted indicate that both firms' profits increase with an increasing returns rate. This is due to fact that the retailer captures more profits through selling processed returns at the price of new product. The 3PRLP unambiguously earns more profit from increasing product returns since the charging fee from processing returns is sole source of revenue. Consequently, as indicated by numerical examples, the changes in the return rate have more impact to the 3PRLP's profit than the retailer's profit.

In addition to analyzing the effects of the returns rate we also examine the effects of holding cost per item. The directions of effects of changes in the holding cost are similar for both firms that is negative. However, the magnitude of effects is quite opposite. Interestingly, the retailer's profit appears to be more sensitive to the holding cost than that of the 3PRLP's profit. We believe this is due to structural setup of profit functions for both firms and articulate that 3PRLP's profit is subdued by the average number of returns being processed.

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