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Studying the Reverse Supply Chain Model with Remanufacturing

Arman Bahari[a], Mohammad Taghi Taghavi Fard[b*] and Mohammad Khalilzadeh[a]

[a] *Department of Industrial Engineering, Faculty of Engineering, Science and Research Branch of Tehran,*
Islamic Azad University, Tehran, Iran
[b] *Faculty of Industrial Management, AllamehTabatabai University, Tehran, Iran*
[*] *Corresponding author: mohammadtaghitaghavifard*

Abstract: Sustainability has become a remarkable issue in most economies, causing many companies to focus on product recovery and reverse supply chain. However, work with quantitative models is still uncommon. This research is focused on inventory control in the remanufacturing. The model helps in maintaining the customer's satisfaction by providing safety stock. A procedure is used for the assessment of manufacturing and remanufacturing goods optimal levels at the same time. The main objective is to minimize the waste and increase the competitive advantage of conversion cost.

Keywords: Reverse Supply Chain (RSC), Inventory Models, Remanufacturing

INTRODUCTION

The concept of reverse supply chain is not new. The reuse of products has beenpreviously applied, essentially for the economic benefits of reusing the component and materials instead of its disposal (Fleischmann *et al.,* 1997). Also, technology advances have reduced the life cycles for many products. Product demand may growth rapidly at first and then decrease a few months later due to the importance of new products. Inventory control under a short life cycle of product is not easy. Due to an increase in many problems such as large safety stock, high costs of obsolescence, and high forecasting errors, it is essential to consider the constantly varying demand and its uncertainty when making inventory management policy (Hsueh, 2011). In addition to economic motivations and technology improvements, environmental concerns have directed the increase in the development of reverse supply chain activities. Moreover, government pressure has contributed to the increasing motivation for global environmental warning and green supply chain management principles (Sheu and Chen, 2012).

Reverse logistics has been implemented long before the term was initially adopted, such as military, customer service policy, and the automotive aftermarket (Rogers *et al.*, 1999). The rise of e-commerce and the positive vision of environmental impacthas elevated the formal use of reverse logistics (Bei *et al.*, 2005). So, in today's business environment, due to most common reasons such as product returns, incorrect delivery of product and damaged products, reserve logistic is inevitable (Fleischmann *et al.*, 1997).

Moreover, it can be of higher importance in one industry over another due to production costs and the nature of remanufacturing of the products (Bazan *et al.*, 2015b). In this way, some products can receive values along the reverse chain bymean of recycling or remanufacturing processes (Silva Filho *et al.*, 2013). There manufacturing process can be briefly described as (Quanwu *et al.*, 2016):

First, products collected from customers (at the end of life) and disassembled into their constituent parts. Next, the components are re manufactured to exact specifications to ensure that they provide the same quality, reliability and durability as new ones. Last, remanufactured components are assembled, tested and made ready for saleas the remanufactured product.

The concern for managing product return flow (Bazan *et al.*, 2015a), justified the growing interest in development of inventory control models to study and analyze reverse supply chains (van der Laan *et al.*, 2006; Behret *et al.*, 2009). Also, another difficulty of managing reverse operations is the need to effectively coordinate manufacturing and remanufacturing activities (Inderfurth *et al.*, 2001). This trend in the industry has led several researchers to investigate such problems and develop appropriate models to account for cases where remanufacturing of used products is an additional choice for the reserve logistics (Nenes *et al.*, 2010).The present study focuses on the deterministic approach of optimizing the reverse logistics inventory model, to analyze the mathematics complication in the associated processes. The paper is organized as follows: a literature review is presented, followed by a review of mathematical models and a discussion summarizing what has been achieved and what needs to be done with the emphasison environmental concerns. The paper concludes with some findings and outlines future researchdirections.

RELATED WORKS

There are numerous studies that analyze inventory models with return flow in Reverse supply chain. These models can be classified into two groups including deterministic models (e.g. Richter and Dobos, 2004; Teunter *et al.*, 2009; Zanoni *et al.*, 2012; Feng *et al.*, 2014; Özceylan *et al.*, 2014) and stochastic models (e.g., Fleischmann *et al.*, 2002; Behret and Korugan, 2009; Zolfagharinia and Haughton, 2012; van Donselaar and Broekmeulen, 2013). In this section, we aim to make contributions to the stochastic and deterministic reviewed modeling literature.

The root of these models is the work of Schrady (1967) (Fleischmann *et al.*, 1997) which is based on the classical economic order quantity (EOQ) model. He analyzed an inventory situation with constant demand and return rates when production and recovery are instantaneous (Brojeswar *et al.*, 2013). The work of Schrady has been developed extensively as presented in the literature (Fleischmann *et al.*, 1997).

Richter's model, a direct extension of the model of Schrady, shows that for low disposal rates, the repair setup cost has no effect on the total lot size, whereas, for large waste disposal rates, the production setup cost has no effect (Richter, 1996b). This assumption by Richter state that some items may be disposed of as waste (Richter, 1996a). Richter and Dobos developed the work of Richter (1996a, 1996b) to discussed a model in which the disposal option of the returned items is allowed and all the recycling batches follow the production batches (Dobos and Richter, 2003).

Similar to Richter, Teunter extended the work of Schrady by assuming that unit holding costs for newly manufactured and remanufactured items are different, and considered more than one production and repair cycles (Teunter, 2001). He considered stochastic demand and return rates and assumed no lead time. Discounted costs were also considered to make the model more realistic (Teunter, 2002). Widyadana and Wee Also developed an integrated solution procedure for each of the two policies of Teunter using algebraic approaches (Widyadana & wee, 2010).

Konstantaras and Papachristos developed the model of Teunter by allowing for the complete back ordering of demand (Konstantaras and Papachristos 2006) and improved his work by developing an exact solution that leads to the optimal number of manufacturing and remanufacturing for certain parameter classes (Konstantarasa, Papachristos, 2008). However, they consider only the restricted classes of (1, R) and (P, 1) policies (Konstantaras and Papachristos 2006).

Koh *et al.* (2002) studied a model allowing the recovery rate to be both smaller and larger than the demand rate. Working within two classes of policies, namely the class of policies with one procurement lot and a variable number of recovery lots and the class of policies with one recovery lot and a variable number of procurement lots, they derived optimal lot-sizing formulas (Koh *et al.*, 2002 (. Choi *et al.* also presented a joint EOQ and EPQ model for an inventory control problem in a reserve supply chain, in which the demand can be satisfied by purchasing brand-newproducts and remanufacturing used products (Choi *et al.*, 2007).

El Saadany and Jaber also extended the work of Richter (1996a, 1996b) to account for setup changeover costs when switching between productions and remanufacturing runs (El Saadany and Jaber, 2008). They suggested that the return flow of used items depends on the purchase price and the accepted quality level of the returned items (El Saadany and Jaber, 2010). Van der Laan *et al.* (1996) considered several inventory control strategies with remanufacturing and disposal (van der Laan *et al.*, 1996) by assuming that the demand rate and return rate are independent (Hsueh, 2011). Also Push and pull strategies are considered in the inventory model (van der Laan and Teunter, 2006) to coordinate production, remanufacturing, and disposal operations. Sun *et al.* in their study investigated a manufacturing and remanufacturing inventory system with return rate dependent on the product demand. Also, a three stage stochastic dynamic programming is developed to explore an optimal inventory policy (Sun *et al.*, 2013).

Another work developed by Poles is a production and inventory system for remanufacturing using a System Dynamics simulation modeling approach. The research findings reveal efficiency in the remanufacturing process with higher remanufacturing capacity if the quantity of returned items and the remanufacturing lead time are increased and decreased respectively (Poles, 2013). A stochastic linear quadratic Gaussian (LQG) model with constraints has been formulated by Silva Filho and Salviano to provide optimal annual plans for manufacturing, remanufacturing and disposal variables. Assuming the demand as stationary and normally distributed, an associated equivalent deterministic problem is introduced. So, optimal inventory-production scenarios can be created by variation of parameters such as return rate of used products, delay of return, or even both (Silva Filho&Salviano, 2013).

Zolfagharinia *et al.* developed a new inventory control model for joint purchasing and remanufacturing in a reverse supply chain. Also, they designed a new hybrid solution method, a meta-heuristic algorithm seeking for a near-optimum solution with an embedded simulation model that approximates the objective value of each generated solution (Zolfagharinia *et al.*, 2014).

The proposed inventory model

Figure (1) is showing the proposed model by assuming that,

- Stock out is allowed.
- Stock out is replaced by the remanufacturing products.

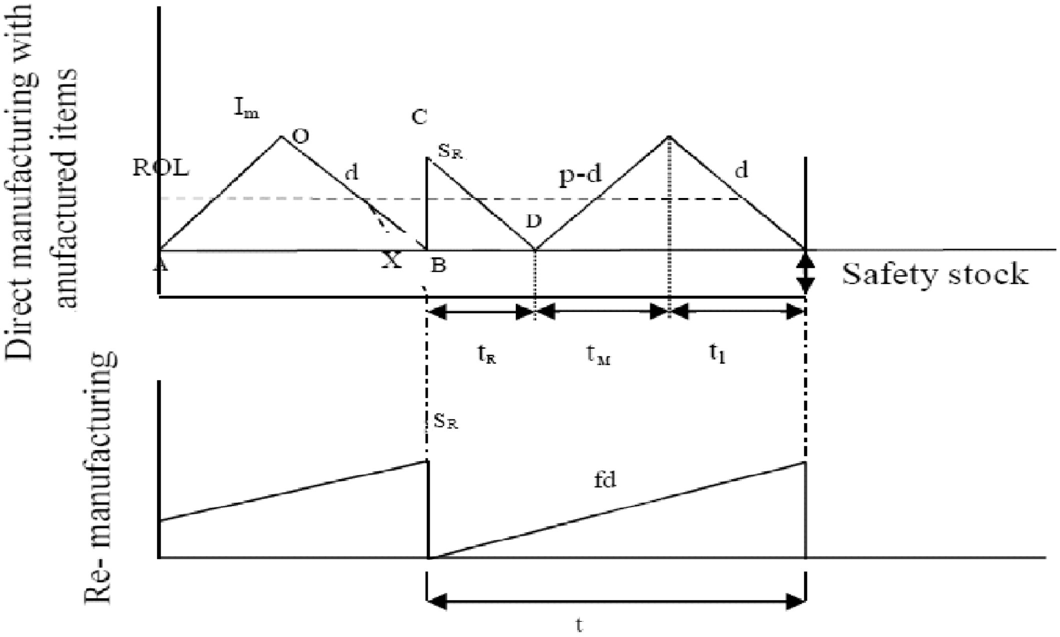

Figure 1: The inventory model with remanufacturing

In the remanufacturing cycle, the products that have the potential of remanufacturing are collected from customers at rate ‘f×d‘. The value of ‘f‘ varies between ‘0‘and ‘1‘and the value of ‘d’ depends on the market demand. At the end of time‘t‘, remanufacturing rate reaches the level of ‘S_R’. At this time, a large portion of remanufactured items is moved to the manufacturing to satisfy the demand. When the remanufactured items inventory levels become zero, the next production cycle begins. In this model assuming that in manufacturing cycle remanufactured items is used. During the time ‘t_R’, all remanufactured goods are used and inventory of final product is comes to zero. At the beginning of time ‘t_m’, direct manufacturing begins with a rate ‘p’ and the market demand is satisfied with rate ‘d’. The final product inventory level rise at a rates (p-d) and at the end of period “, achieves a value ‘I_m’. At the beginning of the time“, the direct manufacturing is stopped and market demand satisfied by the inventory of finished items. At the end of time“inventory level comes to zero. By this moment, final products inventory is carried over from the remanufactured to direct production cycle and process continues. Because this model uses the return products for remanufacturing, the total cost is reduced and productivity is increased. Since the returned items are used for providing the raw materials for remanufacturing, there is a basic ecological benefit and avoids a significant amount of resource depletion. In addition, the possibility of losing the goodwill from the customers, resulting from used inventory, has been completely removed in the model. The successful implementation of this method can reduce the cost of the final product that also leads to a reduction of the raw material supplies.

Variables and parameters of proposed model

Table (1) shown the variables used for the model:

Table 1
Proposed model variables and parameters

Variables	*Description*
D_A	Annual demand for an item
d	demand / consumption rate of items
p	the production rate of the finished product in the direct production
f	fraction of demand
C_{H1}	final products holding cost
C_{H2}	holding cost for the products in remanufacturing cycle
C_o	Direct manufacturing order/set up cost
C_{OR}	Remanufacturing order/setup cost.
I_m	finished products maximum level of in manufacturing
S_R	finished products maximum level in remanufacturing
t	Total cycle time
t_1	The time, in which remanufactured products are consumed
t_m	The time during which inventory prepared in the direct manufacturing
t_d	The Time, in which inventory level for direct manufacturing comes to zero.
Z	The number of standard deviations for a specified service level(extracted from the normal distribution table)
S_d	standard deviation during the lead time
S_i	The standard deviation for each day during the lead time

From figure (1), we can have

TC = inventory holding cost for finished products +inventory holding cost forremanufactured products + finished products inventory set up cost + Remanufactured products inventory set up cost for

$$TC = \left(\frac{C_{H1}\times S_R \times f \times t}{2} + \frac{C_{H1}\times I_m \times p \times t_m}{2d}\right) + \left(\frac{C_{H2}\times f \times d \times t^2}{2}\right) + \left(C_O \times \frac{D_A}{(I_m + S_R)}\right) + \left(C_{OR} \times \frac{D_A}{(I_m + S_R)}\right) \Rightarrow TC = \frac{C_{H1}\times S_R^2}{2d} + \frac{C_{H1}\times p}{2d(p-d)} \times I_m^2 + \frac{C_{H2}\times S_R^2}{2f \times d} + \frac{D_A}{(I_m + S_R)}(C_O + C_{OR}) \Rightarrow TC = \frac{S_R^2}{d}\left(\frac{C_{H1}}{2} + \frac{C_{H2}}{2f}\right) + \frac{C_{H1}\times p}{2d(p-d)} \times I_m^2 + \frac{D_A}{(I_m + S_R)}(C_O + C_{OR}) \quad (1)$$

Equation (1) shows that the total cost is a function of C_{H1}, S_R, d, p, I_m, C_{H2}, f, D_A, C_O anhd C_{OR}. Value of 'S_R 'and' 'I_m' can be found by minimizing the total cost. Therefore, using $\frac{\partial TC}{\partial I_m} = 0$ *and* $\frac{\partial TC}{\partial S} = 0$, the maximum level of final product can be obtained through direct production of (I_m) and remanufacturing of (S_R).

Considering, $\frac{\partial TC}{\partial I_m} = 0$, we have

$$I_m = \frac{2S_R(p-d)}{C_{H1} \times p} \times \left(\frac{C_{H1}}{2} + \frac{C_{H2}}{2f} \right) \tag{2}$$

Now using $\frac{\partial TC}{\partial S_R} = 0$, we can have

$$S_R = \left[\frac{D_A(C_O + C_{OR}) \times 4C_{H1}^2 \times p^2 \times f^3 \times d}{(2(p-d) \times (C_{H1} \times f + C_{H2}) + 2C_{H1} \times p \times f)^2 \times (C_{H1} \times f + C_{H2})} \right]^{\frac{1}{3}} \tag{3}$$

Equations (2) and (3) can be used to determine the values of 'I_m' and 'S_R' respectively.

Due to the demand rate variation, it is so important to consider the stock out condition in the direct manufacturing. The model considering the safety stock is shown as a dotted line in figure (1). Due to higher demand, the zero stock condition take place at X instead of B (figure 1). Therefore to deal with this situation, a safety stock is essential.

The Safety stock can be computed via concept of service level. Service level is adjusted for very high values (more than 90%), For example, a service level of 90% can be achieved if 9 out of every 10 phone calls are answered before the established time limit[1].

The Safety stock can be specified as: $Z\,S_d$.

S_d Can be calculated as:

$$S_d = \sqrt{\sum_{i=1}^{L} (S_{d_i})^2}$$

An example problem

In order to validate the model we consider a sample problem with the following data related to a company (table 2),

Table 2
Data related to sample problem

Parameter	*Values*
D_A	40000 units
C_o	300 IRR.
C_{OR}	150 IRR.
C_{H1}	20IRR./unit/year
C_{H2}	10 IRR./unit/year
f	within the range of 0.1 to 0.9

‘I_m‘and ‘S_R’ can be calculated using these values in the equation (2) and equation (3) and the total costs is computed using ‘I_m’ and ‘S_R’ along with equation (1), (as shown in Table 3).

Table 3
The values of ‘S‘, ‘I_m‘and TC with the variation of ‘f‘.

TC	I_m	S_R	*f*
2342	713	338	0.1
2198	716	511	0.2
2110	660	618	0.3
2051	623	692	0.4
2008	597	746	0.5
1975	578	788	0.6
1949	563	821	0.7
1929	551	848	0.8
1912	541	780	0.9

RESULTS AND ANALYSIS

Table (3) is showing the results obtained from the calculations. Also, the mutual inter-relationships of various parameters are depicted in figures (2) and (3). From the total cost values, there would be no doubt that, the total cost will be decreased through increase of fraction return percentage for remanufacturing (f). The variation of ‘S_R’ with ‘f’ shows that increase rate of ‘S_R’, decreases with increase of the ‘f’ (Figure 2). The variation of ‘I_m’ shows that the rate of decrease in (ΔI_m), decreases with increase in the ‘f’ value and at $f = 0.35$, the values of ‘I_m’ and ‘S_R’ are almost equal (Figure 2).

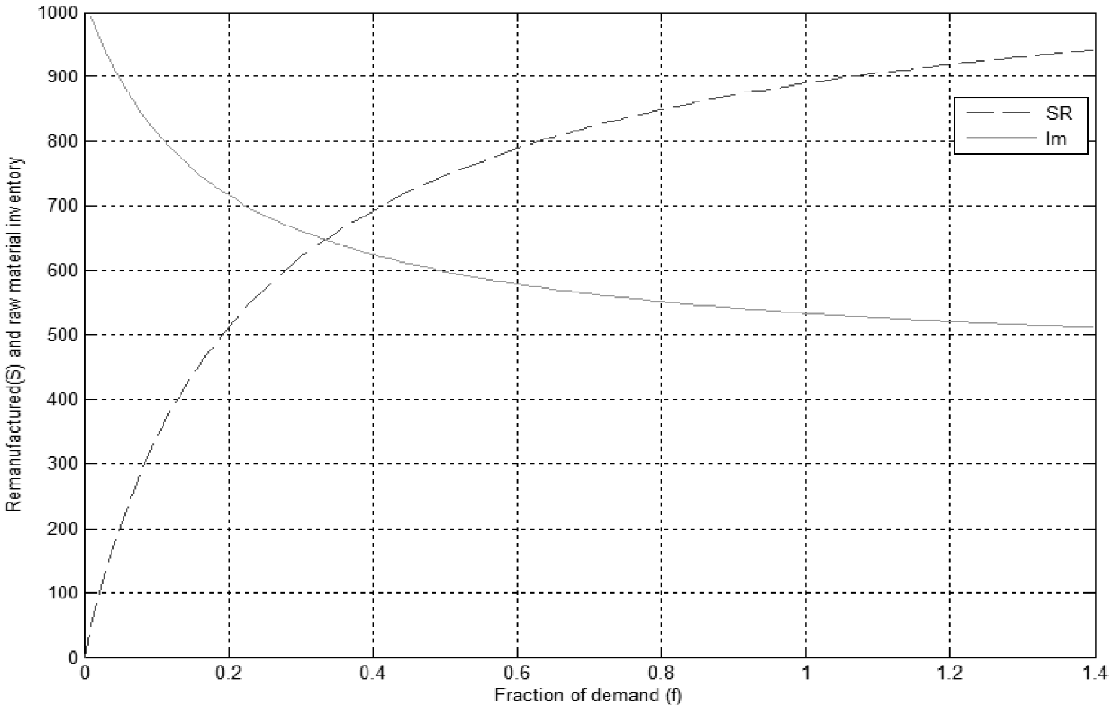

Figure 2: The variation of remanufactured products and finished products in direct production

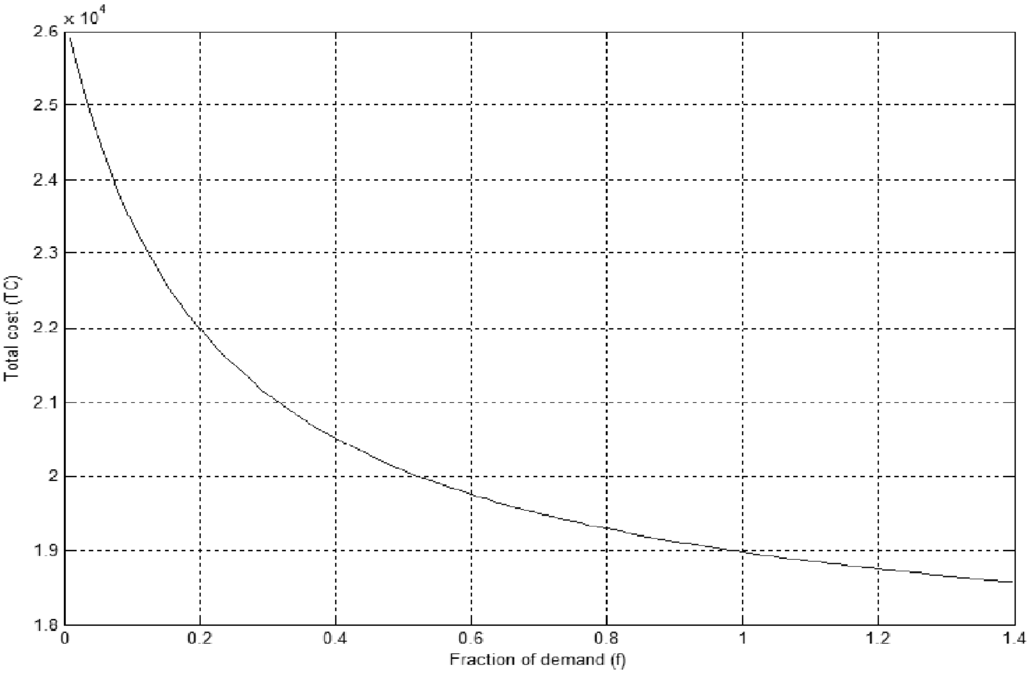

Figure 3: Variation oftotal cost with the fraction of demand

Figure (3) is shown the variation of total cost with the fraction of demand. The exponential nature of the curve shows that ‘TC‘decreases with increase of ‘f’. Due to Variation of ‘f‘depends on the industry and product type, which makes it very difficult to quantify. Also, the main constraint is that all the returned items cannot be remanufactured. In This way, ‘I_m’ and ‘S_R’ values should be adjusted according to the industry type and also fraction of return for remanufacturing should be reviewed accurately.

CONCLUSION

In this study, we analyze a model where the demand can be satisfied with remanufactured and new manufactured products. The system is associated with reverse logistics, in which returned items are served as raw materials. To avoid the stock out anoptimized inventory model is developed.

The results of this study may be extended the following cases. Researchers can add different aspects of recovery to model and check its feasibility. In other case, the collection/demand rate could be treated as random variables. In our paper, customers assumed to be indifferent betweenbuying manufactured and remanufactured products so the future works is investigating the inventory costreducing benefits of remanufacturing for themanufacturers with separate demandstructures for manufactured and remanufactured products.

NOTE

1. *http://whatis.techtarget.com/definition/service-level*

REFERENCES

Bazan, E., Jaber, Zanoni, M.Y., S. (2015a), A review of mathematical inventorymodels for reverse logistics and the future of its modelling: An environmental perspective, Applied Mathematical Modelling, doi: 10.1016/j.apm.2015.11.027.

Bazan, Ehab, Jaber, Mohamad, El Saadany, Ahmed M.A. (2015b), Carbon emissions and energy effects on manufacturing–remanufacturing inventory models, Computers & Industrial Engineering 88, 307–316.

Behret, H., Korugan, A. (2009), Performance analysis of a hybrid system under quality impact of Returns. Comput. Ind. Eng. 56 (2), 507–520.

Bei, W., &Linyan, S. (2005), A review of reverse logistics. *Applied Sciences,* 7, 16–29.

Brojeswar, Pal, Sankar Sana, Shib, Chaudhuri, Kripasindhu, (2013), A stochastic inventory model with product recovery, *CIRP Journal of Manufacturing Science and Technology* 6 , 120–127.

Choi, D.W., Hwang, H., Koh, S.G. (2007), A Generalized Ordering and Recovery Policy for Reusable Items, European *Journal of Operational Research,* 182:764–774.

Dobos, I., & Richter, K. (2003), A production/recycling model with stationary demand and return rates. *Central European Journal of Operations Research,* 11, 35–46.

El Saadany, A. M. A., &Jaber, M. Y. (2008), The EOQ repair and waste disposal model with switching costs. *Computers & Industrial Engineering,* 55, 219–233.

El Saadany, A. M. A., & Jaber, M. Y. (2010), A production/remanufacturing inventory model with price and quality dependent return rate. *Computers & Industrial Engineering,* 58, 352–362.

Feng, Z., Zhiping, W., Chen, Y. (2014), The equilibrium of closed-loop supply chain super network with time-dependent parameters. Transp. Res. Part E: Log.Transp. Rev. 64, 1–11.

Fleischmann, M., Bloemhof-Ruwaard, R. Dekker, E. van der Laan, J.A. van Nunen, L.N. vanWassenhove, (1997), Quantitative models for reverse logistics: a review, *Eur. J. Oper. Res.* 103(1), 1-17.

Fleischmann, M., Kuik, R., Dekker, R. (2002), Controlling inventories with stochastic item returns: a basic model. *Eur. J. Oper. Res.* 138 (1), 63–75.

Hsueh n, Che-Fu, (2011), An inventory control model with consideration of remanufacturing and product life cycle, *Int. J. Production Economics* 133, 645–652.

Inderfurth, K., van der Laan, E. (2001), Leadtime effects and policy improvement for stochastic inventory control with remanufacturing. *Int. J. Prod. Econ.* 71, 381–390.

Koh, S.G., Hwang, H., Sohn, K.I., Ko, C.S. (2002), An optimal ordering and recovery policy for reusable items. *Computers and Industrial Engineering* 43, 59–73.

Konstantarasa, I., Papachristos, S. (2008), A Note on: Developing an Exact Solution for an Inventory System with Product Recovery, *International Journal of Production Economics,* 111: 707–712.

Nenes, Panagiotidou, Sofia, Dekker, Rommert. (2010), Inventory control policies for inspection and remanufacturing of returns: A case study George, *Int. J. Production Economics* 125, 300–312.

Poles, Roberto, (2013), System Dynamics modelling of a production and inventory system for remanufacturing to evaluate system improvement strategies, *Int. J. Production Economics* 144, 189–199.

Quanwu, Zhao, Yu, Zhou, b. (2016), Manufacturer-remanufacturing vs supplier-remanufacturing in a closed-loop supply chain, *Int. J. Production Economics* 176, 21–28.

Richter, K., The EOQ repair and waste disposal model with variable setup numbers, *Eur. J. Oper. Res.* 95(2) (1996a) 313–324.

Richter, K., The extended EOQ repair and waste disposal model, *Int. J. Prod. Econ.* 45(1-3) (1996b) 443–447.

Richter, K., Dobos, I., (2004), Production-inventory control in an EOQ-type reverse logistics system. In: Dyckhoff, H., Lackes, R., Reese, J. (Eds.), Supply Chain Management and Reverse Logistics. Springer, New York, pp. 163–180.

Rogers, Dale S., & Tibben-Lembke, R. S. (1999), Going backwards: Reverse logistics trends and practices (Vol. 2).

Sheu, J.B., Chen, Y.J. (2012), Impact of government financial intervention on competition among green supply chains, *Int. J. Prod. Econ.* 138(1), 201-213.

Silva Filho, O. S., Salviano, I. R., Optimizing a Production-Inventory Systems with Deteriorating and Remanufacturing Products, 6th IFAC Conference on Management and Control of Production and Logistics, the International Federation of Automatic Control September 11-13, 2013. Fortaleza, Brazil.

Sun, X., Wu, M., Hu, F., (2013), Two-Period Inventory Control with Manufacturing and Remanufacturing under Return Compensation Policy. Hindawi Publishing Corporation Discrete Dynamics in Nature and Society.

Tang, O., Teunter, R.H., (2006), Economic lot scheduling problem with returns. *Prod. Oper. Manage.* 15 (4), 488–497.

Teunter, R.H., Economic order quantities for recoverable item inventory system, Nav. Res. Logist. 48(6) (2001) 484–495.

Teunter, R. H., Economic order quantities for stochastic discounted cost inventory system with remanufacturing, Int. J. Logist. 5(2) (2002), 161–175.

Teunter, R., Tang, O., Kaparis, K., (2009), Heuristics for the economic lot scheduling problem with returns. *Int. J. Prod. Econ.*

Van der Laan, E., Dekker, R., Salomon, M., (1996), Product remanufacturing and disposal: a numerical comparison of alternative control strategies. *International Journal of Production Economics* 45, 489–498.

Van der Laan, E., Teunter, R.H., (2006), Simple heuristics for push and pull remanufacturing policies. *Eur. J. Oper. Res.* 175, 1084–1102.

Van Donselaar, K.H., Broekmeulen, R.A.C.M., (2013), Determination of safety stocks in a lost sales inventory system with periodic review, positive lead-time, lot-sizing and a target fill rate. *Int. J. Prod. Econ.* 143 (2), 440–448.

Widyadana, G.A., Wee, H.M., (2010), Revisiting Lot Sizing for an Inventory System with Product Recovery, *Computers and Mathematics with Applications,* 59: 2933–2939.

Zanoni, S., Segerstedt, A., Tang, O., Mazzoldi, L., (2012), Multi-product economic lot scheduling problem with manufacturing and remanufacturing using a basic period policy. *Comput. Ind. Eng.* 62 (4), 1025–1033.

Zolfagharinia, H., Haughton, M.A., (2012), The benefit of information sharing in a logistics outsourcing context. *Int. J. of Logistics Systems and Management* 13 (2), 187–208.

Zolfagharinia, Hossein, Hafezi, Maryam, ZanjiraniFarahani, Reza, Fahimnia, Behnam, (2014), A hybrid two-stock inventory control model for a reverse supply chain, Transportation Research Part E 67, 141–16.