A Sequential Heuristic for Production-Inventory Planning and Supplier Selection based on Quantity Discounts in a Component Remanufacturing Environment

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Abstract

This paper addresses an integrated new problem of production-inventory planning and supplier selection based on quantity discounts in a Closed Loop Supply Chain (CLSC) environment where backorders are allowed. The process of remanufacturing, specifically the problem of recovery of components from the acquired used products and remanufacturing of the components as-good-as new is considered. An existing mathematical model has been considered and modified in line with the current problem. Since the proposed mathematical model is computationally intractable for solving large scale real-life sized problem, a sequential heuristic method is proposed and the same is seen to provide near optimal solution for small scale problem instances. Furthermore, though the prime objective of the study is maximizing profit, the heuristic is designed in a way that encourages deriving maximum benefit from acquired used products even though it might result in compromising on total profit. This is in line with the motto of CLSC to reduce dependency and use of virgin raw materials and also reduce disposal in landfills.

Keywords
Production Planning, Remanufacturing, Sequential Heuristic, Supplier Selection, Quantity Discounts.

1. Introduction

Closed Loop Supply Chain (CLSC) research has been a continuously evolving field over the years (Guide and Wassenhove, 2009). The importance of CLSC is attributed to a firm being able to recover almost 70-80% of value of a product and thereby contribute to reducing the costs of purchasing virgin raw material. Govindan et al., (2015), present a classification of the major decision issues in CLSC. The production planning decision is one of the prime concerns as it acts a backbone to the entire CLSC functioning. Over the years the same has been studied by numerous other researchers.

In this study, we consider the Original Equipment Manufacturer (OEM) to be the entity controlling the entire supply Chain (SC). The product returns from the customers back to the OEM in the form of used vehicles or in some cases, used parts from an automobile, are achieved by means of paying a return acquisition price (Sun et al. (2013)) to the customer. The products returned by the customers are sold in the primary or secondary market after testing, inspection and undergoing some recovery process (Turrisi et al. (2013)). The recovery process could be in the form of repair, refurbishing, remanufacturing, cannibalization, and recycling (Thierry et al. (1995)).

Remanufacturing is considered as a preferred recovery option. By remanufacturing, the returned products are restored to 'as good as new' condition (Dekker et al., (2000)). The remanufacturing cost is observed to be generally between 40–60% of the manufacturing cost and at the same time consuming only 20% of a firm's effort (Dowlatshahi (2012)). Furthermore, due to various issues, all components may not be possible to manufacture or remanufacture within a firm itself. In such cases, they need to be purchased from external suppliers. In a practical scenario, the suppliers offer discounts based on purchase quantity in order to motivate buyers to purchase in bulk.

With this brief background, in this study, we address a production planning – inventory management problem in a CLSC environment involving component remanufacturing considering backorders and quantity discounts.

Furthermore, as the problem is NP-hard, we propose a sequential heuristic algorithm (SHA) for the problem considered in this study and evaluate the performance of the proposed SHA on a set of generated numerical instances. The organization of the paper is as follows: Section 2 provides a brief review of related literatures. In section 3, the research problem is described. In section 4 the proposed SHA is described. Section 5 shows the performance analysis of the proposed SHA in comparison with the mathematical model. Finally, in section 6, we present the conclusions, and future scope of study.

2. Literature Review

Over the years, supply chain research has moved towards CLSC research (Guide and Wassenhove (2009)). Schrady (1967) was one of the pioneers to discuss about the issues in a CLSC. CLSC exists in both, the process industries (Jabbarzadeh et al., 2018), and discrete product manufacturing industries (Malolan and Mathirajan, (2018)). Govindan et al., (2015), classify the CLSC studies with respect to different aspects, one among those being the decision issues considered. The problem considered in this paper falls under the category of production planning-inventory management. Starting with Schrady, (1967), many researchers modelled the problem considering different configurations.

Richter (1996a) model the production-inventory model in the form of an Economic Order Quantity (EOQ) model with an objective of minimizing the cost. Golany et al. (2001) address a single product problem with an objective of minimizing the cost and propose pseudo polynomial algorithms for the same. Teunter (2001) study a deterministic EOQ model of an inventory system with recoverable items. The problem is modeled with an objective of minimizing the costs. Tang and Teunter (2006) address the production-inventory problem under a hybrid setup by means of formulating an ILP model to determine the optimal quantities to manufacture and remanufacture. Teunter et al (2008) consider dedicated lines for manufacturing and remanufacturing and provide a comparison with Tang and Teunter (2006) and conclude that the dedicated line is advantageous over a hybrid line. The objective of both the studies is minimizing the total costs.

Pan et al. (2009) address a capacitated dynamic lot sizing problem. They propose a pseudo-polynomial approach for solving the problem and conclude that it is beneficial to expand the remanufacturing capacity only when returned products exist in a relatively long planning horizon. Saadany and Jaber (2010) develop and analyze an Economic Production Quantity (EPQ) model involving production, remanufacturing and waste disposal decisions. Zhang et al. (2011) address a dynamic capacitated production planning problem in steel enterprise. They initially formulate a model considering remanufacturing with an objective to minimize the costs. Subsequently, they propose Genetic Algorithm (GA) heuristic approach to solve it. Torkaman et al. (2017) propose a MIP model to address a multi-product production-inventory CLSC problem with an objective to minimize the total cost of the system. Chekoubi et al. (2018) propose a MILP based mathematical model for an integrated production-inventory-routing problem in CLSC with an objective to minimize the total cost of the system considering a single product case.

The above studies are oriented towards product level planning only. The studies pertaining to component level planning decisions are scarce. Doh and Lee, (2009) consider a case of satisfying the demand only with the help of remanufactured products in a multi-component scenario. Liu and Yang, (2009), consider quality of parts obtained after dismantling. Kasmara et al., (2011), develop a LP model for a multi-product case involving common components. Their problem is studied under a capacitated environment with an objective to maximize the profit. Chen and Abrishami (2014) address the production-inventory planning problem in a hybrid manufacturing-remanufacturing setup. They formulate their problem as a MILP model and solve it using lagrangian decomposition-based method in a deterministic environment with an objective to minimize total costs.

The quality of return or categories of returns with respect to products is addressed in Malolan and Mathirajan (2018). They tackle a deterministic integrated production-inventory problem based on component remanufacturing. They formulate their problem as an Integer Linear Programming (ILP) model with an objective to minimize the total cost. Their problem is addressed in a single product environment and they consider three categories of returns: commercial returns, end-of-use returns, and end-of-life returns. Malolan and Mathirajan, (2020), address a similar configuration considering multiple products and permitting backorders and they propose a non-linear integer programming model as the solution approach.

The current study seeks to extend the work done by Malolan and Mathirajan, (2020), by including the aspect of quantity discounts offered while purchasing components, which would reflect the real-life application and particularly to motivate the OEM to purchase quantities in bulk. To the best of our knowledge, there is no study addressing an exact similar configuration as the one considered in our study. Due to computational intractability reason, we propose a SHA, for the multi-products, multi-components production planning-inventory management problem involving backorders and quantity discounts. The problem considered in the current study is described in the following section.

3. Problem description

The problem considered in this study involves a closed loop setup modelled in a deterministic setup wherein all the data are known and fixed. The entire CLSC is managed and controlled by the Original Equipment Manufacturer (OEM).The forward chain pertains to demands for the different types of products from customers. This demand is satisfied either by means of assembling new products in the current period or from inventory carried from the previous period. Unsatisfied demand is backordered and possibly satisfied in subsequent periods. The products are assembled using multiple components. The components can be obtained from multiple sources, viz. manufacturing, remanufacturing, or purchasing. All the three sources have an associated cost. The cost for remanufacturing components is the lowest, followed by manufacturing and then purchasing. For manufacturing components, required raw materials are procured from supplier.

In the reverse chain, used products are acquired from customers by paying a suitable acquisition cost (Malolan and Mathirajan, (2018)) depending on the quality of returns of the used product. Based on the usage rate, three return categories of used products are considered, viz. commercial returns, end of use returns, and end of life returns (Malolan and Mathirajan, (2018)). Commercial returns are those types of returns which have had minimal use from the customer end followed by end of use returns and end of life returns. The return categories decide the return acquisition cost. The commercial returns have highest acquisition cost followed by end of use return and end of life return.

After acquiring the used products from the customer, they can either be dismantled based on the stipulated dismantling capacity of every product type or they can be kept in the inventory of used products. Dismantling returned products incurs a dismantling cost. Dismantling the used products yields components which could be classified into two types – remanufacturable and non-remanufacturable. The non-remanufacturable components are those which cannot undergo any kind of operations to get them back to as-good-as new conditions. These components are scrapped. The remaufacturable components undergo remanufacturing operation considering a known capacity for remanufacturing the components thereby incurring a remanufacturing cost. After remanufacturing, the remanufactured components can either be used in assembling the final product or can be stored in the component inventory.

There do exist components which can neither be manufactured nor remanufactured. Such components along with other required components can be purchased from component suppliers who offer quantity discounts on the purchase quantities. There exist two types of quantity discount policies offered by suppliers – marginal quantity discount and all-unit quantity discount. We consider the all-unit quantity discount policy.

For the problem described here, the objective is to come up with an appropriate production plan, by finding the values of the output variables in order to maximize the profit.

4. Proposed SHA

Before presenting the proposed SHA, the assumptions considered in the study are as follows:

1. We consider a deterministic setup. All the data are available before the start of the planning period. All the costs are known and fixed.
2. The demand of primary market is only considered.
3. There are dedicated lines for manufacturing and remanufacturing.
4. The return rate for the product in each return category is a percentage of the demand in that period.
5. There is no cost involved in checking and inspecting a return.
6. The cost of carrying inventory is same for manufactured, remanufactured and purchased component.
7. Lead times and setup up times are zero.

Proposed SHA

Thammatadatrakul and Chiadamrong, (2017), study two policies for inventory control in CLSC, namely, priority to remanufacture (PoR) and priority to manufacture (PoM). They conclude that the PoR policy outperforms the PoM policy in attaining a maximum profit when we have higher return rates. The proposed heuristic in this study considers a PoR policy. Furthermore, in line with the objective of CLSC to reduce disposing wastes in landfills, the proposed sequential heuristic aims to utilize the returned products to the maximum possible extent. Accordingly, the proposed SHA is divided into six major modules, which are presented as follows:

1. ***Input Module:*** Import all input data.

2. ***Assembly module:***
    a. For each time period and each product, compare demand for product in a period (DPP_{pt}) and capacity for assembling the product (CAP_{pt}). Compute the difference between capacity and demand.
    b. If CAP_{pt}>DPP_{pt}, excess capacity for product (ECP_{pt}) in current period = CAP_{pt} – DPP_{pt}. If cumulative demand for products from immediate next period up to the last period,:
        i. *Exceeds the cumulative capacity*: carry inventory (IP_{pt}) equal to minimum of (excess capacity in current period) and (absolute value of sum of difference between cumulative capacity and cumulative demand for subsequent periods up to last period). No. of backordered products (NBP_{pt}) equals zero and no. of products assembled (NPA_{pt}) equals sum of demand in current period and inventory to be carried at the end of current period for each product.
        IP_{pt}= MIN [$ECP_{pt,}$ abs ($\sum_{t=t+1}^{NTP} CAP_{pt} - DPP_{pt}$)]
        NBP_{pt}=0
        NPA_{pt}= $DPP_{pt} + IP_{pt}$
        ii. *Less than or equal to cumulative capacity*: demand for subsequent periods is met. Inventory to be carried at end of current period is zero (IP_{pt}=0), NBP_{pt} is zero. NPA_{pt} equals demand of current period (NPA_{pt}= DPP_{pt})
    c. If CAP_{pt}<DPP_{pt},
        Inventory to be carried is zero (IP_{pt}=0).
        NBP_{pt}= DPP_{pt} - CAP_{pt}
        NPA_{pt}= CAP_{pt}
    d. Do above steps for all products and up to last time period. Compute assembly cost, inventory cost, backorder cost and revenue from selling product.
    e. Compute total component requirement (TCR_{ct}) based on values of no. of products assembled (NPA_{pt}) and bill of materials (NCP_{cp}). [$TCR_{ct} = NPA_{pt}*NCP_{cp}$].
    f. Compute total returns (RET_{pot}) as a percentage of demand for product (DPP_{pt}) based on return rates (RR_{po}). [$RET_{pot} = RR_{po} * DPP_{pt}$].

3. ***Dismantling-remanufacturing module:***
    a. Choose product type with least dismantling cost of used product (DCU) to dismantle first.
    b. No. of dismantled used products (NDU_{pot}) is computed as minimum of available returns and capacity to dismantle (CDU_{pt}). [NDU_{pot} = MIN($RET_{pot,}$ CDU_{pt}].
    c. Starting with first component type, compute number of scrapped components (NSC_{cot}) as a percentage of dismantled components ($NCP_{cp}*NDU_{pot}$) based on rate of scrap (RSC_{co}): (NSC_{cot} = $RSC_{co}*NCP_{cp}*NDU_{pot}$). Compute no. of remanufacturable components = ($NCP_{cp}*NDU_{pot}$)–NSC_{cot}
    d. Number of components to be remanufactured is minimum of available remanufacturable components and available capacity to remanufacture component (CRC_c).
    NRC_{cot} =MIN [($NCP_{cp}*NDU_{pot}$) – NSC_{cot}, CRC_c].
        i. If NRC_{cot}=CRC_c, additional scrap = Remanufacturable components – RC_{cot}, else additional scrap=0. Add additional scrap to NSC_{cot}.
    e. Do above steps for all component types and update TCR_{ct}. Repeat steps till capacity to dismantle is available. Do this for all time periods. Once capacity of dismantling is exhausted, store remaining used products in inventory as Yet to be dismantled used products (YDU_{pot}).

f. Compute acquisition costs, dismantling cost, inventory cost of yet to be dismantled used products, remanufacturing cost, inventory cost of components, and scrap cost of components.

4. ***Manufacturing module:***
   a. For each time period and each component, compare TCR_{ct} in a period and capacity for manufacturing component (CMC_{ct}). Compute the difference between capacity and component requirement.
   b. If $CMC_{ct}>TCR_{ct}$, excess capacity for component (ECC_{ct}) = CMC_{ct} -TCR_{ct}. If cumulative component requirement from immediate next period up to the last period:
      i. *Exceeds the cumulative capacity*: carry inventory of component (IC_{ct}) equal to minimum of (excess capacity in current period) and (absolute value of difference between cumulative capacity and cumulative component requirement for subsequent periods up to last period). If inventory is positive, no. of components expected to be purchased ($NCEP_{ct}$) in the current period equals zero and no. of manufactured components (NMC_{ct}) equals sum of component requirement in current period and inventory to be carried at the end of current period for each component.
      IC_{ct}= MIN [$ECC_{ct,}$ abs ($\sum_{t=t+1}^{NTP} CMC_{ct} - TCR_{ct}$)]
      $NCEP_{ct}$=0
      NMC_{ct}= $TCR_{ct} + IC_{ct}$
      ii. *Less than or equal to cumulative capacity*: component requirement for subsequent periods is met. Inventory to be carried at end of current period is zero (IC_{ct}=0). No. of component expected to be purchased in current period is zero ($NCEP_{ct}$=0). No. of manufactured components (NMC_{ct}) = TCR_{ct} of current period.
   c. If $CMC_{ct}<TCR_{ct}$, inventory equals zero (IC_{ct}=0). No. of components expected to be purchased ($NCEP_{ct}$) in current period-t = TCR_{ct} -CMC_{ct}. No. of manufactured components equals capacity to manufacture component. [NMC_{ct}=CMC_{ct}].
   d. Compute manufacturing cost and inventory cost. Update the components required.
   e. Compute no. of purchased raw materials (NPR_{rt}) and compute purchase cost of raw materials.
   f. Total cost of manufacturing (TCM) module = Manufacturing cost of components+ Inventory cost of components + Purchase cost of raw materials.

5. ***Component purchasing-supplier selection module:***
   a. For each component type, compare the purchase cost offered by suppliers for purchase quantity ($PC_{tt'}$) equal to cumulative component requirement (components to be purchased) starting from current period t up to period t'. [$PC_{tt'} = \sum_{x=t}^{t'} NCEP_{cx}$].
   b. If t=t', inventory=0. Else, if t<t',
      i. Inventory of purchased component (IPC_{ct}) in current period-t =total purchase quantity (t, t') [$PC_{tt'}$]– requirement of component in period t [$NCEP_{ct}$]. Compute corresponding inventory cost.
      ii. For subsequent periods, inventory=inventory carried from previous period (IPC_{ct-1}) – $NCEP_{ct}$.
   c. For every combination of (t, t'; t'>t), and for each component, compute total purchase cost [$TPC_{ctt'}$] for quantity equal to $PC_{tt'}$=Purchase cost + Inventory costs.
   d. Allocation:
      i. For each component, start by finding minimum in column t'=last period, of the $TPC_{ctt'}$ matrix.
      ii. Get the values of t and t' corresponding to lowest total cost and choose the supplier who offers minimum per unit cost for purchase quantity between periods (t, t').
      iii. Eliminate rows>t and columns>t in total cost matrix. Go to column t'=t-1 and repeat the steps till all allocations are done (i.e., till t corresponding to minimum cost value in the t' column is equal to 1).
   e. Total cost of purchase plan = sum of total costs for each component.

6. ***Output Module:***
   Compute profit= Revenue – total costs: (a) Revenue = Revenue earned from selling the products. (b) Total costs = Sum of costs associated with all modules.

5. Performance analysis of the proposed SHA

In this section, the performance of the proposed SHA is analyzed by considering the benchmark procedure: the ILP model, which would be obtained from the modified version of the INLP model proposed by Malolan and Mathirajan (2020). There are nine numerical problem instances, generated randomly, considered for the performance evaluation. For all the 9 instances considered, No. of products = 3, No. of time period (NTP) =4, No. of suppliers=2 and No. of discount intervals=3. No. of components (NC) takes values 4,10 and 20 and No. of raw materials (NRM) takes values 4,8 and 10, respectively. Each of the nine numerical instances are solved using the proposed SHA and the ILP model. . In cases where ILP model does not give us an output for a long time, we interrupt the solver (LINGO) after 3600 seconds (Lee and Wen, (2008)). Also, as the ILP model runs for more than 3600seconds for the instances considered, we run the relaxed ILP model to get optimal solution in considerably lesser time. The solution for the relaxed ILP is the upper bound for the maximum profit. With this, the results obtained from each of the nine problem instances are used to obtain the relative percentage deviation (RPD) score using the equation (1) and the computed score is given in Table 1.

Table 1. Performance Analysis of the Proposed SHA in Comparison with Relaxed ILP Solution

Problem Instance (i)	Components (NC)	Raw materials (NRM)	Relaxed ILP Output [OS]	Heuristic Solution [HS]	RPD
1	4	4	505916000	503539410	**0.47**
2	4	8	371440000	366907631	**1.22**
3	4	10	439294000	435061220	**0.96**
4	10	4	661202000	653453350	**1.17**
5	10	8	1732200000	1697880018	**1.98**
6	10	10	1896306000	1859506013	**1.94**
7	20	4	1055820000	1030198893	**2.43**
8	20	8	2911030000	2870738789	**1.38**
9	20	10	3533870000	3381830761	**4.30**

*OS – Optimal solution

$RPD_i = [(OS_i-HS_i)/OS_i] *100$; i=instance ...... (1)

Out of 9 problem instances considered in this study, from the RPD presented in Table 1, it is observed that the proposed SHA is deviated from the Relaxed ILP model as follows: Minimum deviation :0.47%, average deviation :1.76%, maximum deviation :4.30%, standard deviation: 1.122%. From these descriptive statistics on the deviation, we can conclude that the proposed SHA provides a near optimal solution at a much lesser time as compared to the ILP model.

6. Conclusion and future scope

A production planning-inventory management problem of CLSC is addressed related to a component remanufacturing environment considering backordering and quantity discounts. Particularly, the present study considers multiple products, multiple components, multiple raw materials, multiple planning periods, multiple suppliers, and multiple discount intervals. As the problem is computationally intractable to get optimal solution, a SHA has been proposed. The performance evaluation of the SHA is observed over 9 randomly generated small scale problem instances in comparison with a mathematical model available in the literature. Using the RPD as a performance metric, we conclude that the proposed heuristic gives near optimal solution as compared to the mathematical model.

Future research can look into relaxing certain assumptions of the present study and comparing the performance of the proposed heuristic with the ILP model. Development or application of efficient metaheuristics could also be addressed. As the current study only considers RPD as the performance metric, future studies can compare the heuristic and ILP model using various other performance metrics.

References

Chekoubi Z., Trabelsi,W., and Nathalie,S, The Integrated Production-Inventory-Routing Problem in the Context of Reverse Logistics: The Case of Collecting and Remanufacturing of EOL Products. *4th International Conference on Optimization and Applications (ICOA)*. pp.1–6, 2018.

Chen,M. and Abrishami, P, A Mathematical Model for Production Planning in Hybrid Manufacturing-Remanufacturing Systems. *The International Journal of Advanced Manufacturing Technology*. Vol.71, pp.1187–1196, 2014.

Dekker R, Erwin A. van der Laan and Inderfurth, K, A Review on Inventory Control for Joint Manufacturing and Remanufacturing, *IFAC Proceedings Volumes*, Volume 33, No. 17, pp. 235-240, 2000

Doh,H.H and Lee, D H, Generic production planning model for remanufacturing systems. Proceedings of the Institution of Mechanical Engineers Part B Journal of Engineering Manufacture. Vol.224. pp.159-168, 2010.

Dowlatshahi, S, A Framework for the Role of Warehousing in Reverse Logistics. *International Journal of Production Research.* Vol.50, No..5, pp.1265–1277, 2012.

Golany, B., Yang,J., and Yu,G, Economic Lot-Sizing with Remanufacturing Options, *IIE Transactions*. Vol.33, No..11, pp.995-1004, 2001.

Govindan, K., Soleimani,H., and Devika Kannan, Reverse Logistics and Closed-Loop Supply Chain : A Comprehensive Review to Explore the Future.*European Journal of Operational Research.* Vol. 240, No. 3, pp.603–626, 2015

Guide, Jr.,V.D.R., and Van Wassenhove,L.N, The Evolution of Closed-Loop Supply Chain Research. *Operations Research*. Vol.57, No..1, pp.10–18, 2009

Jabbarzadeh,A., Haughton,M., and Khosrojerdi,A, Closed-Loop Supply Chain Network Design under Disruption Risks: A Robust Approach with Real World Application. *Computers & Industrial Engineering.* Vol.116, pp.178–91,2018.

Kasmara,A, Muraki M, Matsuoka S, Sukoyo S, and Suryadi K, Production Planning in Remanufacturing/Manufacturing Production System. *Environmentally Conscious Design and Inverse Manufacturing*, International Symposium, 2001.

Lee, F C and Wen,U P , Coordinating Replenishment Cycles in Three-Stage Inventory-Distribution Supply Chains, *International Journal of Operations Research*, Vol. 5, No. 4, pp.193−212, 2008.

Liu, G. and Yang, X, Multi-conditioned and Capacitated Production Planning Model for Remanufacturing System. *IEEM 2009 - IEEE International Conference on Industrial Engineering and Engineering Management*. 10.1109/IEEM.2009.5373214, 2009.

Malolan, S. and Mathirajan,M, Inventory and production planning for component remanufacturing in an original equipment manufacturer-closed loop supply chain. *International Journal of Logistics Systems and Management*. Vol. 29, No. 4, pp.524-556, 2018.

Malolan,S and Mathirajan,M, Component remanufacturing: a new prospective profitable business approach for the Indian automobile sector. *OPSEARCH,* Vol. 57, pp.1244–1280, 2020.

Pan, Z., Tang, J. and Liu, O, Capacitated Dynamic Lot Sizing Problems in Closed-Loop Supply Chain, *European Journal of Operational Research*. Vol. 198, pp.810-821, 2009.

Richter, K, The Extended EOQ Repair and Waste Disposal Model. *The International Journal of Production Economics*. Vol. 45. pp. 443-447, 1996a.

Richter, K, The EOQ Repair and Waste Disposal Model with Variable Setup Numbers. *European Journal of Operational Research*. Vol. 96, pp. 313-324, 1996b.

Saadany, A.M.A.E, and Jaber,M.Y, A Production / Remanufacturing Inventory Model with Price and Quality Dependant Return Rate. *Computers & Industrial Engineering.* Vol.58, No. 3, pp.352–62, 2010.

Schrady, D. A, A Deterministic Inventory Model for Repairable Items, *Naval Research Logistics Quarterly,* Vol. 14, No. 3, pp. 391-398,1967.

Sun, X., Wu, M. and Hu, F, Two-Period Inventory Control with Manufacturing and Remanufacturing under Return Compensation Policy, *The Scientific World Journal*. Vol. 2013, pp. 1-8, 2013.

Tang, O. and Teunter, R, Economic Lot Scheduling Problem with Returns. *Production and Operation Management*. Vol. 15, pp. 488-497, 2006.

Teunter, R, Economic Order Quantities for Recoverable Item Inventory System, *Naval Reverse Logistics*, Vol. 48, pp. 484-495, 2001.

Teunter, R., Kaparis, K., and Tang, O, Multi-Product Economic Lot Scheduling Problem with Separate Production Lines for Manufacturing and Remanufacturing. *European Journal of Operational Research.* Vol. 191, pp. 1241-1253, 2008.

Thammatadatrakul, P and Chiadamrong, N, Optimal inventory control policy of a hybrid manufacturing – remanufacturing system using a hybrid simulation optimization algorithm, *Journal of Simulation*, Vol.13, No..1, pp.14-27, 2017.

Thierry, M., Saloman, M., Van Nunen, J. and Van Wassenhove, L, Strategic Issues in Product Recovery Management, *California Management Review*. Vol. 37, pp. 114-135, 1995.

Torkaman, S., Fatemi Ghomi, S. M.T., and Karimi,B, Hybrid Simulated Annealing and Genetic Approach for Solving a Multi-Stage Production Planning with Sequence-Dependent Setups in a Closed-Loop Supply Chain .*Applied Soft Computing Journal.* Vol. 71, pp.1085–1104, 2017.

Turrisi, M., Bruccoleri,M., and Cannella,S, Impact of Reverse Logistics on Supply Chain Performance. *International Journal of Physical Distribution & Logistics Management*. Vol. 43, Issue 7, pp.564-585, 2013

Zhang, J., Liu,X., and Tu,Y.L, A Capacitated Production Planning Problem for Closed-Loop Supply Chain with Remanufacturing. *The International Journal of Advanced Manufacturing Technology*. Vol. 54, No. 5-8, pp.757-766, 2011.

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