A bi-objective tactical planning model for the reverse supply chain of durable products

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Abstract
End-Of-Life durable products contain valuable sub-assemblies that can create value if recovered efficiently. We propose a mixed-integer programming model for medium–term planning of return acquisition, disassembly, and disposition activities in the reverse supply chain of durable products. Formulated based on a generic disassembly tree, the model has the flexibility to capture all plausible means of recovery for each class of components in such products. Moreover, we incorporate the non-homogeneous quality of the return stream by considering two quality categories. By adopting a profit-oriented strategy, the firm might only acquire high quality cores and a small portion of the poor quality ones. While poor quality cores constitute the majority of return stream of durable products, this strategy would leave the large quantity of such items in the outdoor yards which would become environmental eyesores over time. In order to investigate the environmental impacts of recovery decisions we introduce a second objective function that maximizes the total recovery amount. The model seeks a trade-off between financial goals of the firms and the take-back targets imposed by legislation. The model is solved by epsilon-constraint method for a realistic-scale case study.

Keywords
Reverse supply chain, production planning, durable products, bi-objective optimization

1. Introduction
Durable products, featured by their long life cycle, incorporate consumer, commercial, and industrial equipment. Recent legislations on the take-back of used products by the original equipment manufacturers (OEM) along with the potential value that can be recovered from End-Of-Life (EOL) durable products have motivated a more efficient reverse supply chain management among manufacturers. A reverse supply chain (RSC) processes used product returns so as to recover value by re-processing them via remanufacturing, part harvesting, and material recycling. Tactical planning in a RSC encompasses decisions regarding used products acquisition/grading, assignment of used items to proper disposition (recovery) options, and production/inventory planning for associated disposition processes. The objective is to assure the economic viability of the supply chain while taking into account environmental issues [1].

The prevailing studies on RSC tactical planning either address the acquisition/grading problem [2-8] or production planning for remanufacturing [9-11]. Partial integration of tactical-level decisions in reverse and closed loop supply chain has been investigated in [12, 13]. EOL durable products contain a variety of modules, parts, residues, and materials can be recovered by different types of disposition methods. The existing RSC tactical planning models in the literature cover only a few of disposition options, such as product remanufacturing and material recycling. It is worth mentioning that the acquisition planning models have focused mainly on deriving optimal control policies in single or multi-stage inventory systems under various assumptions in terms of quality states of the return. An inventory control model was proposed in [7] to decide on the procurement and remanufacturing lot sizes in the context of cellphone resellers. An inventory lot sizing model was proposed in [2] that decides on the optimal collection and use of remanufacturable returns over a finite life-cycle. The impact of uncertain quality of returns on the profitability of a RSC was investigated in [8]. With the objective of maximizing the expected profit, their model decides on the quantities to transport from each collection site to the refurbishing center and the quantity to refurbish.
A single-period model for planning of acquisition and recycling operations in the RSC of EOL electronics was proposed in [14]. They considered bulk recycling as the main recovery option and proposed separate models for collectors and recyclers. Another single-period model for the integrated planning of acquisition, disassembly, and bulk recycling was proposed in [13] in the context of electronic waste recovery. With the objective of predicting relevant impact of the waste electrical and electronics equipment (WEEE) directives in Germany, a mixed integer programming model was developed in [15] for integrated planning of acquisition, disassembly and material recycling for electronic waste. An integrated multi-period model for operations planning of a forward manufacturing and a used-product reverse supply chain was proposed in [12]. Material recycling and disposal are the disposition options they considered in the model. A multi-period supply planning model in a reverse logistics network was proposed in [11]. The authors assumed that the parts can be supplied from external suppliers and/or through remanufacturing or refurbishing of the used parts dismantled from the used products. A multi-period production and inventory planning model in a closed-loop supply chain was proposed in [10]. The disposition options in the aforementioned network consist of disassembly, product and module remanufacturing and product disposal. They also assumed the incoming products have different quality levels. A multi-period production planning model for a remanufacturing firm was proposed in [3]. In this study returned products are assumed to be graded into three quality levels. The proper disposition option, i.e., product remanufacturing or salvage, is determined based on the grading result. The model provided in [3] was extended in [9] by considering uncertain quality of the returned items. They proposed a multi-stage stochastic programming model to decide on the number of products to grade, the graded core to remanufacture as well as the number of cores to salvage.

Recognizing the aforementioned gaps in the literature and the need for a more generalized modeling framework for RSC tactical planning in the context of EOL durable products, we propose a new mixed-integer programming (MIP) model that is flexible to incorporate most of the RSC configurations plausible in such industries. We also use a generic disassembly tree (reverse Bill-of-Material) in order to represent common components of such products and to incorporate all possible disposition (recovery) options in tackling them. Consequently, we consider a RSC configuration that encompasses collection, disassembly, remanufacturing, part harvesting, bulk recycling, material recycling, and disposal centers. In this context and in a multi-period planning horizon, we are looking for tactical level (medium-term) decisions in terms of: 1) lot sizing of used products acquisition (procurement) and disassembly/grading, 2) optimal assignment of products to alternative recovery processes, 3) aggregate production planning for remanufacturing, bulk-recycling and material recycling, and 4) inventory planning for the product, modules, parts, residues, and material. We also assume the return stream fits into good and poor quality levels. In order to enforce the firms to take the responsibility of the negative environmental impact of their return stream, we introduce an environmental objective function in addition to the financial one in the RSC tactical planning model. While the financial objective function seeks profit maximization of the recovery operations, the environmental one aims for maximizing the total quantity of acquired used-products in the return stream with different quality states. The second objective function is in conflict with the first one due to scarcity of high quality returned items and low profitability of low quality ones which constitutes the main portion of the return stream. The proposed model is applied on a realistic scale academic case study focused on the recovery of electronics waste. The epsilon-constraint method is then implemented to solve the resulting bi-objective MIP model.

The rest of the paper is organized as follows. In section 2, we provide more details on the problem investigated in this paper. Section 3 presents the problem formulation. Section 4 incorporates the case study along with the experimental results. Conclusion and future areas of research are provided in section 5.

2. Problem description

In this section we first elaborate on the features of a generic durable product investigated in this study. Then, we provide the characteristics of the RSC corresponding to such products.

2.1 Product features

Durable products such as large appliances have a modular architecture and consist of multiple and various types of components as depicted in figure 1.
When a durable product is disassembled, it yields modules, parts, residues, solid materials, in addition to hazardous and non-recoverable components. Modules, such as a washing machine motor are units of products that undergo the remanufacturing process. In this study we assume that modules of both quality levels can be brought up to the same quality level through the remanufacturing processes. We also assume that poor quality modules can be recovered through bulk recycling in the case of capacity overflow. Parts such as a washing tube are another category of components in the disassembly process that undergo the harvesting process if they meet certain criteria so as to be used as spare parts. We assume that each product yields different numbers of a specific part depending on its quality level. If parts are not qualified for harvesting, they would undergo the bulk recycling process. Solid materials in the product such as plastic, iron, copper and aluminum are separated after the product is disassembled. Such solid materials can directly undergo the appropriate recycling processes. Nevertheless, a big fraction of materials are combined with other compounds (residues) and it is not easy to extract them through simple activities in material recycling units. Such residues are recovered through bulk recycling process. It encompasses shredding and different separation methods that first transform the residue into flakes and then separate different categories of materials based on their physical properties. Hazardous components of the product in addition to those components with no value are salvaged (e.g. landfilled or incinerated).

2.2. Reverse supply chain configuration
The reverse supply chain consists of collection, disassembly/grading, remanufacturing, part harvesting, bulk recycling, and material recycling facilities. End-of-life returns are collected in the collection facility as illustrated in figure 2. Based on the total amount of return at the collection center, which is assumed to be deterministic, the firm decides what quantity of EOL products of each quality to purchase in each period in the planning horizon. The purchased EOL products are stored to be sent to disassembly facilities. At the disassembly facility, the yielded components are categorized into the high and poor quality modules, reusable parts, residues, recyclable solid materials and both hazardous and non-hazardous disposable components. Each category of items is kept in its inventory until they are transferred to their corresponding disposition facility. Remanufactured items are raised to the same quality level and they will be sold in the market. Reusable parts are stored in the inventory until they are cleaned in the harvesting facility and sold to the spare part market. We also consider a flow between reusable part and module inventory to the bulk recycling facility in order to compensate the capacity shortage of remanufacturing or lack of demand for remanufactured modules and spare parts. At material recycling facilities, a fraction of useless materials are sent to disposal facilities and the rest would be shipped to the recycled material inventory in order to be sold in the market. The separated materials from bulk recycling such as ferrous and non-ferrous metals and plastic are also sent to their corresponding material recycling facilities.

3. Mathematical formulation
In the context of the RSC described in 2.2 we formulate the integrated medium-term acquisition, disassembly/grading, and disposition production and inventory planning as a bi-objective MIP model in this section. Prior to presenting the mathematical model, we summarize the model notations.
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Figure 2: Reverse supply chain configuration for a generic durable product

3.1 Notations

Indices

- \( a \) : part, \( a = \{1 \ldots A\} \)
- \( m \) : modules, \( m = \{1 \ldots M\} \)
- \( k \) : quality level, \( k = \{1 \ldots K\} \)
- \( t \) : time period, \( t = \{1 \ldots T\} \)
- \( l \) : material, \( l = \{1 \ldots L\} \)

Parameters

- \( Q_{it} \) : quantity of collected products of quality \( k \) in period \( t \)
- \( \mu_{km} \) : number of module type \( m \) available in each unit of product with quality \( k \)
- \( \upsilon_{ka} \) : number of part type \( a \) available in each unit of product with quality \( k \)
- \( \lambda_k \) : mass (kg) of residues in each unit of product with quality \( k \)
- \( \kappa_{k,l} \) : mass (kg) of material \( l \) in each unit of product with quality \( k \)
- \( \varepsilon_k \) : mass (kg) of disposable components in each unit of product with quality \( k \)
- \( \beta_l \) : percentage of material \( l \) after bulk recycling of residues
- \( \gamma \) : percentage of recycled material sent to disposal
- \( \delta \) : percentage of bulk-recycled residues sent to disposal
- \( \omega_{mod}^m \) : weight of each module \( m \) (kg)
- \( \omega_{part}^a \) : weight of each part \( a \) (kg)

Demand

- \( d_{it}^{comp} \), \( comp \in \{\text{mod, part, mat}\}, i \in \{m,a,l\} \) : demand for remanufactured module \( m \), harvested part \( a \), and recycled material \( l \) in period \( t \)

Price

- \( p_{it}^{disp} \), \( disp \in \{\text{rem, harv, recm}\}, i \in \{m,a,l\} \) : price of remanufactured module \( m \), harvested part \( a \), and recycled material \( l \)

Cost

- \( h_{prod}^k \) : unit holding cost of product with quality \( k \)
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\[ p_{\text{disp}} = \{ \text{part, harv, mod, rem, res, mat.} \} \]

\[ i \in \{ a, d, m, m, -,-, l, l, - \} \]

\[ c_{\text{prod}} \]

\[ c_{\text{disa}} \]

\[ c_{\text{disp}} \]

\[ d_{\text{disp}} \in \{ \text{disp, disa, rem, harv, bulk, recm, dp} \}, i \in \{ -,-, a, l, - \} \]

\[ c_{\text{rem}} \]

\[ c_{\text{disp}} \]

\[ \text{capacity} \]

\[ w_{\text{lab-disp}} \]

\[ w_{\text{Mach-disp}} \]

\[ w_{\text{inv-prod}} \]

\[ w_{\text{inv-comp}} \]

\[ \phi_{\text{lab-disp}} \]

\[ \phi_{\text{Mach-disp}} \]

\[ \phi_{\text{inv-prod}} \]

\[ \phi_{\text{inv-comp}} \]

\[ \{ \text{mod, rem, part, harv, res, mat.} \} \]

\[ i \in \{ \text{m, m, a, a, -,-, l, l} \} \]

\[ \{ \text{part, recm, dp} \} \]

\[ \{ \text{mod, rem, part, harv, res, mat.} \} \]

\[ \{ \text{mat, recm} \} \]

\[ \text{decision variables} \]

\[ X_{\text{prod}} \]

\[ X_{\text{disa}} \]

\[ X_{\text{rem}} \]

\[ X_{\text{harv}} \]

\[ X_{\text{rem}} \]

\[ X_{\text{bulk}} \]

\[ X_{\text{rem-res}} \]

\[ X_{\text{part-res}} \]

\[ X_{\text{disp}} \]

\[ I_{\text{prod}} \]

unit holding cost of part \( a \), harvested part \( a \), modules \( m \), remanufactured modules \( m \), residues, materials \( l \), recycled materials \( l \), and disposable components

cost of purchasing product with quality \( k \)
cost of disassembly of each unit of product

cost of bulk recycling of residues (/kg), harvesting of parts, recycling materials and disposal

cost of remanufacturing of each module \( m \) with quality \( k \)

fixed cost for setting up bulk recycling, remanufacturing, and part harvesting facilities

total labor hours available for disassembly, remanufacturing, part harvesting, bulk recycling, and material recycling in period \( t \)
total machine hours available for disassembly, remanufacturing, part harvesting, bulk recycling, and material recycling in period \( t \)
total product inventory capacity in period \( t \)
total inventory capacity for modules, remanufactured modules, parts, harvested parts, residues, material, recycled material, and disposable in period \( t \)
labor hour required to disassemble each unit of product, and bulk recycle each kg of residues

labor hour required to harvest each unit of part \( a \), and recycle each kg of material \( l \)
labor hour required to remanufacture each unit of module \( m \) of quality \( k \)
machine hour required to disassemble each unit of product, and bulk recycle each kg of residues

machine hour required to harvest each unit of part, and recycle each kg of material \( l \)
machine hour required to remanufacture each unit of module \( m \) of quality \( k \)

inventory occupation by each unit of product

inventory occupation by each unit of module \( m \), remanufactured module \( m \), part \( a \), harvested part \( a \), kg of residues, kg of material \( l \), and kg of recycled material \( l \)
number of products of quality \( k \) purchased in period \( t \)
number of products of quality \( k \) disassembled in period \( t \)
number of module \( m \) of quality \( k \) to remanufacture in period \( t \)
number of part \( a \) to harvest in period \( t \)
mass (kg) of material \( l \) to recycle in period \( t \)
mass (kg) of residues to bulk recycle in period \( t \)
number of module \( m \) of quality \( k \) sent to residues inventory
number of part \( a \) sent from inventory of parts to residues
mass of non-recoverable components to dispose in each period inventory level of product of quality \( k \) in period \( t \)
3.2 Bi-objective mixed-integer programming model

Objective functions:
While the first objective maximizes the forward and recovery network profit, the second one addresses the environmental impacts of the designed recovery network through maximizing the amount of recovery as follows:

Objective function 1

\[
\text{Max Profit} = \text{REV} - \text{COR} - \text{IHC}
\]

where

REV (revenue):

\[
\sum_{m \in M} \sum_{t \in T} \sum_{a \in A} p_{rem}^m S_{mod}^m + \sum_{a \in A} \sum_{t \in T} p_{harv}^a S_{harv}^a + \sum_{l \in L} \sum_{t \in T} p_{recm}^l S_{recm}^l + \sum_{l \in L} p_{mat}^l S_{mat}^l
\]

COR (cost of recovery):

\[
\sum_{k \in K} \sum_{t \in T} c_{k} \prod_{k} X_{k,t} + \sum_{k \in K} \sum_{m \in M} \sum_{t \in T} c_{mod}^m I_{k,m,t} + \sum_{m \in M} \sum_{t \in T} c_{rem}^m I_{k,m,t} + \sum_{a \in A} \sum_{t \in T} c_{disa}^a X_{a,t} + \sum_{l \in L} \sum_{t \in T} c_{disl}^l X_{l,t} + \sum_{t \in T} c_{cap} x_{cap}^t + \sum_{t \in T} c_{fix} x_{fix}^t + \sum_{t \in T} c_{ivar} x_{ivar}^t + \sum_{t \in T} c_{ivar} x_{ivar}^t
\]

IHC (inventory holding cost):

\[
\sum_{k \in K} \sum_{t \in T} c_{prod}^k I_{k,t} + \sum_{a \in A} \sum_{t \in T} c_{harv}^a I_{a,t} + \sum_{l \in L} \sum_{t \in T} c_{mat}^l I_{l,t} + \sum_{t \in T} c_{mat}^l I_{l,t} + \sum_{l \in L} \sum_{t \in T} c_{recm}^l I_{l,t} + \sum_{t \in T} c_{recm}^l I_{l,t} + \sum_{t \in T} c_{disa}^a X_{a,t} + \sum_{l \in L} \sum_{t \in T} c_{disl}^l X_{l,t} + \sum_{t \in T} c_{cap} x_{cap}^t + \sum_{t \in T} c_{fix} x_{fix}^t + \sum_{t \in T} c_{ivar} x_{ivar}^t + \sum_{t \in T} c_{ivar} x_{ivar}^t
\]

Objective function (2)
The second environmental objective function (2) ensures that firm maximizes the returned products acquisition amount as follows:

\[
\text{Max } \sum_{k \in K} \sum_{t \in T} X_{k,t}^{prod}
\]

Constraints
We consider four categories of constraints including inventory balance, sales, set-up, and capacity constraints. The capacity constraints include machine capacity, labor capacity and inventory capacity. Each set of constraints are presented as follows.

Inventory balance constraints:
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Returned products:
\[ I_{k,j}^{\text{prod}} + X_{k,j}^{\text{prod}} - X_{k,j}^{\text{disa}} = I_{k,j}^{\text{prod}} \quad \forall k, t \]  
(3)

Modules:
\[ I_{k,m,j}^{\text{mod}} + \mu_{k,m} X_{k,j}^{\text{disa}} - X_{k,m,j}^{\text{rem}} - X_{k,m,j}^{\text{rem-res}} = I_{k,m,j}^{\text{mod}} \quad \forall k, m, t \]  
(4)

Parts:
\[ I_{a,i}^{\text{part}} + \sum_{k} v_{a,i,k} X_{k,j}^{\text{disa}} - X_{a,i}^{\text{harv}} - X_{a,i}^{\text{part-res}} = I_{a,i}^{\text{part}} \quad \forall a, t \]  
(5)

Residues:
\[ I_{t-1}^{\text{res}} + \sum_{k} \sum_{m} \omega_{m} X_{k,m,t}^{\text{rem-res}} + \sum_{a} \alpha_{a} X_{a,i}^{\text{disa}} + \sum_{k} \sum_{a} \omega_{a} X_{a,i}^{\text{part-res}} - X_{t}^{\text{bulk}} = I_{t}^{\text{res}} \quad \forall t \]  
(6)

Materials:
\[ I_{t-1}^{\text{mat}} + \sum_{k} \sum_{m} \delta_{m} X_{k,m,t}^{\text{disa}} + \sum_{a} \gamma_{a} X_{a,i}^{\text{disa}} + \sum_{k} \sum_{a} \delta_{a} X_{a,i}^{\text{part-res}} - X_{t}^{\text{bulk}} = I_{t}^{\text{mat}} \quad \forall l, t \]  
(7)

Remanufactured modules:
\[ I_{m,j}^{\text{rem}} + \sum_{k} X_{k,m,j}^{\text{disa}} + \sum_{k} X_{k,m,j}^{\text{rem}} = I_{m,j}^{\text{rem}} \quad \forall m, t \]  
(8)

Harvested parts:
\[ I_{a,i}^{\text{harv}} + X_{a,i}^{\text{harv}} - S_{a,i}^{\text{part}} = I_{a,i}^{\text{harv}} \quad \forall a, t \]  
(9)

Recycled materials:
\[ I_{l,j}^{\text{recm}} + (1-\gamma) X_{l,j}^{\text{recm}} - S_{l,j}^{\text{mat}} = I_{l,j}^{\text{recm}} \quad \forall l, t \]  
(10)

Non-recoverable components:
\[ I_{l,j}^{\text{dp}} + \sum_{k} \delta_{k} X_{k,j}^{\text{disa}} + \sum_{l} \gamma_{l} X_{l,j}^{\text{disa}} + \delta X_{l,j}^{\text{bulk}} - X_{l}^{\text{bulk}} = I_{l,j}^{\text{dp}} \quad \forall t \]  
(11)

Sales Constraints
\[ S_{m,j}^{\text{mod}} \leq d_{m,j}^{\text{mod}} \quad \forall m, t \]  
(12)
\[ S_{a,i}^{\text{part}} \leq d_{a,i}^{\text{part}} \quad \forall a, t \]  
(13)
\[ S_{l,j}^{\text{mat}} \leq d_{l,j}^{\text{mat}} \quad \forall l, t \]  
(14)

Set-up constraints
\[ X_{k,m,j}^{\text{rem}} \leq M \times Y_{t}^{\text{rem}} \quad \forall k, m, t \]  
(15)
\[ X_{a,i}^{\text{harv}} \leq M \times Y_{t}^{\text{harv}} \quad \forall a, t \]  
(16)
\[ X_{t}^{\text{bulk}} \leq M \times Y_{t}^{\text{bulk}} \quad \forall t \]  
(17)

Capacity constraints:
Labor/machine capacity
Remanufacturing
\[ \sum_{k \in K} \sum_{m \in M} X_{k,m,j}^{\text{lab-rem}} \leq W_{l}^{\text{lab-rem}} \quad \forall l \]  
(18)

Part harvesting
\[ \sum_{a \in A} X_{a,i}^{\text{lab-part}} \leq W_{l}^{\text{lab-harv}} \quad \forall l \]  
(19)

Material recycling
\[ \sum_{l \in L} X_{l,j}^{\text{lab-recm}} \leq W_{l}^{\text{lab-recm}} \quad \forall l \]  
(20)
4. Experimental results

Finding a case study with representative data was one of the major challenges in this study. In fact, none of the existing models in the literature are formulated based on a complete disassembly tree and hence do not include all recovery options with corresponding parameters. In order to validate model (1)-(35) we consider an academic case on electronic waste that contains 2 modules, 10 parts, and 2 types of material, where the data are inspired by the real data available in [1], [10, 11], [14], and [16]. The resulting model includes 576 inventory balance constraints, 216 capacity constraints, and 984 decision variables. CPLEX 12.3 solved the aforementioned model in a few seconds.

4.1. Epsilon-constraint method

In this method, one objective function is chosen as the primary objective function and the second objective is transferred into a constraint for the first model. The constraint is then bounded with some values. By varying this bound a set of “non-dominated” or “pareto-optimal” solutions are then obtained. In this paper, we consider “profit” as the main objective function (Z_1(X)) and the “total acquisition amount” (Z_2(X)) is added as a new constraint to model (1)-(35). Hence, the new model can be presented in a compact form as follows:

\[
\begin{align*}
\text{Max } Z_1(X) \\
\text{St. } \\
X \in F_d, \\
Z_1(X) \geq Z_2(X),
\end{align*}
\]
where \( F_d \) is the feasible region of both objective functions, i.e., constraints (3)-(35), and \( L_2 \) is the lower bound of the second objective function. Finally, we define a range for the right-hand-side of the new constraint in model (36) (\( L_2 \)). This range can be generated by taking an arbitrary number \( \gamma \) and using the following formula:

\[
L_2 = Z_2(X^1) + [h/(\gamma-1)] \times [Z_2(X^2) - Z_2(X^1)], \text{ where } h = 0, 1, 2, \ldots
\]

By fixing \( \gamma \) to 20 and using equation (37) we divide the range of the second objective to 20 equivalent intervals. Next, by plugging different values of each \( L_2 \) into model (36) we generate 20 non-dominated solutions. Figure 3 illustrates the set of non-dominated solutions for the case study under discussion. For the sake of simplicity, the results in figure 3 are provided in terms of the percentage of deviation from optimal objective value for each objective function. As it can be observed in this figure, while moving from one pareto solution to the other, one objective is improved and the other is degraded. The top left point represent the optimum acquisition quantity (second objective) and the bottom right point indicates the optimum profit (first objective). In this example, if the decision maker aims for maximizing the profit, 18% of returned items would be left in the environment. Furthermore, by increasing the acquisition quantity to 8%, the firm’s profit would be decreased by 6%.

![Figure 3: Set of non-dominated solutions](image)

4.2. Analysis of the results
Based on our experimental experiments and as it is expected, high quality returned products are all purchased due to their low recovery cost and high profitability. In contrary, high quality returned products are scarce comparing to the poor quality products. Hence, the maximization of our environmental objective function would target the acquisition of poor quality products. By maximizing that objective function the firm avoids high landfill penalties and reaches recovery target set by government. Nevertheless, by taking this objective as the primary goal a low profit can be expected due to the high cost of remanufacturing poor quality modules and low value of items recovered from poor quality products. Therefore, it is crucial to utilize the trade-off between both objectives prior to make decisions on acquisition amounts of returned products. The decision maker must choose a solution according to the desired profit margin, target recovery percentage, and penalties incurred for leaving the EOL products in the environment.

5. Conclusion
In this paper, we proposed a bi-objective, multi-period mixed integer linear programming model for integrated acquisition, disassembly, disposition, production and inventory planning in a RSC corresponding to durable products. The proposed model accommodates a multi-period setting, a complete disassembly tree, all types of disposition (recovery) processes plausible for each product component, in addition to the non-homogeneity in the quality state of the return stream. The paper also contributes to the reverse supply chain tactical planning by improving the understanding of the relationship between environmental and financial impacts of the firm decision on the quantity of returned items undertaken for the recovery purpose. The proposed general tactical planning model
is then justified by an academic case study focused on the RSC of electronic waste. The epsilon-constraint method was implemented to solve the resulting bi-objective mixed-integer programming model. It provided important insights regarding the relationship between a profit-oriented and an environment-oriented strategy taken by manufacturers while dealing with large quantities of returned products. A natural extension of the setting considered in this paper is to extend the model into a multi-product and multi-facility RSC setting. Furthermore, the proposed model can be integrated into a forward supply chain tactical planning model.

References