Dynamic production planning in forward-reverse supply chains considering different transportation modes

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Abstract
This paper develops a mathematical programming model for a multi-period and multi-product forward-reverse supply chain under dynamic condition to determine the optimal values of tactical level decisions. The tactical level decisions include decisions related to production and distribution planning, inventory amount, transportation mode, quantity of collected and recovered products in the forward and reverse sides of the considered supply chain. The acquired results justify the capability of the proposed model in determining the optimal values of tactical level decisions in different echelons of a forward-reverse supply chain network.

Keywords: Production planning, forward-reverse supply chain, dynamic, distribution planning

1. Introduction
Forward-reverse supply chains are the network of organizations, people, activities, information and resources involved in providing new goods from suppliers to the customers and collecting of used products from final customers and remanufacturing, recovering or disposal them in a suitable way. Therefore, Forward-reverse supply chain management is the process of integrating and utilizing suppliers, manufacturers, warehouses and retailers in the forward side and collecting, recovering and disposal activities in the reverse side; so new products are produced and delivered to the end users at the right quantities and at the right time and then the used products are collected and recovered and/or disposed in the suitable way [1]. Many companies such as Dell, HP, Kodak, Canon, and Xerox have achieved many economic advantages through collecting and recovering the used products.
The increasing interest in evaluating the performance of supply chain networks over the past years indicates the need for the development of complex optimization models able to answer unsolved questions in the context of production and distribution planning [٢]. On the other hand, recovering and redistribution of used products has attracted many attentions by the researchers and practitioners in the last decade due to environmental challenges, governmental limitations and economic reasons [٣]. However, many researchers [٤] have stated that planning for the forward and reverse supply chain, separately, leads to sub-optimality in the planning of supply chain. Consequently, the main aim of an integrated production and distribution planning model in a forward-reverse supply chain would be determining the number of products produced in the plants, the number of products recovered in recovery centers, the amount of flows between different entities existing in the different echelons of the supply chain, the amount of inventories to be stored in distribution centers, the amount of collected products, and the amount of recoverable and non-recoverable products. Integrated production and distribution planning is a medium range capacity planning that typically includes a time horizon from 3 to18 months [٥]. It should be noted that other forms of planning such as master production schedule, capacity requirements planning and material requirements planning follow the outcomes of aggregate production and distribution planning and are determined in a hierarchical way [٦] according to supply chain planning matrix. Acquiring used products (planning for purchasing used products) can reduce the uncertainty of quality, quantity and timing of returns [٧]. Some studies [٨] have assumed that the manufactured

products are as the same as new products and are sold in the same markets with the same prices. However, according to the life cycle of products this assumption may not be reasonable in the real world. Consequently, in this paper, we assume that remanufactured products are sold in second markets with lower prices.

In this paper, we present a novel model for multiple products, multiple periods integrated production and distribution planning in a forward-reverse supply chain network consisting of multiple production sites and transportation modes which integrates production and distribution plans in the forward and reverse sides of the supply chain, simultaneously. In the proposed model, the main real-world assumptions such as direct or indirect shipments, several customer zones for new, recovered, and non-recovered products, service level of customers, and multiple transportation modes are considered. To the best of our knowledge, there is no research paper with the mentioned contributions in the literature of forward-reverse supply chains.

The remainder of this paper is organized as follows. In Section 2, we define our notations and develop a new linear programming model for the forward-reverse supply chain network planning. The results and discussions are presented in Section 3. Section 4 presents conclusions extracted from the proposed model and its solutions.

2. The proposed mathematical programming model

The concerned aggregate production-distribution planning model for the forward-reverse supply chains is of multi-site, multi-echelon, multi-period, and multi-product network type. A practical situation of such problem can be found in several industries such as printers and copiers production, namely Xerox and Kodak companies, or digital cameras production, namely Canon Company. New products are produced and also recovered products are recovered in hybrid manufacturing/recovery (HMR) centers and shipped to the hybrid distribution/redistribution (HDR) sites. As it was mentioned by Pishvaee et al. [37], hybrid processing facilities offer potential cost savings compared with separate distribution or collection centers in a forward-reverse supply chain network.

In addition, new products could be directly shipped from HMR centers to customer zones to fulfill new products' demands before reaching due dates. At HDR centers, some products are stored and the rest is shipped to customer zones through different transportation modes. Also, some new products are hold as safety stock to face with unscheduled changes in customer needs.

It is worthy to note that new products' customers have higher priority respect to recovered products' customers when assigning resources to customers. Therefore, direct shipment of products and holding safety stock options are presented only for new products. New products are delivered to customers in a pull manner, while demands of recovered products are fulfilled in a push way where their raw material are provided from collected used products and thus are limited. Therefore, some demands of recovered products may not be fulfilled

Used products are purchased from customer zones and shipped to collection centers. After testing and evaluating the quality of used products in collection centers, they are classified into recoverable and non-recoverable products. The recoverable products are shipped to HMR centers and the non-recoverable products are sold to material customers.

In the proposed model, delivery time of products to customers might be violated which may lead to deviations from predetermined customer service levels based on senior management's preferences. For example, customers with targeted service level 100% receive products before their promised delivery times.

The objective function aims to maximize the net present value of total profit which is achieved through subtracting the total costs from the total revenues. Total revenues are acquired from selling different types of products in predetermined customer zones. Total costs include production costs, recovery costs, transportation costs, purchasing costs of used products, testing and evaluating costs of collected products, inventory holding costs, and advertisement costs.

The following notations are used to formulate the problem mathematically.

Indices

i	Index of hybrid manufacturing/recovery centers (i=1,…,I)
j	Index of hybrid distribution/redistribution centers (j=1,…,J)
k	Index of first markets' customer zones (new products) (k=1,…,K)
l	Index of second markets' customer zones (recovered products) (l=1,…,L)
m	Index of collection centers (m=1,…,M)
n	Index of transportation modes (n=1,…,N)
p	Index of products (p=1,…,P)
t	Index of time periods (t=1,…,T)

Parameters

$D1_{kpt}$	Demand of customer k for new product p in period t
$D2_{lpt}$	Demand of customer l for recovered product p in period t
$Re1_{kpt}$	Amount of returns of product p from customer k in period t
$Re2_{lpt}$	Amount of returns of product p from customer l in period t
$\beta1_p$	Recoverable percentage of product p collected from the first markets' customers in period t
$\beta2_p$	Recoverable percentage of product p collected from the second markets' customers in period t
$SS1_{jpt}$	Safety stock level of new product p at distribution/redistribution center j in period t
Pr_{jknpt}	Unit Selling price of new product p shipped from distribution/redistribution center j to customer k by transportation mode n in period t
$Pr1_{iknpt}$	Unit Selling price of new product p shipped from manufacturing/recovery center i to customer k by transportation mode n in period t
$Pr2_{jlnpt}$	Unit Selling price of recovered product p shipped from distribution/redistribution center j to customer l by transportation mode n in period t
$Pr3_{pt}$	Unit Selling price of non-recoverable product p sold to material customers in period t
$Pur1_{kpt}$	Unit Purchasing cost of used product p from customer k in period t
$Pur2_{lpt}$	Unit Purchasing cost of used product p from customer l in period t
Pc_{ipt}	Manufacturing cost of new product p at manufacturing/recovery center i in period t
Rc_{ipt}	Unit Recovery cost of used product p at manufacturing/recovery center i in period t
Hpc_{mpt}	Unit Processing and quality test costs of used product p at collection center m in period t
$Hic1_{jpt}$	Unit holding cost of new product p at distribution/redistribution center j in period t
$Hic2_{jpt}$	Unit holding cost of recovered product p at distribution/redistribution center j in period t
sc_{lpt}	Unit shortage cost of recovered product p for customer l in period t
$Ha1_{kpt}$	Unit advertising cost of product p at customer zone k in period t
$Ha2_{lpt}$	Unit advertising cost of product p at customer zone l in period t
r	Interest rate
BC_t	Maximum budget assigned for advertising and marketing activities in period t
Tc_{ijnpt}	Unit transportation cost of new product p shipped from manufacturing/recovery center i to distribution/redistribution center j by transportation mode n in period t
$Tc1_{iknpt}$	Unit transportation cost of new product p shipped from manufacturing/recovery center i to customer k by transportation mode n in period t
$Tc2_{jknpt}$	Unit transportation cost of new product p shipped from distribution/redistribution center j to customer k by transportation mode n in period t
$Tc3_{jlnpt}$	Unit transportation cost of recovered product p shipped from distribution/redistribution center j to customer l by transportation mode n in period t
$Tc4_{kmpt}$	Unit transportation cost of used product p shipped from customer k to collection center m in period t
$Tc5_{lmpt}$	Unit transportation cost of used product p shipped from customer l to collection center m in period t
$Tc6_{mipt}$	Unit transportation cost of used product p shipped from collection center m to manufacturing/recovery center i in period t
Td_{ikn}	Delivery time from manufacturing/recovery center i to customer k by transportation mode n
Te_{kp}	Expected delivery time of customer k for new product p in any period
$Td1_{jkn}$	Delivery time from distribution/redistribution center j to customer k by transportation mode n (in days)
$Td2_{jln}$	Delivery time from distribution/redistribution center j to customer l by transportation mode n (in days)
$Te1_{lp}$	Expected delivery time of customer l for recovered product p in any period (in days)

$Sl1_k$	Average predetermined service level for customer *k* (the percentage of on-time deliveries)
$Sl2_l$	Average predetermined service level for customer *l* (the percentage of on-time deliveries)
b_p	Required storage capacity per unit of product *p* (volume)
$b1_p$	Required production capacity per unit of product *p* (machine-hour/unit)
$b2_p$	Required recovery capacity per unit of product *p* (machine-hour/unit)
$b3_p$	Required handling capacity per unit of product *p* at collection centers (machine-hour/unit)
$Ca1_i$	Maximum capacity of hybrid manufacturing/recovery center *i*
$Ca2_j$	Maximum capacity of hybrid distribution/redistribution center *j*
$Ca3_m$	Maximum capacity of collection center *m*

Variables

x_{jknpt}	Quantity of new product *p* shipped from distribution/redistribution *j* to customer *k* by transportation mode *n* in period *t*
$x1_{iknpt}$	Quantity of new product *p* shipped from manufacturing/recovery center *i* to customer *k* by transportation mode *n* in period *t*
$x2_{jlnpt}$	Quantity of recovered product *p* shipped from distribution/redistribution center *j* to customer *l* by transportation mode *n* in period *t*
$x3_{ijnpt}$	Quantity of new product *p* shipped from manufacturing/recovery center *i* to distribution/redistribution center *j* by transportation mode *n* in period *t*
$x4_{ijnpt}$	Quantity of recovered product *p* shipped from manufacturing/recovery center *i* to distribution/redistribution center *j* by transportation mode *n* in period *t*
xe_{ipt}	Quantity of new product *p* manufactured at manufacturing/recovery center *i* in period *t*
y_{kmpt}	Quantity of returned product *p* shipped from customer *k* to collection center *m* in period *t*
$y1_{lmpt}$	Quantity of returned product *p* shipped from customer *l* to collection center *m* in period *t*
$y2_{pt}$	Quantity of scraped product *p* sold to material customers in period *t*
$y3_{mipt}$	Quantity of recoverable product *p* shipped from collection center *m* to manufacturing/recovery center *i* in period *t*
$IC1_{jpt}$	Inventory level of product *p* at distribution/redistribution center *j* in period *t*
$IC2_{jpt}$	Inventory level of recovered product *p* at distribution/redistribution center *j* in period *t*
λ_{lpt}	Backorder quantity of recovered product *p* for customer *l* in period *t*
Rp_{pt}	Quantity of recoverable product *p* in period *t*

Objective function: The proposed model aims to maximize the net present value of total profit (that is, total profit = total revenues – total costs). The total revenues are resulted from products sold in different customer zones including customers of new products, customers of recovered products, and customers of non-recoverable products and thus can be formulated as follows:

$$\sum_j\sum_k\sum_n\sum_p\sum_t \overline{Pr}_{jknpt} x_{jknpt} + \sum_i\sum_k\sum_n\sum_p\sum_t \overline{Pr1}_{iknpt} x1_{iknpt} + \sum_j\sum_l\sum_p\sum_n\sum_t \overline{Pr2}_{jlnpt} x2_{jlnpt}$$
$$+\sum_p\sum_t \overline{Pr3}_{pt} y2_{pt}$$

Note that new products could be directly shipped from the HMR sites to customers or shipped through HDR centers. Although the costs incurred by direct shipments are higher than traditional indirect shipments, a particular case of interest is that the selling price in both types of shipments to be equal. In fact, direct shipment strategy is used to fulfill customer expectations within their maximal allowable times and thus customers should not charge more costs due to direct shipments utilized by the companies in supply chain. On the other hand, utilizing direct shipment strategy via different transportation modes boosts customer's beliefs about the delivery times obligated by the supply chain members.

The total costs which is a common efficiency criterion to optimize decisions made to use different resources in supply chain planning models efficiently include transportation costs, production and recovering costs, quality testing costs of collected products, inventory holding costs, purchasing the used products, advertisement costs, and shortage costs.

In this regard, the transportation costs encompass shipping costs between different echelons of the closed-loop supply chain in both forward and reverse sides via various transportation modes. The total transportation costs can be formulated as follows:

$$\sum_i\sum_j\sum_n\sum_p\sum_t Tc_{ijnpt}\,x3_{ijnpt} + \sum_i\sum_k\sum_n\sum_p\sum_t Tc1_{iknpt}\,x1_{iknpt} + \sum_j\sum_k\sum_n\sum_p\sum_t Tc2_{jknpt}\,x_{jknpt} +$$
$$\sum_j\sum_k\sum_n\sum_p\sum_t Tc3_{jlnpt}\,x2_{jlnpt} + \sum_k\sum_m\sum_p\sum_t Tc4_{kmpt}\,y_{kmpt} +$$
$$\sum_l\sum_m\sum_p\sum_t Tc5_{lmpt}\,y1_{lmpt} + \sum_m\sum_i\sum_p\sum_t Tc6_{mipt}\,y3_{mipt} + \sum_i\sum_j\sum_n\sum_p\sum_t Tc_{ijnpt}\,x4_{ijnpt}$$

The other types of costs could be written as follows:
Production and recovering costs in HMR centers:

$$\sum_i\sum_p\sum_t Pc_{ipt}\,xe_{ipt} + \sum_i\sum_p\sum_t Rc_{ipt}\Big(\sum_m y3_{mipt}\Big)$$

Handling costs in collection centers including the testing and evaluating of used products):

$$\sum_m\sum_p\sum_t Hpc_{mpt}\Big(\sum_k y_{kmpt} + \sum_l y1_{lmpt}\Big)$$

Inventory holding costs in HDR centers:

$$\sum_m\sum_i\sum_p\sum_t Tc6_{mipt}\,y3_{mipt} + \sum_i\sum_j\sum_n\sum_p\sum_t Tc_{ijnpt}\,x4_{ijnpt}$$

Purchasing costs of used products from customers:

$$\sum_k\sum_p\sum_t \overline{Pur1}_{kpt}\Big(\sum_m y_{kmpt}\Big) + \sum_l\sum_p\sum_t \overline{Pur2}_{lpt}\Big(\sum_m y1_{lmpt}\Big)$$

Advertisement costs in different customer zones for new and recovered products:

$$\sum_k\sum_p\sum_t Ha1_{kpt}\Big(\sum_j\sum_n x_{jknpt} + \sum_i\sum_n x1_{iknpt}\Big) + \sum_l\sum_p\sum_t Ha2_{lpt}\Big(\sum_j\sum_n x2_{jlnpt}\Big)$$

Finally, shortage costs related to recovered products:

$$\sum_l\sum_p\sum_t \overline{sc}_{lpt}\,\lambda_{lpt}$$

It is worthy to note that to calculate the net present values of the total revenues and total costs, the coefficient $\frac{1}{(1+r)^t}$ in which r denotes the interest rate, should be multiplied by the above-mentioned equations. However, this coefficient has been omitted from the afore-mentioned equations for simplicity.
Consequently, we would have the following objective function:

$$
\begin{aligned}
Max\ \ Z = & \Bigg[\sum_j \sum_k \sum_n \sum_p \sum_t \overline{Pr}_{jknpt} x_{jknpt} + \sum_i \sum_k \sum_n \sum_p \sum_t \overline{Pr1}_{iknpt} x1_{iknpt} \\
& + \sum_j \sum_l \sum_p \sum_n \sum_t \overline{Pr2}_{jlnpt} x2_{jlnpt} + \sum_p \sum_t \overline{Pr3}_{pt} y2_{pt} \Bigg] - \\
& \Bigg[\sum_i \sum_j \sum_n \sum_p \sum_t Tc_{ijnpt} x3_{ijnpt} + \sum_i \sum_k \sum_n \sum_p \sum_t Tc1_{iknpt} x1_{iknpt} + \sum_j \sum_k \sum_n \sum_p \sum_t Tc2_{jknpt} x_{jknpt} + \\
& \sum_j \sum_k \sum_n \sum_p \sum_t Tc3_{jlnpt} x2_{jlnpt} + \sum_k \sum_m \sum_p \sum_t Tc4_{kmpt} y_{kmpt} + \sum_l \sum_m \sum_p \sum_t Tc5_{lmpt} y1_{lmpt} + \\
& \sum_m \sum_i \sum_p \sum_t Tc6_{mipt} y3_{mipt} + \sum_i \sum_j \sum_n \sum_p \sum_t Tc_{ijnpt} x4_{ijnpt} + \sum_i \sum_p \sum_t Pc_{ipt} xe_{ipt} + \sum_i \sum_p \sum_t Rc_{ipt} (\sum_m y3_{mipt}) + \\
& \sum_m \sum_p \sum_t Hpc_{mpt} (\sum_k y_{kmpt} + \sum_l y1_{lmpt}) + \sum_j \sum_p \sum_t HIc1_{jpt} Ic1_{jpt} + \sum_j \sum_p \sum_t HIc2_{jpt} Ic2_{jpt} + \\
& \sum_k \sum_p \sum_t \overline{Pur1}_{kpt} (\sum_m y_{kmpt}) + \sum_l \sum_p \sum_t \overline{Pur2}_{lpt} (\sum_m y1_{lmpt}) + \sum_k \sum_p \sum_t Ha1_{kpt} (\sum_j \sum_n x_{jknpt} + \sum_i \sum_n x1_{iknpt}) + \\
& \sum_l \sum_p \sum_t Ha2_{lpt} (\sum_j \sum_n x2_{jlnpt}) + \sum_l \sum_p \sum_t \overline{sc}_{lpt} \lambda_{lpt} \Bigg]
\end{aligned} \qquad (1)
$$

Model constraints

Inventory balance constraints in the forward side: The following constraints express the inventory-related and demand satisfaction constrains in the HMR and HDR centers in the forward side.

$$\sum_j \sum_n x_{jknpt} + \sum_i \sum_k x1_{iknpt} = \overline{D1}_{kpt} \qquad \forall k, p, t \qquad (2)$$

$$Ic1_{jp,t-1} + \sum_i \sum_n x3_{ijnpt} - Ic1_{jpt} = \sum_k \sum_n x_{jknpt} \qquad \forall j, p, t \qquad (3)$$

$$Ic1_{jpt} \geq SS1_{jpt} \qquad \forall j, p, t \qquad (4)$$

$$xe_{ipt} = \sum_j \sum_n x3_{ijnpt} + \sum_k \sum_n x1_{iknpt} \qquad \forall i, p, t \qquad (5)$$

$$\sum_j \sum_n x2_{jlnpt} + \lambda_{lpt} - \lambda_{lp,t-1} = \overline{D2}_{lpt} \qquad \forall l, p, t \qquad (6)$$

$$Ic2_{jp,t-1} + \sum_i \sum_n x4_{ijnpt} - Ic2_{jpt} = \sum_l \sum_n x2_{jlnpt} \qquad \forall j, p, t \qquad (7)$$

Constraints (2) ensure that all demands of customers for new products are satisfied. Constraints (3) and (4) are inventory balancing equations and safety stock levels at HDR centers. It is worthy to note that determination of the safety stock levels could be performed via the forward inventory coverage concept. That is, the safety stock levels in current period are calculated according to the demands of customers in the next period as follows: $SS1_{jpt} = \alpha_p D1_{kp,t+1}$, where α_p and $D1_{kp,t+1}$ indicate the forward inventory coverage factor of new product p and the most possible value of demands for new products at the next period, respectively. Obviously, the safety stock levels for the last period T is achieved based on the first period demands for the new product. Constraint (5) show the total new products produced at HMR centers in any period. Constraints (6) and (7) are the demand constraint, being satisfied or being left as back-orders, and inventory balancing equation for the recovered products at HDR centers.

Inventory balance constraints in the reverse side:

$$\sum_m y_{kmpt} = \overline{Re1}_{kpt} \qquad \forall k,p,t \tag{8}$$

$$\sum_m y1_{lmpt} = \overline{Re2}_{lpt} \qquad \forall l,p,t \tag{9}$$

$$Rp_{pt} = \overline{\beta 1}_p \sum_k \sum_m y_{kmpt} + \overline{\beta 2}_p \sum_l \sum_m y1_{lmpt} \qquad \forall p,t \tag{10}$$

$$y2_{pt} = (1-\overline{\beta 1}_p)\sum_k \sum_m y_{kmpt} + (1-\overline{\beta 2}_p)\sum_l \sum_m y1_{lmpt} \qquad \forall p,t \tag{11}$$

$$Rp_{pt} = \sum_m \sum_i y3_{mipt} \qquad \forall p,t \tag{12}$$

$$\sum_j \sum_n x4_{ijnpt} = \sum_m y3_{mipt} \qquad \forall i,p,t \tag{13}$$

Constraints (8) and (9) assure that all of the used products are collected from both customer types. Constraints (10) and (11) distinguish the collected products into the recoverable and non-recoverable products based on their qualities. Constraint (12) represents that all recoverable products shipped from collection centers to the HMR centers are recovered. Constraint (13) links the amount of recovered products in the forward side with the recoverable products shipped to HMR sites in the reverse side. Indeed, the balance of recovered products is established at HMR centers.

Delivery time constraints:

$$Td_{ikn} x1_{iknpt} - (1-sl_k) Te_{kp} x1_{iknpt} \le Te_{kp} x1_{iknpt} \qquad \forall i,k,n,p,t \tag{14}$$

$$Td1_{jkn} x_{jknpt} - (1-sl_k) Te_{kp} x_{jknpt} \le Te_{kp} x_{jknpt} \qquad \forall j,k,n,p,t \tag{15}$$

$$Td2_{jln} x2_{jlnpt} - (1-sl1_l) Te1_{lp} x2_{jlnpt} \le Te1_{lp} x2_{jlnpt} \qquad \forall j,l,n,p,t \tag{16}$$

Constraints (14) and (15) state that the new products are delivered to corresponding customers according to predetermined customer service levels about the new products' deliveries. For example, customers with targeted service level 100% (i.e. sl_k=1) will receive new products in their expectation time. Constraint (16) is similar to constraints (14) and (15) but for the recovered products.

Capacity constraints:

$$\sum_p b1_p xe_{ipt} + \sum_j \sum_n \sum_p b2_p x4_{ijnpt} \le ca1_i \qquad \forall i,t \tag{17}$$

$$\sum_i \sum_n \sum_p b_p x3_{ijnpe} + \sum_i \sum_n \sum_p b_p x4_{ijnpt} + \sum_p b_p Ic1_{jpt} + \sum_p b_p Ic2_{jpt} \le ca2_j \qquad \forall j,t \tag{18}$$

$$\sum_k \sum_p b3_p y_{kmpt} + \sum_l \sum_p b3_p y1_{lmpt} \le ca3_m \qquad \forall m,t \tag{19}$$

Constraint (17) represents the maximum capacity level utilizations in HMR centers for both new and recovered products. Constraints (18) and (19) are similar to constraint (17) for the HDR and collection centers, respectively. Constraint (20) demonstrates that the amount of new products directly shipped is restricted. This could be explained due to budget limitations about direct shipment of products.

$$\sum_i \sum_k \sum_n \sum_p \sum_t x1_{iknpt} \le UB(\sum_k \sum_p \sum_t D1_{kpt}) \tag{20}$$

Budget limitation:

$$\sum_k \sum_p Ha1_{kpt} (\sum_j \sum_n x_{jknpt} + \sum_i \sum_n x1_{iknpt}) + \sum_j \sum_l \sum_n \sum_p Ha2_{lpt} x2_{jlnpt} \le BC_t \qquad \forall t \tag{21}$$

Constraint (21) considers the budget limitation for advertisement activities in different customer zones in any period. Finally, constraint (22) indicates the non-negativity and type of different decision variables.

$$x_{jknpt}, x1_{iknpt}, x2_{jlnpt}, x3_{ijnpt}, x4_{ijnpt}, \lambda_{lpt}, xe_{ipt}, y_{kmpt}, y1_{lmpt}, y2_{pt}, y3_{mipt}, Ic1_{jpt}, Ic2_{jpt} \geq 0 \quad \forall i, j, k, n, p, l, m, t \tag{22}$$

3. Results and discussions

In this section, a numerical example with reasonable size is presented to investigate the applicability and appropriateness of the proposed model.

Table 1: The amount of tactical level decisions of the considered supply chain

Product type	Period	New	Recovered	Non-recovered	Inventory (new)	Inventory (recovered)
1	1	6728	3131	900	611	351
	2	5839	3016	863	613	1181
	3	5553	2845	823	606	1643
2	1	6977	2971	1071	651	0
	2	6031	2901	1047	644	454
	3	5791	2833	1022	685	860
3	1	7083	2579	1205	654	0
	2	6106	2641	1231	627	34
	3	5879	2671	1248	663	226

The proposed model is coded in Lingo 11.0 optimization software and solved on a Pentium dual-core 2.60 GHZ computer with 4 GB RAM. Table 1 illustrates the amount of new products, recovered products, amount of non-recovered products sold to material customers, and inventory of new and recovered products in different periods. These results could be used as the inputs in master production planning or material requirement planning. Also, the senior management has good insight for requirements of different products in different periods to fulfill customer demands in right quantity and right time.

4. Conclusion

The proposed model for the forward-reverse supply chain network planning is able to consider different transportation modes, direct or indirect shipments, and several customer zones for different products beside the traditional features considered for tackling such problems in the literature. The proposed model is able to provide medium-term aggregate plans in forward-reverse supply chains involving different types of customers. The need for such a model may be observed in high-tech electronics, copiers and printer's industries. The following research directions could be covered by researchers and practitioners in the future. Considering another objective for example maximization of responsiveness or minimization of environmental issues in the context of multi-objective programming could be addressed. Also, the proposed model has a general structure which could be implemented in real cases of industries with required modifications.

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