

## A Mixed Integer Linear Programming Model Proposal for Network Design of a Multi-Phase, Environmental and Flexible Closed Loop Supply Chain

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### Abstract

To provide a competitive edge in today's conditions of globalization businesses are required to go beyond the classical methods. When we take into account the basic structure of the contemporary value chain and its importance, we can describe supply chains as "Outstanding Competitiveness Creator Source" for businesses. In this context this can be said that a supply chain network design decision which has a strategic importance in all processes including procurement of raw materials, manufactured products and services delivered to the customer, even after sales services is a critical decision for businesses. On the other hand because of the awareness of customers, being more searching and questioning and taking into account not only ergonomics but also the environmental impact of products in the information society, businesses are required to make environmentally sensitive activities in all conducting business processes. In this study, a model is proposed for the design of a supply chain distribution network that may be suitable for new business processes which are shaped by globalization and the information society's effect. The model includes raw material supply, production, distribution, recycling activities design as flexible and environmentally sensitive processes for a product with more than one component.

**Keywords:** A supply chain network desing, environmentally sensitivity, flexibility, a mixed integer linear programming

### 1. The Concepts of Supply Chain Management, Reverse Supply Chain Management and Closed Loop Supply Chain Management

Due to the causes such as environmental concerns, economic reasons, laws, institutional and social responsibility, sustainable development, maintaining the natural resources, and less consumption of material, the activities of recovery has gained importance. Because of all these reasons, the concepts of supply chain management, reverse supply chain, and closed loop supply chain offering a holistic approach, both more profitable and environmental friendly have gained importance.

Supply chain management can be considered as a structure showing development around customer orientated institutional vision; managing the internal and external connections of a business enterprise; and following this, providing the integration and coordination of synergy between in- functionality and in-organization. The successful integration of internal supply chain predominantly depends on the perfect and timely information share between the rings in supply chain (Min and Zhou, 2002).

The increasing perception of consumer responsibility has made obligatory the producers of original equipment and other actors of supply chain to collect the products they produced after the use of final consumer; to make them usable; and appropriate removal of the materials and products that will not be able to be recovered, in order to prevent from wasting, and to form the infrastructure of sustainable development. (Krikke et al 2004)

Supply chain management, in parallel with economic, technological, legal, and ecological changes and development, forms a basis for a lot of new concepts and interdisciplinary studies. From this point of view, first of all, it is necessary to define the concepts of reverse logistic and closed loop. In the scope of management of reverse chain supply, there are the activities carried out for the recovery of product and the product flow of producer that were backwardly used.

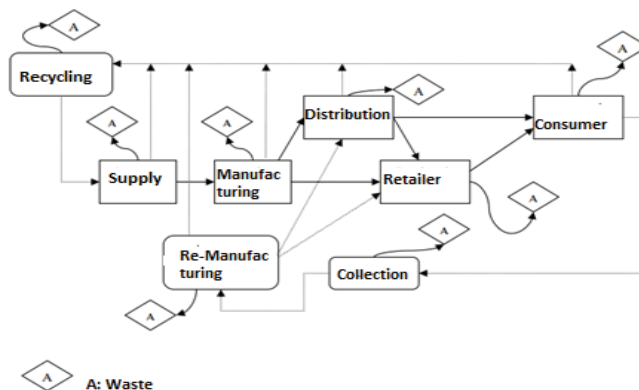
The approach of management of reverse supply chain includes the efforts of collecting the products that are not possible to use due to completing their lifetimes or that are returned due to reasons such as lack of quality, product recall, and post-guarantee and sale service from the points of consumption; of examining; and adding value to these products, of recovering them (Erol et al., 2006: 4).

Management and planning of reverse logistic process has some characteristics. These can be considered as follows (Özgün, 2007: 32-33):

- *That material flow is uncertain:* The firms do not know the amount of product to reloop and when it will return
- *Unclear quality and diversity of the returning products:* The return flow of products presents diversity.
- *Customer loyalty:* The return of products largely depends on the final customer or the final user
- *That the time is critical:* The routes of material are uncertain. For reusing and rearranging, it is necessary to very rapidly recover the active value of returning product
- *Uncertain market demand:* The price and demand of secondary markets is not clear. In the place, where the processes of reverse logistic and demand fluctuations occur, for the returning materials, in terms of being able to realize the services of installation, transportation and the other relevant services, it has to have a structure supporting the flexible capacity.
- *Improving value:* In order to make maximum the capital value forming in the returns, there is a need for new markets.

A well application of reverse supply chain reduces the cost of firm to acquire raw material and material; lowers the purchase power of customer, shortens his/her reaction time; performs social responsibility; and improving the image of environment–firm, provides competitive advantage to the firm (Nakıboğlu, 2007: 181).

Reverse logistic makes a relationship between the market presenting the used product to the marketplace and market presenting the new product. If these two markets overlap, it is termed closed loop supply chain. Closed loop not only includes the activities of supply chain and advanced supply chain, but also, additionally includes the activities of reverse supply chain (Özkan, 2010: 23).



**Figure 1:** Closed Loop Supply Chain (Beamon, 1999)

According to Paksoy (2012), in the systems, where the structure of closed loop supply chain, the final products emerging in the network of advanced supply chain are collected from the customers and without going out of loop, subjecting to recycling, are again included in the process (Paksoy,2012:9)

Management of reverse supply chain, in order to protect the environment and provide the sustainable development, makes it difficult the aim of firms to make profit. These aims are overlapping aims, not conflicting

ones. Dowlatshahi (2000) suggest that via remanufacturing, 40-60% of the cost of an original product can be saved. Adding the new value to the used products or reuse of certain materials brings together very important savings and as a result of this, causes the increases in the profitability rate.

### 1.1 Design of Supply Chain Network and Modeling

Besides the design in the business enterprise, transporting material, scheduling, production planning and controlling, the relationships with the other business enterprises are also important. In supply chain management, success, rather than an individual phenomenon, is in the meaning of modeling the complex network of business relationship and managing by coordinating it.

Planning the distribution networks is one of the main areas, in which strategic planning is applied. A plan of strategic distribution network is developed to meet a set of certain needs along a given planning horizon. A good plan must supply right goods, in right amounts, in right place, and right time to the customer and define suitable distribution network. Plan of distribution network, beside determining profit, the service presented to the customer, it most include the number of distribution center to be opened, their location, and to which customers they will serve, technical detail such as selection of transporting methods to be used. As the number of storage increase, the delivery costs reduce and cost of storage increases (Paksoy and Altıparmak, 2003:152).

## 2. The Problem

In this part of the study an effective SCM model that will help to ensure is proposed. In this model, we a network design is made with suppliers, factories, distribution centers, retailers, collection centers, recycling centers and customers under the constraint of material requirements. A mixed integer mathematical model which is modelled by taking into account supply chain constraints with linear is given below.

In this model there are more than one products, suppliers, factories, distribution centers, retailers, customers, collection centers, recycling centers and one waste. Because of flexible structure of supply chain, product flow between stages may be directly or hopping. In stages failed / defective products are sent to collection center and then recycling center or waste according to their repair the state. There is a detailed decomposition in recycling center because products occurs two-tier components. The aims of this system is to minimize cost of CO2 emissions released during transport as well as the transportation costs. Firms use different vehicles which have different motors and release different CO2 emissions. We assumed that the vehicles transport capacity is unlimited.

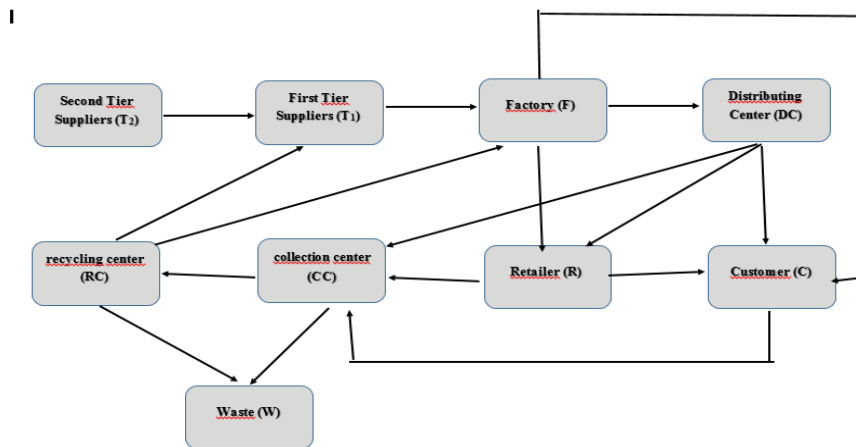


Figure 2: Our Network Design for Supply Chain

## 2.1 Identification of Model Parameters

### 2.1.1 Indices:

<b>v:</b> Products	<b>r:</b> Distribution Center (DC)
<b>n:</b> Second Tier Component	<b>u:</b> Perakendeciler (P)
<b>p:</b> First Tier Component	<b>k:</b> Customer (M)
<b>s:</b> Second Tier Suppliers (T <sub>2</sub> )	<b>l:</b> Collection Center (CC)
<b>i:</b> First Tier Suppliers (T <sub>1</sub> )	<b>m:</b> Recycling Center (RC)
<b>j:</b> Factory (F)	<b>t:</b> Vehicles (T)

### 2.1.2 Transport Quantity Between Stages

- $X_{sitvnp}$  : Transport quantity with vehicle t for second tier component of product v from T<sub>2</sub> to T<sub>1</sub>
- $Y_{ijtv}$  : Transport quantity with vehicle t for first tier component of product v from T<sub>1</sub> to F
- $Z_{jrtv}$  : Transport quantity with vehicle t for product v from F to DC
- $W_{jutv}$  : Transport quantity with vehicle t for product v from F to P
- $V_{jktv}$  : Transport quantity with vehicle t for product v from F to C
- $S_{rutv}$  : Transport quantity with vehicle t for product v from DC to R
- $H_{rktv}$  : Transport quantity with vehicle t for product v from DC to C
- $A_{ritv}$  : Transport quantity with vehicle t for product v from DC to CC
- $B_{uktv}$  : Transport quantity with vehicle t for product v from R to C
- $R_{ultv}$  : Transport quantity with vehicle t for product v from R to CC
- $E_{kitv}$  : Transport quantity with vehicle t for product v from C to CC
- $F_{itv}$  : Transport quantity with vehicle t for product v from CC to W
- $G_{imtv}$  : Transport quantity with vehicle t for product v from TM to RC
- $K_{mjtv}$  : Transport quantity with vehicle t for first tier component of product v from RC to F
- $L_{mitvnp}$  : Transport quantity with vehicle t for second tier component of product v from RC to T<sub>1</sub>
- $N_{mtvnp}$  : Transport quantity with vehicle t for second tier component of product v from RC to W
- $CO_2^t$  : CO<sub>2</sub> quantity for vehicle t. (gr/km)

### 2.1.3 Transport By Vehicle t

- $I_{sitvnp}$  : If second tier component of product v transport will happen from T<sub>2</sub> to T<sub>1</sub> with vehicle t it's value is 1, in other cases it's value is 0
- $I_{ijtv}$  : If first tier component of product v transport will happen from T<sub>1</sub> to F with vehicle t it's value is 1, in other cases it's value is 0
- $I_{jrtv}$  : If product v transport will happen from F to DC with vehicle t it's value is 1, in other cases it's value is 0
- $I_{jutv}$  : If product v transport will happen from F to R with vehicle t it's value is 1, in other cases it's value is 0
- $I_{jktv}$  : If product v transport will happen from F to C with vehicle t it's value is 1, in other cases it's value is 0
- $I_{rutv}$  : If product v transport will happen from DC to R with vehicle t it's value is 1, in other cases it's value is 0
- $I_{rktv}$  : If product v transport will happen from DC to C with vehicle t it's value is 1, in other cases it's value is 0
- $I_{ritv}$  : If product v transport will happen from DC to CC with vehicle t it's value is 1, in other cases it's value is 0
- $I_{uktv}$  : If product v transport will happen from R to C with vehicle t it's value is 1, in other cases it's value is 0
- $I_{ultv}$  : If product v transport will happen from R to CC with vehicle t it's value is 1, in other cases it's value is 0
- $I_{kitv}$  : If product v transport will happen from C to CC with vehicle t it's value is 1, in other cases it's value is 0
- $I_{itv}$  : If product v transport will happen from CC to W with vehicle t it's value is 1, in other cases it's value is 0
- $I_{imtv}$  : If product v transport will happen from CC to RC with vehicle t it's value is 1, in other cases it's value is 0
- $I_{mjtv}$  : If first tier component of product v transport will happen from RC to F with vehicle t it's value is 1, in other cases it's value is 0

- $I_{mitvpn}$  : If second tier component of product  $v$  transport will happen from RC to  $T_1$  with vehicle  $t$  it's value is 1, in other cases it's value is 0
- $I_{mtvpn}$  : If second tier component of product  $v$  transport will happen from RC to W with vehicle  $t$  it's value is 1, in other cases it's value is 0

#### 2.1.4 Costs:

- $C_{sitvpn}$  : Unit transportation cost of second tier component of product  $v$  with vehicle  $t$  from  $T_2$  to  $T_1$ (TL / Piece)
- $C_{ijtv}$  : Unit transportation cost of second tier component of product  $v$  with vehicle  $t$  from  $T_1$  to F(TL / Piece)
- $C_{jrtv}$  : Unit transportation cost of product  $v$  with vehicle  $t$  from F to DC(TL / Piece)
- $C_{jutv}$  : Unit transportation cost of product  $v$  with vehicle  $t$  from F to R(TL / Piece)
- $C_{jktv}$  : Unit transportation cost of product  $v$  with vehicle  $t$  from F to C(TL / Piece)
- $C_{rutv}$  : Unit transportation cost of product  $v$  with vehicle  $t$  from DC to R(TL / Piece)
- $C_{rktv}$  : Unit transportation cost of product  $v$  with vehicle  $t$  from DC to C(TL / Piece)
- $C_{ritv}$  : Unit transportation cost of product  $v$  with vehicle  $t$  from DC to CC(TL / Piece)
- $C_{uktv}$  : Unit transportation cost of product  $v$  with vehicle  $t$  from R to C(TL / Piece)
- $C_{ultv}$  : Unit transportation cost of product  $v$  with vehicle  $t$  from R to CC(TL / Piece)
- $C_{klv}$  : Unit transportation cost of product  $v$  with vehicle  $t$  from C to CC(TL / Piece)
- $C_{ltv}$  : Unit transportation cost of product  $v$  with vehicle  $t$  from CC to W(TL / Piece)
- $C_{lmtv}$  : Unit transportation cost of product  $v$  with vehicle  $t$  from CC to RC(TL / Piece)
- $C_{mjtv}$  : Unit transportation cost of first tier component of product  $v$  with vehicle  $t$  from RC to F(TL / Piece) (TL / Piece)
- $C_{mitvpn}$  : Unit transportation cost of second tier component of product  $v$  with vehicle  $t$  from RC to  $T_1$ (TL / Piece)
- $C_{mtvpn}$  : Unit transportation cost of second tier component of product  $v$  with vehicle  $t$  from RC to W(TL / Piece)
- $C_{co2}$  : Unit transportation cost of CO<sub>2</sub> (TL/tones)

#### 2.1.5 Component Usage Rates:

- $W_{pn}$ : Second tier component usage rate in first tier component
- $W_{vp}$ : First tier component usage rate in product  $v$

#### 2.1.6 Distances Between Stages:

- $D_{si}$ : Distance between  $T_2$  and  $T_1$  (km)
- $D_{ij}$  : Distance between  $T_1$  and F (km)
- $D_{jr}$ : Distance between F and DC (km)
- $D_{ju}$ : Distance between F and R (km)
- $D_{jk}$ : Distance between F and C (km)
- $D_{ru}$ : Distance between DC and R (km)
- $D_{rk}$ : Distance between DC and C (km)
- $D_{ri}$ : Distance between DC and CC (km)
- $D_{uk}$ : Distance between R and C (km)
- $D_{ul}$ : Distance between R and CC (km)
- $D_{kl}$ : Distance between C and CC (km)
- $D_l$  : Distance between CC and W (km)
- $D_{lm}$  : Distance between CC and RC (km)
- $D_{mj}$ : Distance between RC and F (km)
- $D_{mi}$ : Distance between RC and  $T_1$  (km)
- $D_m$  : Distance between RC and W (km)

### 2.1.7 Capacities:

- $e_{fv}$ : Capacity of F for product v (piece)
- $e_{rv}$ : Capacity of DC for product v (piece)
- $e_{uv}$ : Capacity of R for product v (piece)
- $e_{lv}$ : Capacity of CC for product v (piece)
- $e_{mvp}$ : Capacity of RC for first tier component of product v (piece)
- $e_{mvpn}$ : Capacity of RC for second tier component of product v (piece)
- $e_{kv}$ : Demand of C for product v (piece)
- $a_{svpn}$ : Capacity of T<sub>2</sub> for second tier component of product v (piece)
- $a_{ivp}$ : Capacity of T<sub>1</sub> for second tier component of product v (piece)

### 2.1.8 Recycling Rates:

- $W_{kl}$ : Product v rate collected from C to take CC
- $W_{lm}$ : Product v rate collected from CC to take RC
- $W_{mjvp}$ : First tier component of product v rate collected from RC to take F
- $W_{mivpn}$ : Second tier component of product v rate collected from RC to take T<sub>1</sub>

### 2.1.9 Deterioration Rates:

- $\alpha_{jr}$ : Deterioration rate being while transportation from F to DC
- $\alpha_{ju}$ : Deterioration rate being while transportation from F to R
- $\alpha_{jk}$ : Deterioration rate being while transportation from F to C
- $\alpha_{ru}$ : Deterioration rate being while transportation from DC to R
- $\alpha_{rk}$ : Deterioration rate being while transportation from DC to C
- $\alpha_{uk}$ : Deterioration rate being while transportation from R to C

## 2.2 Objective Function:

### 2.2.1 Transportation Costs:

$$\begin{aligned} & \sum_s \sum_i \sum_t \sum_v \sum_p \sum_n C_{sitvvp} X_{sitvvpn} + \sum_i \sum_j \sum_t \sum_v \sum_p C_{ijtvvp} Y_{ijtvvp} + \sum_j \sum_r \sum_t \sum_v C_{jrtv} Z_{jrtv} + \\ & \sum_j \sum_u \sum_t \sum_v C_{jutv} W_{jutv} + \sum_j \sum_k \sum_t \sum_v C_{jktv} V_{jktv} + \sum_r \sum_u \sum_t \sum_v C_{rutv} S_{rutv} + \sum_r \sum_k \sum_t \sum_v C_{rktv} H_{rktv} + \\ & \sum_r \sum_l \sum_t \sum_v C_{rltv} A_{rltv} + \sum_u \sum_k \sum_t \sum_v C_{uktv} B_{uktv} + \sum_u \sum_l \sum_t \sum_v C_{ultv} R_{ultv} + \sum_k \sum_l \sum_t \sum_v C_{kltv} E_{kltv} + \\ & \sum_l \sum_t \sum_v C_{ltv} F_{ltv} + \sum_t \sum_m \sum_t \sum_v C_{lmtv} G_{lmtv} + \sum_m \sum_j \sum_t \sum_v \sum_p C_{mjtvvp} K_{mjtvvp} + \\ & \sum_m \sum_i \sum_t \sum_v \sum_p \sum_n C_{mitvvp} L_{mitvvp} + \sum_m \sum_t \sum_v \sum_p \sum_n C_{mtvvp} N_{mtvvp} \end{aligned}$$

### 2.2.2 CO<sub>2</sub> Costs:

$$\begin{aligned} & C_{CO_2} [\sum_s \sum_i \sum_t \sum_v \sum_p \sum_n CO_2^t D_{si} I_{sitvvpn} + \sum_i \sum_j \sum_t \sum_v \sum_p CO_2^t D_{ij} I_{ijtvvp} + \sum_j \sum_r \sum_t \sum_v CO_2^t D_{jr} I_{jrtv} + \\ & \sum_j \sum_u \sum_t \sum_v CO_2^t D_{ju} I_{jutv} + \sum_j \sum_k \sum_t \sum_v CO_2^t D_{jk} I_{jktv} + \sum_r \sum_u \sum_t \sum_v CO_2^t D_{ru} I_{rutv} + \sum_r \sum_k \sum_t \sum_v CO_2^t D_{rk} I_{rktv} + \\ & \sum_r \sum_l \sum_t \sum_v CO_2^t D_{rl} I_{rltv} + \sum_u \sum_k \sum_t \sum_v CO_2^t D_{uk} I_{uktv} + \sum_u \sum_l \sum_t \sum_v CO_2^t D_{ul} I_{ultv} + \sum_k \sum_l \sum_t \sum_v CO_2^t D_{kl} I_{kltv} + \\ & \sum_l \sum_t \sum_v CO_2^t D_{lt} I_{ltv} + \sum_t \sum_m \sum_t \sum_v CO_2^t D_{lm} I_{lmtv} + \sum_m \sum_j \sum_t \sum_v \sum_p CO_2^t D_{mj} I_{mjtvvp} + \\ & \sum_m \sum_i \sum_t \sum_v \sum_p \sum_n CO_2^t D_{mi} I_{mitvvp} + \sum_m \sum_t \sum_v \sum_p \sum_n CO_2^t D_m I_{mtvvp}] \end{aligned}$$

### 2.2.3 Objective Function:

Min [ Transportation costs + CO<sub>2</sub> costs (b.2)]

### 2.3 Constraints:

#### 2.3.1 Capacity Constraints:

- $\sum_t \sum_i X_{sitvnp} \leq a_{svpn} ; \forall s, v, p, n$
- $\sum_t \sum_j Y_{ijtvp} \leq a_{ivp} ; \forall i, v, p$
- $\sum_r \sum_t Z_{jrvt} + \sum_u \sum_t W_{jutv} + \sum_k \sum_t V_{jktv} \leq e_{jv} ; \forall j, v$
- $\sum_u \sum_t S_{rutv} + \sum_l \sum_t A_{rltv} + \sum_k \sum_t H_{rktv} \leq e_{rv} ; \forall r, v$
- $\sum_k \sum_t B_{uktv} + \sum_l \sum_t R_{ultv} \leq e_{uv} ; \forall u, v$
- $\sum_m \sum_t G_{lmtv} + \sum_t F_{ltv} \leq e_{lv} ; \forall l, v$
- $\sum_i \sum_t L_{mitvnp} + \sum_t N_{mtvnp} \leq e_{mvpn} ; \forall m, v, p, n$
- $\sum_j \sum_t K_{mjtv} \leq e_{mvp} ; \forall m, v, p$

#### 2.3.2 Equilibrium Constraints:

- $\sum_s X_{sitvnp} = w_{pn} \sum_j Y_{ijtvp} ; \forall i, t, v, p, n$
- $\sum_i Y_{ijtvp} = w_{vp} [\sum_r Z_{jrvt} + \sum_u W_{jutv} + \sum_k V_{jktv} ; \forall j, t, v, p$
- $(1 - \alpha_{jrv}) \sum_j Z_{jrvt} = \sum_u S_{rutv} + \sum_k H_{rktv} ; \forall r, t, v$
- $\alpha_{jrv} \sum_j Z_{jrvt} = A_{rltv} ; \forall r, l, t, v$
- $(1 - \alpha_{ruv}) \sum_r S_{rutv} + (1 - \alpha_{juv}) \sum_j W_{jutv} = \sum_k B_{uktv} ; \forall u, t, v$
- $\alpha_{ruv} \sum_r S_{rutv} + \alpha_{juv} \sum_j W_{jutv} = R_{ultv} ; \forall u, l, t, v$
- $(1 - \alpha_{ukv}) \sum_u B_{uktv} + (1 - \alpha_{jkv}) \sum_j V_{jktv} + (1 - \alpha_{rkv}) \sum_r H_{rktv} \geq e_{kv} ; \forall k, v$
- $e_{kv} w_{klv} = E_{kltv} ; \forall k, l, t, v$
- $w_{lmv} [\sum_r A_{rltv} + \sum_u R_{ultv} + \sum_k E_{kltv}] = \sum_m G_{lmtv} ; \forall l, t, v$
- $(1 - w_{lmv}) [\sum_r A_{rltv} + \sum_u R_{ultv} + \sum_k E_{kltv}] = F_{ltv} ; \forall l, t, v$
- $w_{mjvp} w_{vp} \sum_l G_{lmtv} = \sum_j K_{mjtv} ; \forall m, t, v, p$
- $w_{mivpn} w_{vpn} \sum_l G_{lmtv} = \sum_i L_{mitvnp} ; \forall m, t, v, p, n$
- $(1 - w_{mivpn} w_{vpn} - w_{jvp} w_{vp}) \sum_l G_{lmtv} = N_{mtvnp} ; \forall m, t, v, p, n$

#### 2.3.3 Transportation Constraints:

- $X_{sitvnp} - MI_{sitvnp} \leq 0$
- $X_{sitvnp} - MI_{sitvnp} \geq 1 - M$
- $Y_{ijtvp} - MI_{ijtvp} \leq 0$
- $Y_{ijtvp} - MI_{ijtvp} \geq 1 - M$
- $Z_{jrvt} - MI_{jrvt} \leq 0$
- $Z_{jrvt} - MI_{jrvt} \geq 1 - M$
- $W_{jutv} - MI_{jutv} \leq 0$
- $W_{jutv} - MI_{jutv} \geq 1 - M$
- $V_{jktv} - MI_{jktv} \leq 0$
- $V_{jktv} - MI_{jktv} \geq 1 - M$
- $S_{rutv} - MI_{rutv} \leq 0$
- $S_{rutv} - MI_{rutv} \geq 1 - M$
- $H_{rktv} - MI_{rktv} \leq 0$
- $H_{rktv} - MI_{rktv} \geq 1 - M$
- $A_{rltv} - MI_{rltv} \leq 0$
- $A_{rltv} - MI_{rltv} \geq 1 - M$
- $B_{uktv} - MI_{uktv} \leq 0$
- $B_{uktv} - MI_{uktv} \geq 1 - M$

- $R_{ultv} - MI_{ultv} \leq 0$
- $R_{ultv} - MI_{ultv} \geq 1 - M$
- $E_{kltv} - MI_{kltv} \leq 0$
- $E_{kltv} - MI_{kltv} \geq 1 - M$
- $F_{ltv} - MI_{ltv} \leq 0$
- $F_{ltv} - MI_{ltv} \geq 1 - M$
- $G_{lmtv} - MI_{lmtv} \leq 0$
- $G_{lmtv} - MI_{lmtv} \geq 1 - M$
- $K_{mjtv} - MI_{mjtv} \leq 0$
- $K_{mjtv} - MI_{mjtv} \geq 1 - M$
- $L_{mitv} - MI_{mitv} \leq 0$
- $L_{mitv} - MI_{mitv} \geq 1 - M$
- $N_{mtv} - MI_{mtv} \leq 0$
- $N_{mtv} - MI_{mtv} \geq 1 - M$

### 2.3.4 Notation Constraints:

- $I_{sitv}, I_{ijtv}, I_{jrtv}, I_{jutv}, I_{jktv}, I_{rutv}, I_{rktv}, I_{rltv}, I_{uktv}, I_{ultv}, I_{kltv}, I_{ltv}, I_{lmtv}, I_{mjtv}, I_{mitv}, I_{mtv} = \{0, 1\}$
- $X_{sitv}, Y_{ijtv}, Z_{jrtv}, W_{jutv}, V_{jktv}, S_{rutv}, H_{rktv}, A_{rltv}, B_{uktv}, R_{ultv}, E_{kltv}, F_{ltv}, G_{lmtv}, K_{mjtv}, L, N_{mtv} \geq 0$

### 3. Conclusion

A supply chain is the network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services delivered to the ultimate consumer (Christopher 1992). In other words, a supply chain consists of multiple firms, both upstream (i.e., supply) and downstream (i.e., distribution), and the ultimate consumer.

In this study, environmental friendly and flexible closed loop supply chain network is considered. In this scope, first of all, after referring to the concepts of supply chain, closed loop, and reverse supply chain, the subject will be scrutinized in more detail via modeling. Optimality of this proposed model can be tested in future studies and the model can be developed in accordance with the structure of the modern supply chain.

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