

## **Chapter 3 System Architecture**

In this chapter, an integrated logistics model (ILM) will be formulated to optimize the trade-off between the business logistics system (BLS) and the reverse logistics system (RLS). First, the integrated logistics system (ILS) proposed in this thesis presents the configuration of the channels in IT industry. Second, the ILS will be analyzed the relationships among members, their functions, and their activities in section 3.2. Finally, those activities and cash flows will be translated into algebra, and the notation applied in this study will be introduced briefly in section 3.3.

### **3.1 Formation of the Integrated Logistics System**

In order to formulate the integrated logistics model (ILM), an integrated logistics system (ILS) must be developed. After reviewing the literatures about the business logistics and the reverse logistics, an ILS for IT industry is proposed and showed as Figure 3.1-1. There are eleven members in it, they include raw material suppliers, manufactures, wholesalers, retailers, end-customers, collecting points, recycle plants, disassembly plants, landfills/incinerators, secondary material market and the RMF (Recycling Management Fund of the Environmental Protection Administration).

### **3.2 System Analysis**

The system analysis about the integrated logistics system (ILS) for IT industry will be separated into two parts. It will discuss about the functions and activities in each member in section 3.2.1 and how cash flows in section 3.2.2, respectively.



### **3.2.1 Functions and Activities**

There are some specific functions in each member (except RMF) and some specific activities in each function, so the work about analyzing those functions and activities must be taken. The functions studied in this study include manufacture, added value, procurement, inventory, transportation, and treatment. Then, those functions and activities in the ILS will be analyzed and explained as follows.

1. Raw material suppliers have functions and activities as follows:

(1) Manufacture:

- a. Manufacture raw materials.

(2) Procurement:

- a. Procure virgin materials.

(3) Inventory:

- a. Stock virgin materials.
- b. Stock raw materials.

(4) Transportation:

- a. Transport raw materials to manufactures.

2. Manufactures have functions and activities as follows:

(1) Manufacture:

- a. Manufacture demanded products.

(2) Added value:

- a. Demanded products are added value by manufactures.

(3) Procurement:

- a. Procure raw materials from raw material suppliers.
- b. Procure reused raw materials from secondary material market.

(4) Inventory:

- a. Stock raw materials.
  - b. Stock demanded products.
- (5) Transportation:
  - a. Transport demanded products to wholesalers.
  - b. Transport demanded products to retailers.
  - c. Transport demanded products to end-customers.
- 3. Wholesalers have functions and activities as follows:
  - (1) Added value:
    - a. Demanded products are added value by wholesalers.
  - (2) Procurement:
    - a. Procure demanded products from manufactures.
  - (3) Inventory:
    - a. Stock demanded products.
  - (4) Transportation:
    - a. Transport demanded products to retailers.
    - b. Transport demanded products to end-customers.
- 4. Retailers have functions and activities as follows:
  - (1) Added value:
    - a. Demanded products are added value by retailers.
  - (2) Procurement:
    - a. Procure demanded products from manufactures.
    - b. Procure demanded products from wholesalers.
  - (3) Inventory:
    - a. Stock demanded products.
  - (4) Transportation:
    - a. Transport demanded products to end-customers.

5. End-customers have functions and activities as follows:
  - (1) Procurement:
    - a. Procure demanded products from manufactures.
    - b. Procure demanded products from wholesalers.
    - c. Procure demanded products from retailers.
  - (2) Transportation:
    - a. Transport useless products to collecting points.
    - b. Transport useless products to recycle plants.
    - c. Transport useless products to disassembly plants.
6. Collecting points have functions and activities as follows:
  - (1) Procurement:
    - a. Procure useless products from end-customers.
  - (2) Inventory:
    - a. Stock useless products.
  - (3) Transportation:
    - a. Transport useless products to recycle plants.
    - b. Transport useless products to disassembly plants.
7. Recycle plants have functions and activities as follows:
  - (1) Procurement:
    - a. Procure useless products from end-customers.
    - b. Procure useless products from collecting points.
  - (2) Inventory:
    - a. Stock useless products.
  - (3) Transportation:
    - a. Transport useless products to disassembly plants.
8. Disassembly plants have functions and activities as follows:

(1) Procurement:

- a. Procure useless products from end-customers.
- b. Procure useless products from collecting points.
- c. Procure useless products from recycle points.

(2) Inventory:

- a. Stock useless products.
- b. Stock reusable materials.
- c. Stock derivative waste.

(3) Transportation:

- a. Transport reusable materials to secondary material market.
- b. Transport derivative waste to landfills or incinerators.

(4) Treatment:

- a. Treat useless products.

9. Secondary material market have functions and activities as follows:

(1) Manufacture:

- a. Manufacture reused raw materials.

(2) Procurement:

- a. Procure reusable materials from disassembly points.

(3) Inventory:

- a. Stock reusable materials.
- b. Stock reused raw materials.

(4) Transportation:

- a. Transport reused raw materials to manufacturers.

10. Landfills/ Incinerators have functions and activities as follows:

(1) Inventory:

- a. Stock derivative waste.

(2) Treatment:

a. Treat derivative waste.

To give a perspective view of functions and activities in each member, a table about functions and activities will be set and showed as Table 3.2-1. If there is the function in the member, it will be checked in the box. Besides, the number of checks (✓) will depend on how many different activities in the function. Table 3.2-1 can't display what kinds of activities, but there are aforementioned descriptions which relevant to those activities in this section.

Table 3.2-1 Functions and Activities in Each Member

Members	Functions					
	Manufacture	Added value	Procurement	Inventory	Transportation	Treatment
Raw material suppliers	✓		✓	✓✓	✓	
Manufacturers	✓	✓	✓✓	✓✓	✓✓✓	
Wholesalers		✓	✓	✓	✓✓	
Retailers		✓	✓	✓	✓	
End-Customers			✓✓✓		✓✓✓	
Collecting points			✓	✓	✓✓	
Recycle plants			✓✓	✓	✓	
Disassembly plants			✓✓✓	✓✓✓	✓✓	✓
Secondary material market	✓		✓	✓✓	✓	
Landfills / Incinerators				✓		✓

### 3.2.2 Cash Flows

As showed in Figure 3.1-1, there are some cash flows among members. There are three kinds of cash flows, including recycle fee, revenue, and subsidy, in this study. Then, the cash flows in the ILS will be analyzed and explained as follows. By the way, although the cash flows in the RMF are described, they are not considered in the ILM. In other words, the RMF will be taken as an external variable.

1. Raw material suppliers get revenue from manufacturers, when they sell raw materials to manufacturers.
2. Manufactures get revenue from wholesalers, retailers, and end-customers, respectively, when they sell demanded products to wholesalers, retailers, and end-customers. Besides, manufactures have to pay recycling-and-treatment fees (recycle fees), depending on the quantities of demand products manufactured by them, to the RMF.
3. Wholesalers get revenue from retailers and end-customers, respectively, when they sell demanded products to retailers and end-customers.
4. Retailers get revenue from end-customers, when they sell demanded products to end-customers.
5. End-customers get revenue from collecting points, recycle plants, and disassembly plants, respectively, when they sell useless products to collecting points, recycle plants, and disassembly plants.
6. Collecting points get revenue from recycle plants and disassembly plants, respectively, when they sell useless products to recycle plants and disassembly plants.
7. Recycle plants get revenue from disassembly plants, when they sell useless products to disassembly plants.



8. Disassembly plants get subsidy from the RMF, when they have treated useless products. Besides, disassembly plants get revenue from secondary material market, when they sell reusable materials to secondary material market.
9. Secondary material market get revenue from manufacturers, when they sell reused raw materials to manufacturers.
10. The RMF gets recycle fee from manufacturers and give subsidy to disassembly plants.

Table 3.2-2 Cash Flows in Each Member

Members	Cash Flows		
	Recycle Fee	Revenue	Subsidy
Raw material suppliers		✓	
Manufacturers	✓	✓✓✓	
Wholesalers		✓✓	
Retailers		✓	
End-Customers		✓✓✓	
Collecting points		✓✓	
Recycle plants		✓	
Disassembly plants		✓	✓
Secondary material market		✓	
RMF	✓		✓

Similarly, it will be also set a table to give a perspective view of cash flows among members. In Table 3.2-2, the number of checks (✓) will depend on how many different cash flows in each member. As the previous section, the detail content of

cash flows can't be recognized in the table but in the aforementioned descriptions.

### 3.3 Specification of State Variables

In this section, the main notions used in this study will be introduced. First, in order to make clear state variables and system functions, subscripts and sets will be described in section 3.3.1. Then, state variables will be defined in section 3.3.2.

#### 3.3.1 Subscripts and Sets

All subscripts and sets used in this study are showed, respectively, in Table 3.3-1 and Table 3.3-2. They enumerate the physical definition of each subscript and set as follows.

Table 3.3-1 Definitions of Subscripts

Subscripts	Definitions
<i>rms</i>	Representation for raw material suppliers
<i>m</i>	Representation for manufacturers
<i>ws</i>	Representation for wholesalers
<i>r</i>	Representation for retailers
<i>ec</i>	Representation for end-customers
<i>cp</i>	Representation for collecting points
<i>rp</i>	Representation for recycle plants
<i>dp</i>	Representation for disassembly plants
<i>smm</i>	Representation for secondary material market
<i>li</i>	Representation for landfills/ incinerators
<i>vm</i>	Representation for virgin materials
<i>vm – I</i>	Representation for virgin materials to be stocked
<i>vm – P</i>	Representation for virgin materials to be procured
<i>vm – E</i>	Representation for virgin materials to be exhausted
<i>rm</i>	Representation for raw materials
<i>rm – M</i>	Representation for raw materials to be manufactured
<i>rm – I</i>	Representation for raw materials to be stocked
<i>rm – P</i>	Representation for raw materials to be procured
<i>rm – E</i>	Representation for raw materials to be exhausted

<i>rm – m</i>	Representation for raw materials to manufacturers
<i>p</i>	Representation for demanded products
<i>p – M</i>	Representation for demanded products to be manufactured
<i>p – AV</i>	Representation for demanded products to be added value
<i>p – P</i>	Representation for demanded products to be procured
<i>p – I</i>	Representation for demanded products to be stocked
<i>p – ws</i>	Representation for demanded products to wholesalers
<i>p – r</i>	Representation for demanded products to retailers
<i>p – ec</i>	Representation for demanded products to end-customers
<i>up</i>	Representation for useless products
<i>up – I</i>	Representation for useless products to be stocked
<i>up – TR</i>	Representation for useless products to be treated
<i>up – P</i>	Representation for useless products to be procured
<i>up – cp</i>	Representation for useless products to collecting points
<i>up – rp</i>	Representation for useless products to recycle plants
<i>up – dp</i>	Representation for useless products to disassembly plants
<i>dw</i>	Representation for derivative waste
<i>dw – I</i>	Representation for derivative waste to be stocked
<i>dw – TR</i>	Representation for derivative waste to be treated
<i>dw – D</i>	Representation for derivative waste to be derived
<i>dw – li</i>	Representation for derivative waste to landfills/ incinerators
<i>rbm</i>	Representation for reusable materials
<i>rbm – I</i>	Representation for reusable materials to be stocked
<i>rbm – P</i>	Representation for reusable materials to be procured
<i>rbm – M</i>	Representation for reusable materials to be manufactured
<i>rbm – E</i>	Representation for reusable materials to be exhausted
<i>rbm – smm</i>	Representation for reusable materials to secondary material market
<i>rrm</i>	Representation for reused raw materials
<i>rrm – M</i>	Representation for reused raw materials to be manufactured
<i>rrm – P</i>	Representation for reused raw materials to be procured
<i>rrm – I</i>	Representation for reused raw materials to be stocked
<i>rrm – m</i>	Representation for reused raw materials to manufacturers
<i>bl</i>	Representation for the business logistics system
<i>rl</i>	Representation for the reverse logistics system
<i>bl – rl</i>	Representation for the integration of the business logistics system and the reverse logistics system

Table 3.3-2 Definitions of Sets and Subsets

Sets	Definitions	Subsets	Definitions
$I$	A set denoting the members or layers in the integrated logistics system (Expect RMF)	$i$	Member or layer
$K$	A set denoting the time intervals	$k$	Time interval
$J_4$	A set denoting the raw material suppliers in layer 4	$j_4$	Raw material supplier in layer 4
$J_3$	A set denoting the manufacturers in layer 3	$j_3$	Manufacturer in layer 3
$J_2$	A set denoting the wholesalers in layer 2	$j_2$	Wholesaler in layer 2
$J_1$	A set denoting the retailers in layer 1	$j_1$	Retailer in layer 1
$J_0$	A set denoting the end-customers in layer 0	$j_0$	End-customer in layer 0
$J_{-1}$	A set denoting the collecting points in layer -1	$j_{-1}$	Collecting point in layer -1
$J_{-2}$	A set denoting the recycle plants in layer -2	$j_{-2}$	Recycle plant in layer -2
$J_{-3}$	A set denoting the disassembly plants in layer -3	$j_{-3}$	Disassembly plant in layer -3
$J_{-4}$	A set denoting the secondary material market in layer -4	$j_{-4}$	Secondary material market in layer -4
$J_{-5}$	A set denoting the landfills/incinerators in layer -5	$j_{-5}$	Landfills/incinerators in layer -5

### 3.3.2 State Variables

First, all of variables and state variables used in this study are showed, respectively, in Table 3.3-3 and Table 3.3-4. They enumerate the physical definition of variables and state variables as follows.

Table 3.3-3 Definitions of Variables

Variables	Definitions
$M$	The unit cost of manufacture
$AV$	The unit cost of added value
$P$	The unit cost of procurement
$I$	The unit cost of inventory
$T$	The unit cost of transportation
$TR$	The unit cost of treatment
$RF$	The unit recycle fee of manufacturing products
$R$	The unit revenue of selling products
$S$	The unit subsidy of treating products
$Q$	The quantity of products

Table 3.3-4 Definitions of State Variables

State Variables	Definitions
$M_{products}^{j_i}(k)$	The unit cost of manufacturing products in time interval k in $j^{th}$ member in layer i
$M_{rm}^{j_4}(k)$	The unit cost of manufacturing raw materials in time interval k in $j^{th}$ raw material supplier in layer 4
$M_p^{j_3}(k)$	The unit cost of manufacturing demanded products in time interval k in $j^{th}$ manufacturer in layer 3
$M_{rm}^{j_4}(k)$	The unit cost of manufacturing reused raw materials in time interval k in $j^{th}$ secondary material market in layer -4
$AV_p^{j_i}(k)$	The unit cost of adding value to demanded products in time interval k in $j^{th}$ member in layer i
$AV_p^{j_3}(k)$	The unit cost of adding value to demanded products in time interval k in $j^{th}$ manufacturer in layer 3
$AV_p^{j_2}(k)$	The unit cost of adding value to demanded products in time interval k in $j^{th}$ wholesaler in layer 2
$AV_p^{j_1}(k)$	The unit cost of adding value to demanded products in time interval k in $j^{th}$ retailer in layer 1
$P_{products}^{j_i}(k)$	The unit cost of procuring products in time interval k in $j^{th}$ member in layer i
$P_{vm}^{j_4}(k)$	The unit cost of procuring virgin materials in time interval k in $j^{th}$ raw material supplier in layer 4
$P_{rm}^{j_3}(k)$	The unit cost of procuring raw materials in time interval k in $j^{th}$ manufacturer in layer 3

$P_{rm}^{j_3}(k)$	The unit cost of procuring reused raw materials in time interval k in $j^{\text{th}}$ manufacturer in layer 3
$P_p^{j_2}(k)$	The unit cost of procuring demanded products in time interval k in $j^{\text{th}}$ wholesaler in layer 2
$P_p^{j_1}(k)$	The unit cost of procuring demanded products in time interval k in $j^{\text{th}}$ retailer in layer 1
$P_p^{j_0}(k)$	The unit cost of procuring demanded products in time interval k in $j^{\text{th}}$ end-customer in layer 0
$P_{up}^{j_{-1}}(k)$	The unit cost of procuring useless products in time interval k in $j^{\text{th}}$ collecting point in layer -1
$P_{up}^{j_{-2}}(k)$	The unit cost of procuring useless products in time interval k in $j^{\text{th}}$ recycle plant in layer -2
$P_{up}^{j_{-3}}(k)$	The unit cost of procuring useless products in time interval k in $j^{\text{th}}$ disassembly plant in layer -3
$P_{rbm}^{j_{-4}}(k)$	The unit cost of procuring reusable materials in time interval k in $j^{\text{th}}$ secondary material market plant in layer -4
$I_{products}^{j_i}(k)$	The unit cost of stocking products in time interval k in $j^{\text{th}}$ member in layer i
$I_{vm}^{j_4}(k)$	The unit cost of stocking virgin materials in time interval k in $j^{\text{th}}$ raw material supplier in layer 4
$I_{rm}^{j_4}(k)$	The unit cost of stocking raw materials in time interval k in $j^{\text{th}}$ raw material supplier in layer 4
$I_{rm}^{j_3}(k)$	The unit cost of stocking raw materials in time interval k in $j^{\text{th}}$ manufacturer in layer 3
$I_p^{j_3}(k)$	The unit cost of stocking demanded products in time interval k in $j^{\text{th}}$ manufacturer in layer 3
$I_p^{j_2}(k)$	The unit cost of stocking demanded products in time interval k in $j^{\text{th}}$ wholesaler in layer 2
$I_p^{j_1}(k)$	The unit cost of stocking demanded products in time interval k in $j^{\text{th}}$ retailer in layer 1
$I_{up}^{j_{-1}}(k)$	The unit cost of stocking useless products in time interval k in $j^{\text{th}}$ collecting point in layer -1
$I_{up}^{j_{-2}}(k)$	The unit cost of stocking useless products in time interval k in $j^{\text{th}}$ recycle plant in layer -2
$I_{up}^{j_{-3}}(k)$	The unit cost of stocking useless products in time interval k in $j^{\text{th}}$ disassembly plant in layer -3
$I_{rbm}^{j_{-3}}(k)$	The unit cost of stocking reusable materials in time interval k in $j^{\text{th}}$ disassembly plant in layer -3

$I_{dw}^{j-3}(k)$	The unit cost of stocking derivative waste in time interval k in $j^{\text{th}}$ disassembly plant in layer -3
$I_{rbm}^{j-4}(k)$	The unit cost of stocking reusable materials in time interval k in $j^{\text{th}}$ secondary material market in layer -4
$I_{rrm}^{j-4}(k)$	The unit cost of stocking reused raw materials in time interval k in $j^{\text{th}}$ secondary material market in layer -4
$I_{dw}^{j-5}(k)$	The unit cost of stocking derivative waste in time interval k in $j^{\text{th}}$ landfill/ incinerator in layer -4
$TR_{products}^{j_i}(k)$	The unit cost of treating products in time interval k in $j^{\text{th}}$ member in layer i
$TR_{up}^{j-3}(k)$	The unit cost of treating useless products in time interval k in $j^{\text{th}}$ disassembly plant in layer -3
$TR_{dw}^{j-5}(k)$	The unit cost of treating derivative waste in time interval k in $j^{\text{th}}$ landfill/ incinerator in layer -5
$T_{products-members}^{j_i}(k)$	The unit cost of transporting products to members in time interval k in $j^{\text{th}}$ member in layer i
$T_{rm-m}^{j_4}(k)$	The unit cost of transporting raw materials to manufacturers in time interval k in $j^{\text{th}}$ raw material supplier in layer 4
$T_{p-ws}^{j_3}(k)$	The unit cost of transporting demanded products to wholesalers in time interval k in $j^{\text{th}}$ manufacturer in layer 3
$T_{p-r}^{j_3}(k)$	The unit cost of transporting demanded products to retailers in time interval k in $j^{\text{th}}$ manufacturer in layer 3
$T_{p-ec}^{j_3}(k)$	The unit cost of transporting demanded products to end-customers in time interval k in $j^{\text{th}}$ manufacturer in layer 3
$T_{p-r}^{j_2}(k)$	The unit cost of transporting demanded products to retailers in time interval k in $j^{\text{th}}$ wholesaler in layer 2
$T_{p-ec}^{j_2}(k)$	The unit cost of transporting demanded products to end-customers in time interval k in $j^{\text{th}}$ wholesaler in layer 2
$T_{p-ec}^{j_1}(k)$	The unit cost of transporting demanded products to end-customers in time interval k in $j^{\text{th}}$ retailer in layer 1
$T_{up-cp}^{j_0}(k)$	The unit cost of transporting useless products to collecting points in time interval k in $j^{\text{th}}$ end-customer in layer 0
$T_{up-rp}^{j_0}(k)$	The unit cost of transporting useless products to recycle plants in time interval k in $j^{\text{th}}$ end-customer in layer 0
$T_{up-dp}^{j_0}(k)$	The unit cost of transporting useless products to disassembly plants in time interval k in $j^{\text{th}}$ end-customer in layer 0
$T_{up-rp}^{j-1}(k)$	The unit cost of transporting useless products to recycle plants in time interval k in $j^{\text{th}}$ collecting point in layer -1

$T_{up-dp}^{j-1}(k)$	The unit cost of transporting useless products to disassembly plants in time interval $k$ in $j^{th}$ collecting point in layer -1
$T_{up-dp}^{j-2}(k)$	The unit cost of transporting useless products to disassembly plants in time interval $k$ in $j^{th}$ recycle plant in layer -2
$T_{rbm-smm}^{j-3}(k)$	The unit cost of transporting reusable materials to secondary material market in time interval $k$ in $j^{th}$ disassembly plant in layer -3
$T_{dw-li}^{j-3}(k)$	The unit cost of transporting derivative waste to landfills/ incinerators in time interval $k$ in $j^{th}$ disassembly plant in layer -3
$T_{rrm-m}^{j-4}(k)$	The unit cost of transporting reused raw materials to manufacturers in time interval $k$ in $j^{th}$ secondary material market in layer -4
$RF^{j_3}(k)$	The unit recycle fee of manufacturing demanded products in time interval $k$ in $j^{th}$ manufacturer in layer 3
$R_{products-members}^{j_i}(k)$	The unit revenue of selling products to members in time interval $k$ in $j^{th}$ member in layer $i$
$R_{rm-m}^{j_4}(k)$	The unit revenue of selling raw materials to manufacturers in time interval $k$ in $j^{th}$ raw material supplier in layer 4
$R_{p-ws}^{j_3}(k)$	The unit revenue of selling demanded products to wholesalers in time interval $k$ in $j^{th}$ manufacturer in layer 3
$R_{p-r}^{j_3}(k)$	The unit revenue of selling demanded products to retailers in time interval $k$ in $j^{th}$ manufacturer in layer 3
$R_{p-ec}^{j_3}(k)$	The unit revenue of selling demanded products to end-customers in time interval $k$ in $j^{th}$ manufacturer in layer 3
$R_{p-r}^{j_2}(k)$	The unit revenue of selling demanded products to retailers in time interval $k$ in $j^{th}$ wholesaler in layer 2
$R_{p-ec}^{j_2}(k)$	The unit revenue of selling demanded products to end-customers in time interval $k$ in $j^{th}$ wholesaler in layer 2
$R_{p-ec}^{j_1}(k)$	The unit revenue of selling demanded products to end-customers in time interval $k$ in $j^{th}$ retailer in layer 1
$R_{up-cp}^{j_0}(k)$	The unit revenue of selling useless products to collecting points in time interval $k$ in $j^{th}$ end-customer in layer 0
$R_{up-rp}^{j_0}(k)$	The unit revenue of selling useless products to recycle plants in time interval $k$ in $j^{th}$ end-customer in layer 0
$R_{up-dp}^{j_0}(k)$	The unit revenue of selling useless products to disassembly plants in time interval $k$ in $j^{th}$ end-customer in layer 0
$R_{up-rp}^{j-1}(k)$	The unit revenue of selling useless products to recycle plants in time interval $k$ in $j^{th}$ collecting point in layer -1
$R_{up-dp}^{j-1}(k)$	The unit revenue of selling useless products to disassembly plants in time interval $k$ in $j^{th}$ collecting point in layer -1



$R_{up-dp}^{j-2}(k)$	The unit revenue of selling useless products to disassembly plants in time interval k in $j^{th}$ recycle plant in layer -2
$R_{rbm-smm}^{j-3}(k)$	The unit revenue of selling reusable materials to secondary material market in time interval k in $j^{th}$ disassembly plant in layer -3
$R_{rrm-m}^{j-4}(k)$	The unit revenue of selling reused raw materials to manufacturers in time interval k in $j^{th}$ secondary material market in layer -4
$S^{j-3}(k)$	The unit subsidy of treating useless products in time interval k in $j^{th}$ disassembly plant in layer -3
$Q_{products-Activity}^{j_i}(k)$	The quantity of products to be done some activity in time interval k in $j^{th}$ member in layer i
$Q_{rm-M}^{j_4}(k)$	The quantity of raw materials manufactured in time interval k in $j^{th}$ raw material supplier in layer 4
$Q_{p-M}^{j_3}(k)$	The quantity of demanded products manufactured in time interval k in $j^{th}$ manufacturer in layer 3
$Q_{rrm-M}^{j-4}(k)$	The quantity of reused raw materials manufactured in time interval k in $j^{th}$ secondary material market in layer -4
$Q_{rbm-M}^{j-3}(k)$	The quantity of reusable materials manufactured in time interval k in $j^{th}$ disassembly plant in layer -3
$Q_{p-AV}^{j_3}(k)$	The quantity of demanded products added value in time interval k in $j^{th}$ manufacturer in layer 3
$Q_{p-AV}^{j_2}(k)$	The quantity of demanded products added value in time interval k in $j^{th}$ wholesaler in layer 2
$Q_{p-AV}^{j_1}(k)$	The quantity of demanded products added value in time interval k in $j^{th}$ retailer in layer 1
$Q_{vm-P}^{j_4}(k)$	The quantity of virgin materials procured in time interval k in $j^{th}$ raw material supplier in layer 4
$Q_{rm-P}^{j_3}(k)$	The quantity of raw materials procured in time interval k in $j^{th}$ manufacturer in layer 3
$Q_{rrm-P}^{j_3}(k)$	The quantity of reused raw materials procured in time interval k in $j^{th}$ manufacturer in layer 3
$Q_{p-P}^{j_2}(k)$	The quantity of demanded products procured in time interval k in $j^{th}$ wholesaler in layer 2
$Q_{p-P}^{j_1}(k)$	The quantity of demanded products procured in time interval k in $j^{th}$ retailer in layer 1
$Q_{p-P}^{j_0}(k)$	The quantity of demanded products procured in time interval k in $j^{th}$ end-customer in layer 0
$Q_{up-P}^{j-1}(k)$	The quantity of useless products procured in time interval k in $j^{th}$ collecting point in layer -1

$Q_{up-P}^{j-2}(k)$	The quantity of useless products procured in time interval k in $j^{th}$ recycle plant in layer -2
$Q_{up-P}^{j-3}(k)$	The quantity of useless products procured in time interval k in $j^{th}$ disassembly plant in layer -3
$Q_{rbm-P}^{j-4}(k)$	The quantity of reusable materials procured in time interval k in $j^{th}$ secondary material market in layer -4
$Q_{vm-I}^{j_4}(k)$	The quantity of virgin materials stocked in time interval k in $j^{th}$ raw material supplier in layer 4
$Q_{rm-I}^{j_4}(k)$	The quantity of raw materials stocked in time interval k in $j^{th}$ raw material supplier in layer 4
$Q_{rm-I}^{j_3}(k)$	The quantity of raw materials stocked in time interval k in $j^{th}$ manufacturer in layer 3
$Q_{p-I}^{j_3}(k)$	The quantity of demanded products stocked in time interval k in $j^{th}$ manufacturer in layer 3
$Q_{p-I}^{j_2}(k)$	The quantity of demanded products stocked in time interval k in $j^{th}$ wholesaler in layer 2
$Q_{p-I}^{j_1}(k)$	The quantity of demanded products stocked in time interval k in $j^{th}$ retailer in layer 1
$Q_{up-I}^{j-1}(k)$	The quantity of useless products stocked in time interval k in $j^{th}$ collecting point in layer -1
$Q_{up-I}^{j-2}(k)$	The quantity of useless products stocked in time interval k in $j^{th}$ recycle plant in layer -2
$Q_{up-I}^{j-3}(k)$	The quantity of useless products stocked in time interval k in $j^{th}$ disassembly plant in layer -3
$Q_{rbm-I}^{j-3}(k)$	The quantity of reusable materials stocked in time interval k in $j^{th}$ disassembly plant in layer -3
$Q_{dw-I}^{j-3}(k)$	The quantity of derivative waste stocked in time interval k in $j^{th}$ disassembly plant in layer -3
$Q_{rbm-I}^{j-4}(k)$	The quantity of reusable materials stocked in time interval k in $j^{th}$ secondary material market in layer -4
$Q_{rrm-I}^{j-4}(k)$	The quantity of reused raw materials stocked in time interval k in $j^{th}$ secondary material market in layer -4
$Q_{dw-I}^{j-5}(k)$	The quantity of derivative waste stocked in time interval k in $j^{th}$ landfill/ incinerator in layer -5
$Q_{up-TR}^{j-3}(k)$	The quantity of useless products treated in time interval k in $j^{th}$ disassembly plant in layer -3
$Q_{dw-TR}^{j-5}(k)$	The quantity of derivative waste treated in time interval k in $j^{th}$ landfill/ incinerator in layer -5

$Q_{vm-E}^{j_4}(k)$	The quantity of virgin materials exhausted in time interval k in $j^{th}$ raw material supplier in layer 4
$Q_{rm-E}^{j_3}(k)$	The quantity of raw materials exhausted in time interval k in $j^{th}$ manufacturer in layer 3
$Q_{rbm-E}^{j_{-4}}(k)$	The quantity of reusable materials exhausted in time interval k in $j^{th}$ secondary material market in layer -4
$Q_{dw-D}^{j_{-2}}(k)$	The quantity of derivative waste derived in time interval k in $j^{th}$ recycle plant in layer -2
$Q_{dw-D}^{j_{-3}}(k)$	The quantity of derivative waste derived in time interval k in $j^{th}$ disassembly plant in layer -3
$Q_{products-members}^{j_i}(k)$	The quantity of products transported to members in time interval k in $j^{th}$ member in layer i
$Q_{rm-m}^{j_4}(k)$	The quantity of raw materials transported to manufacturers in time interval k in $j^{th}$ raw material supplier in layer 4
$Q_{p-ws}^{j_3}(k)$	The quantity of demanded products transported to wholesalers in time interval k in $j^{th}$ manufacturer in layer 3
$Q_{p-r}^{j_3}(k)$	The quantity of demanded products transported to retailers in time interval k in $j^{th}$ manufacturer in layer 3
$Q_{p-ec}^{j_3}(k)$	The quantity of demanded products transported to end-customers in time interval k in $j^{th}$ manufacturer in layer 3
$Q_{p-r}^{j_2}(k)$	The quantity of demanded products transported to retailers in time interval k in $j^{th}$ wholesaler in layer 2
$Q_{p-ec}^{j_2}(k)$	The quantity of demanded products transported to end-customers in time interval k in $j^{th}$ wholesaler in layer 2
$Q_{p-ec}^{j_1}(k)$	The quantity of demanded products transported to end-customers in time interval k in $j^{th}$ retailer in layer 1
$Q_{up-cp}^{j_0}(k)$	The quantity of useless products transported to collecting points in time interval k in $j^{th}$ end-customer in layer 0
$Q_{up-rp}^{j_0}(k)$	The quantity of useless products transported to recycle plants in time interval k in $j^{th}$ end-customer in layer 0
$Q_{up-dp}^{j_0}(k)$	The quantity of useless products transported to disassembly plants in time interval k in $j^{th}$ end-customer in layer 0
$Q_{up-rp}^{j_{-1}}(k)$	The quantity of useless products transported to recycle plants in time interval k in $j^{th}$ collecting point in layer -1
$Q_{up-dp}^{j_{-1}}(k)$	The quantity of useless products transported to disassembly plants in time interval k in $j^{th}$ collecting point in layer -1
$Q_{up-dp}^{j_{-2}}(k)$	The quantity of useless products transported to disassembly plants in time interval k in $j^{th}$ recycle plant in layer -2

$Q_{rbm-smm}^{j-3}(k)$	The quantity of reusable materials transported to secondary material market in time interval k in $j^{th}$ disassembly plant in layer -3
$Q_{dw-li}^{j-3}(k)$	The quantity of derivative waste transported to landfills/ incinerators in time interval k in $j^{th}$ disassembly plant in layer -3
$Q_{rrm-m}^{j-4}(k)$	The quantity of reused raw materials transported to manufacturers in time interval k in $j^{th}$ secondary material market in layer -4

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Since the ILM is used to meet the maximum profit, all the activities and cash flows in each member have to translate into cost or revenue. In other words, Table 3.3-5 and Table 3.3-6 will utilize algebraic way to represent Table 3.2-1 and Table 3.2-2, respectively.

Table 3.3-5 Represent Functions and Activities by Using Algebra

i	Members	Functions					
		Manufacture	Added value	Procurement	Inventory	Transportation	Treatment
4	Raw material suppliers	$M_{rm}^{j_4}(k)$ $\times Q_{rm-M}^{j_4}(k)$		$P_{vm}^{j_4}(k)$ $\times Q_{vm-P}^{j_4}(k)$	$I_{vm}^{j_4}(k)$ $\times Q_{vm-I}^{j_4}(k)$ ; $I_{rm}^{j_4}(k)$ $\times Q_{rm-I}^{j_4}(k)$	$T_{rm-m}^{j_4}(k)$ $\times Q_{rm-m}^{j_4}(k)$	

3	Manufacturers	$M_p^{j_3}(k)$ $\times Q_{p-M}^{j_3}(k)$	$AV_p^{j_3}(k)$ $\times Q_{p-AV}^{j_3}(k)$	$P_{rm}^{j_3}(k)$ $\times Q_{rm-p}^{j_3}(k)$ ; $P_{rrm}^{j_3}(k)$ $\times Q_{rrm-p}^{j_3}(k)$	$I_{rm}^{j_3}(k)$ $\times Q_{rm-l}^{j_3}(k)$ ; $I_p^{j_3}(k)$ $\times Q_{p-l}^{j_3}(k)$	$T_{p-ws}^{j_3}(k)$ $\times Q_{p-ws}^{j_3}(k)$ ; $T_{p-r}^{j_3}(k)$ $\times Q_{p-r}^{j_3}(k)$ ; $T_{p-ec}^{j_3}(k)$ $\times Q_{p-ec}^{j_3}(k)$	
2	Wholesalers		$AV_p^{j_2}(k)$ $\times Q_{p-AV}^{j_2}(k)$	$P_p^{j_2}(k)$ $\times Q_{p-p}^{j_2}(k)$	$I_p^{j_2}(k)$ $\times Q_{p-l}^{j_2}(k)$	$T_{p-r}^{j_2}(k)$ $\times Q_{p-r}^{j_2}(k)$ ; $T_{p-ec}^{j_2}(k)$ $\times Q_{p-ec}^{j_2}(k)$	
1	Retailers		$AV_p^{j_1}(k)$ $\times Q_{p-AV}^{j_1}(k)$	$P_p^{j_1}(k)$ $\times Q_{p-p}^{j_1}(k)$	$I_p^{j_1}(k)$ $\times Q_{p-l}^{j_1}(k)$	$T_{p-ec}^{j_1}(k)$ $\times Q_{p-ec}^{j_1}(k)$	
0	End-Customers			$P_p^{j_0}(k)$ $\times Q_{p-p}^{j_0}(k)$		$T_{up-cp}^{j_0}(k)$ $\times Q_{up-cp}^{j_0}(k)$ ; 	

						$T_{up-rp}^{j_0}(k) \quad ;$ $\times Q_{up-rp}^{j_0}(k) ;$ $T_{up-dp}^{j_0}(k)$ $\times Q_{up-dp}^{j_0}(k)$	
-1	Collecting points			$P_{up}^{j-1}(k)$ $\times Q_{up-p}^{j-1}(k)$	$I_{up}^{j-1}(k)$ $\times Q_{up-I}^{j-1}(k)$	$T_{up-rp}^{j-1}(k) \quad ;$ $\times Q_{up-rp}^{j-1}(k) ;$ $T_{up-dp}^{j-1}(k)$ $\times Q_{up-dp}^{j-1}(k)$	
-2	Recycle plants			$P_{up}^{j-2}(k)$ $\times Q_{up-p}^{j-2}(k)$	$I_{up}^{j-2}(k)$ $\times Q_{up-I}^{j-2}(k)$	$T_{up-dp}^{j-2}(k)$ $\times Q_{up-dp}^{j-2}(k)$	

-3	Disassembly plants			$P_{up}^{j-3}(k) \times Q_{up-p}^{j-3}(k)$	$\begin{aligned} &I_{up}^{j-3}(k) \times Q_{up-l}^{j-3}(k); \\ &I_{rbm}^{j-3}(k) \times Q_{rbm-l}^{j-3}(k); \\ &I_{dw}^{j-3}(k) \times Q_{dw-l}^{j-3}(k); \end{aligned}$	$\begin{aligned} &T_{rbm-smm}^{j-3}(k) \times Q_{rbm-smm}^{j-3}(k); \\ &T_{dw-li}^{j-3}(k) \times Q_{dw-li}^{j-3}(k) \end{aligned}$	$TR_{up}^{j-3}(k) \times Q_{up-TR}^{j-3}(k)$
-4	Secondary material market	$M_{rrm}^{j-4}(k) \times Q_{rrm-M}^{j-4}(k)$		$P_{rbm}^{j-4}(k) \times Q_{rbm-p}^{j-4}(k)$	$\begin{aligned} &I_{rbm}^{j-4}(k) \times Q_{rbm-l}^{j-4}(k); \\ &I_{rrm}^{j-4}(k) \times Q_{rrm-l}^{j-4}(k) \end{aligned}$	$T_{rrm-m}^{j-4}(k) \times Q_{rrm-m}^{j-4}(k)$	
-5	Landfills / Incinerators				$I_{dw}^{j-5}(k) \times Q_{dw-l}^{j-5}(k)$		$TR_{dw}^{j-5}(k) \times Q_{dw-TR}^{j-5}(k)$



Table 3.3-6 Represent Cash Flows by Using Algebra

i	Members	Cash Flows		
		Recycle Fee	Revenue	Subsidy
4	Raw material suppliers		$R_{rm-m}^{j_4}(k) \times Q_{rm-m}^{j_4}(k)$	
3	Manufacturers	$RF^{j_3}(k) \times Q_{p-M}^{j_3}(k)$	$R_{p-ws}^{j_3}(k) \times Q_{p-ws}^{j_3}(k) ;$ $R_{p-r}^{j_3}(k) \times Q_{p-r}^{j_3}(k) ;$ $R_{p-ec}^{j_3}(k) \times Q_{p-ec}^{j_3}(k)$	
2	Wholesalers		$R_{p-r}^{j_2}(k) \times Q_{p-r}^{j_2}(k) ;$ $R_{p-ec}^{j_2}(k) \times Q_{p-ec}^{j_2}(k)$	
1	Retailers		$R_{p-ec}^{j_1}(k) \times Q_{p-ec}^{j_1}(k)$	
0	End-Customers		$R_{up-cp}^{j_0}(k) \times Q_{up-cp}^{j_0}(k) ;$ $R_{up-rp}^{j_0}(k) \times Q_{up-rp}^{j_0}(k) ;$	

			$R_{up-dp}^{j_0}(k) \times Q_{up-dp}^{j_0}(k)$	
-1	Collecting points		$R_{up-rp}^{j_{-1}}(k) \times Q_{up-rp}^{j_{-1}}(k) ;$ $R_{up-dp}^{j_{-1}}(k) \times Q_{up-dp}^{j_{-1}}(k)$	
-2	Recycle plants		$R_{up-dp}^{j_{-2}}(k) \times Q_{up-dp}^{j_{-2}}(k)$	
-3	Disassembly plants		$R_{rbm-smm}^{j_{-3}}(k) \times Q_{rbm-smm}^{j_{-3}}(k)$	$S^{j_{-3}}(k) \times Q_{up-TR}^{j_{-3}}(k)$
-4	Secondary material market		$R_{rrm-m}^{j_{-4}}(k) \times Q_{rrm-m}^{j_{-4}}(k)$	

