# A Quantitative model of Reverse Logistics for Computer Waste Management in the South of Thailand

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**Abstract:** A fast obsolescence, rapid advanced technology and low initial cost of personal computer result in increasing the number of computer waste. The personal computer contains lead, tin and other heavy metals which can be released into the environment during disposal with potential adverse effects on human health. Currently, an appropriate management system for computer waste has been not proposed completely in Thailand. Consequently, this research constructs a reverse supply chain model to minimize total cost for a computer waste management system. There are five members involved in the system: raw materials, junk shops, collection sites, recycle factories and disposers. Total costs used in this study consists of transportation cost, operating cost, fixed cost for new facilities, final disposal cost and landfill cost. The results suggest that five collectors should be opened for collecting the computer waste. The total cost of the computer waste management system is about 61 million baht. Moreover, this study describes the behavior of the various decision-makers, such as the sources of electronic waste, the recyclers, the processors, as well as the consumers associated with the demand for the distinct products. Ultimately, the benefits in this research are to understand the reverse logistics system through the developed model for designing optimal managing system.

**Keywords:** Reverse Logistics, Computer Waste Management System, Linear Analytical Model

## 1. INTRODUCTION

Last two decades, the demand of computer has been rapidly growth because of the advance in technology which has caused the short of computer service life and low computer's price. Since the volume of computer waste is quickly increased, it would create severe environment problems due to the fact that the computer. This is because the computer elements contain various harmful chemical such as mercury, lead, copper, etc. These chemicals are seriously affecting to human health and damaging the environment. In fact, they can be reused, if an appropriate waste management system is operated. In addition, the cost of management of computer waste is relatively high. In Thailand, the computer waste management system is not effectiveness and the operating cost is quite high. Most computer waste systems are burning system and landfill system

From the problem statement, this research aims to fulfill a reverse logistic concept to an appropriate computer waste management system in the southern area of Thailand. A mixed integer linear programming (MILP) method is employed to solve a model which is representative to the system behaviors.

## 2. COMPUTER WASTE NETWORK

Reverse logistics is the process of moving goods from their typical final destination for the purpose of capturing value, or proper disposal. It consists of planning, implementing, and controlling the efficient cost, effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin. Reverse logistics can be applied on various system such as containers, recycling, packaging materials and redesigning packaging to use less material or reduce power consumption. In this study, the computer waste management network model for reverse supply chain management is developed as presented in Figure 1. The network consists of raw materials, junk shops, collection sites, recycle factories and disposer.

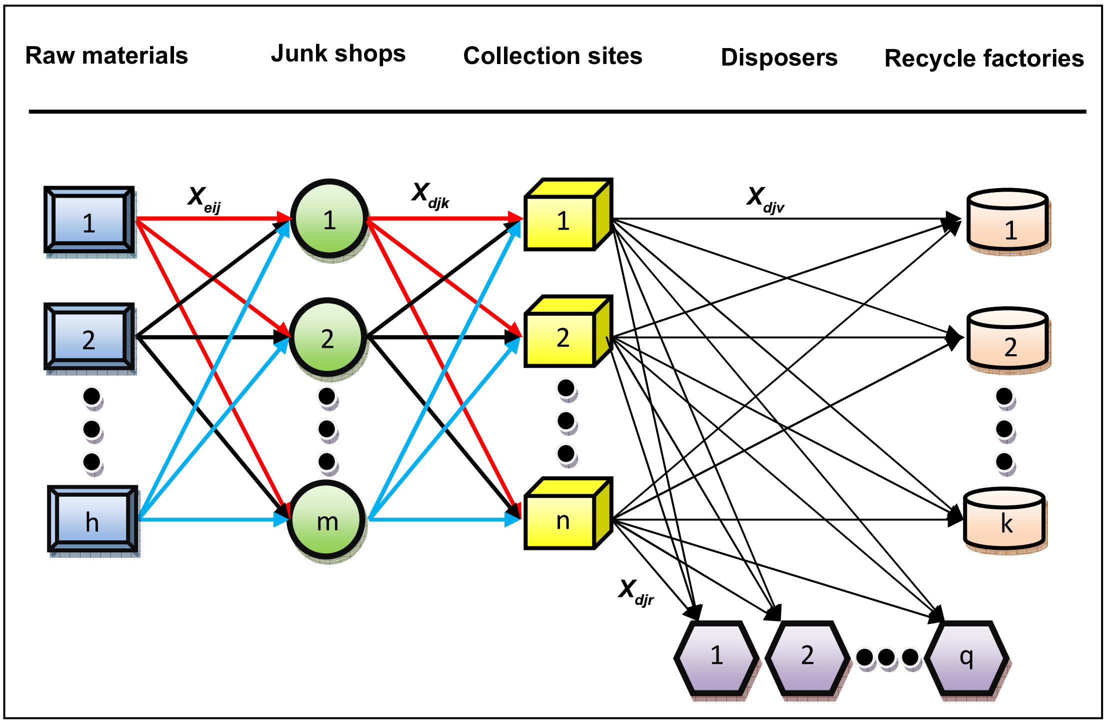


Figure 1: Computer waste Supply Chain Network

## 3. LITERATURE REVIEW

Several authors have studied product recovery system from many points of view. Jayaraman, Guide, and Srivastava (1999) and Hirsch et al. (2000) gave systematic overviews of the logistic network of reuse and recycling. Other research papers focused on the use of mathematical models in strategic level to allocate product recovery facilities in a reverse logistics system for different types of discarded products. Sharma et al. (2007), Jayaraman et al. (2001), Assavapokee et al. (2006), Shih (2000) as well as Pochampally and Gupta (2003) developed a three-phase mathematical programming approach to design a reverse logistics network. Phase one is to identify the most economical product from a set of used products. Then, potential facilities are identified in phase two from a set of candidate recovery facilities by using analytic hierarchy process. Phase three is to solve a mixed integer linear programming to obtain location of facilities and product flows across the established recovery network.

## 4 RESEARCH

The following section is represented each stage for developing the logistics network model for computer waste management system.

### 4.1 Model Input

In this step, the required data for logistics network modeling are collected. A typical network configuration problem involves large input data, including information as shown in the subsequent topics.

1. Location of raw materials, Junk shops, collection sites and recycle factories
2. Potential locations of collectors.
3. Transportation rates.
4. Operation cost per unit.
5. Inventory cost per unit.

Under these assumptions, the MILP is used to develop a reverse logistic model. The integer decisions in the model represent the existences of potential locations of collectors. The following verbal model represents the objective and constraints of the MILP model considered in the paper.

### 4.2 Model for Facility Location and Capacity Allocation

In this section, the mathematical model is formulated with the reverse logistics network design problem as a mixed integer linear programming (MILP) model. This model specifically captures the reverse logistics design problem at the strategic level. The objective of the model is to find the reverse logistics infrastructure setting that minimizes the total cost (transportation cost, operation cost and fixed cost for a new collector).

**OBJECTIVE FUNCTION:**

$$Min\left[\sum_{i=1}^{h}\sum_{j=1}^{m} c_{eij}x_{eij} + \sum_{j=1}^{m}\sum_{k=1}^{n} c_{djk}x_{djk} + \sum_{j=1}^{m}\sum_{r=1}^{q} c_{wjr}x_{wjr} + \sum_{k=1}^{n} F_k Y_k + \sum_{k=1}^{n}\sum_{v=1}^{o} c_{dkv}x_{dkv}\right]$$

(1)

**CONSTRAINTS:**

$$\sum_{j=1}^{m} x_{eij} \le S_i \qquad \text{for } i = 1,2,\ldots,h \qquad (2)$$

: The total amount shipped from raw material site cannot exceed the raw material site's capacity.

$$\sum_{i=1}^{h} x_{eij} * 0.41 - \sum_{k=1}^{n} x_{pjk} \ge 0 \qquad \text{for } j = 1,2,\ldots,m \qquad (3)$$

: The amount plastics shipped out of junk shops cannot exceed the quantity of raw material site received.

$$\sum_{i=1}^{h} x_{eij} * 0.07 - \sum_{k=1}^{n} x_{fjk} \geq 0 \qquad \text{for } j = 1,2,\ldots,m \qquad (4)$$

: The amount iron shipped out of junk shops cannot exceed the quantity of raw material site received.

$$\sum_{i=1}^{h} x_{eij} * 0.05 - \sum_{k=1}^{n} x_{ujk} \geq 0 \qquad \text{for } j = 1,2,\ldots,m \qquad (5)$$

: The amount copper shipped out of junk shops cannot exceed the quantity of raw material site received.

$$\sum_{i=1}^{h} x_{eij} * 0.33 - \sum_{k=1}^{n} x_{mjk} \geq 0 \qquad \text{for } j = 1,2,\ldots,m \qquad (6)$$

: The amount monitors shipped out of junk shops cannot exceed the quantity of raw material site received.

$$\sum_{i=1}^{h} x_{eij} * 0.14 - \sum_{r=1}^{p} x_{wjr} \geq 0 \qquad \text{for } j = 1,2,\ldots,m \qquad (7)$$

: The amount waste shipped out of junk shops cannot exceed the quantity of raw material site received.

$$\sum_{k=1}^{n} x_{pjk} + \sum_{k=1}^{n} x_{fjk} + \sum_{k=1}^{n} x_{cjk} + \sum_{k=1}^{n} x_{mjk} \leq C_k Y_k \qquad \text{for } j = 1,2,\ldots,m \qquad (8)$$

: The amount produced in the junk shops cannot exceed collection sites's capacity.

$$\sum_{k=1}^{n} x_{pjk} - \sum_{v=1}^{o} x_{pkv} \geq 0 \qquad \text{for } k = 1,2,\ldots, n \qquad (9)$$

: The amount plastics shipped out of collection sites cannot exceed the quantity of junk shops received.

$$\sum_{k=1}^{n} x_{fjk} - \sum_{v=1}^{o} x_{fkv} \geq 0 \qquad \text{for } k = 1,2,\ldots, n \qquad (10)$$

: The amount iron shipped out of collection sites cannot exceed the quantity of junk shops received.

$$\sum_{k=1}^{n} x_{ujk} - \sum_{v=1}^{o} x_{ukv} \geq 0 \qquad \text{for } k = 1,2,\ldots, n \qquad (11)$$

: The amount copper shipped out of collection sites cannot exceed the quantity of junk shops received.

$$\sum_{k=1}^{n} x_{mjk} - \sum_{v=1}^{o} x_{mkv} \geq 0 \qquad \text{for } k = 1,2,\ldots, n \qquad (12)$$

: The amount monitor shipped out of collection sites cannot exceed the quantity of junk shops received.

$$\sum_{r=1}^{q} x_{wjr} \leq K_r \qquad \text{for } r = 1,2,\ldots, q \qquad (13)$$

: The amount waste in the junk shops cannot exceed disposer's capacity.

$$\sum_{v=1}^{o} x_{pkv} \leq D_{pv} \qquad \text{for } v = 1,2,\ldots, o \qquad (14)$$

: The amount plastics shipped to customer must cover the demand.

$$\sum_{v=1}^{o} x_{fkv} \leq D_{fv} \qquad \text{for } v = 1,2,\ldots, o \qquad (15)$$

: The amount iron shipped to customer must cover the demand.

$$\sum_{v=1}^{o} x_{ukv} \leq D_{uv} \qquad \text{for } v = 1,2,\ldots, o \qquad (16)$$

: The amount copper shipped to customer must cover the demand.

$$\sum_{v=1}^{o} x_{mkv} \leq D_{mv} \qquad \text{for } v = 1,2,\ldots, o \qquad (17)$$

: The amount monitor shipped to customer must cover the demand.

$$\sum_{j=1}^{m} x_{eij} = \sum_{k=1}^{n} x_{djk} + \sum_{r=1}^{q} x_{wjr} \qquad (18)$$

$$\sum_{k=1}^{n} x_{djk} = \sum_{k=1}^{n} x_{pjk} + \sum_{k=1}^{n} x_{fjk} + \sum_{k=1}^{n} x_{ujk} + \sum_{k=1}^{n} x_{mjk} \qquad (19)$$

$$\sum_{v=1}^{o} x_{dkv} = \sum_{v=1}^{o} x_{pkv} + \sum_{v=1}^{o} x_{fkv} + \sum_{v=1}^{o} x_{ukv} + \sum_{v=1}^{o} x_{mkv} \qquad (20)$$

$$x_{eij}, x_{djk}, x_{wjr}, x_{dkv} \geq 0 \qquad (21)$$

$$Y_k \in \{0,1\} \qquad (22)$$

: 1 if there is a collection site opened at location k, 0 otherwise

Where

$h$ = number of raw material sites

$m$ = number of junk shops

$n$ = number of collection sites

$o$ = number of recycle factories

$p$ = number of disposers

$e$ = computers product

$p$ = plastics

$f$ = iron

$u$ = copper

$m$ = monitors

$w$ = waste products

$D_{pv}$ = demand of plastics from customer $i$

$D_{fv}$ = demand of Iron from customer $i$

$D_{uv}$ = demand of copper from customer $i$

$D_{mv}$ = demand of monitors from customer $i$

$C_k$ = capacity of collector $k$

$K_r$ = capacity of disposer $r$

$S_i$ = supply capacity of raw material site *i*

$F_k$ = fixed cost of locating collection sites at site *k*

$c_{eij}$ = cost of transportation and production per one unit from raw material site *i* to junk shops *j*

$c_{pjk}$ = Cost of transportation and production per one unit of plastic from junk shops *j* to collection sites *k*

$c_{fjk}$ = Cost of transportation and production per one unit of iron from junk shops *j* to collection sites *k*

$c_{ujk}$ = Cost of transportation and production per one unit of copper from junk shops *j* to collection sites *k*

$c_{wjr}$ = Cost of transportation and production per one unit of waste from junk shops *j* to disposer *r*

$c_{mjk}$ = Cost of transportation and production per one unit of monitor from junk shops *j* to collector *k*

$c_{pkv}$ = Cost of transportation and production per one unit of plastic from collection sites *k* to recycle factory *v*

$c_{fkv}$ = Cost of transportation and production per one unit of iron from collection sites *k* to recycle factory *v*

$c_{ukv}$ = Cost of transportation and production per one unit of copper from collection sites *k* to recycle factory *v*

$c_{mkv}$ = Cost of transportation and production per one unit of monitor from collection sites *k* to recycle factory *v*

$c_{djk}$ = Cost of transportation and production per one unit from junk shops *j* to collection sites *k*

$x_{eij}$ = The amount of computers products from raw material site *i* to junk shops *j*

$x_{pjk}$ = The amount of plastics from junk shops *j* to collection sites *k*

$x_{fjk}$ = The amount of iron from junk shops *j* to collection sites *k*

$x_{ujk}$ = The amount of copper from junk shops *j* to collection sites *k*

$x_{mjk}$ = The amount of monitors from junk shops *j* to collection sites *k*

$x_{wjr}$ = The amount of waste products from junk shops *j* to disposer *r*

$x_{pkv}$ = The amount of plastics from collection sites *k* to recycle factory *v*

$x_{fkv}$ = The amount of iron from collection sites *k* to recycle factory *v*

$x_{ukv}$ = The amount of copper from collection sites *k* to recycle factory *v*

$x_{mkv}$ = The amount of monitors from collection sites *k* to recycle factory *v*

$x_{djk}$ = The amount products of from junk shops *j* to collection sites *k*

$x_{dkv}$ = The amount products of from collection sites *k* to recycle factory *v*

### 4.3 Model Output

The results are shown that the total costs in the supply chain of computer waste management system was 61.5 million baht apporoximately as shown in Table 1. In addition, the collection sites stations are found at Hadyai Songkhla, Muang Nokornsrithammarat, Muang Surattani, Muang Phuket, Muang Trang, Muang Narathiwas, Muang Krabi, Muang Chumporn, Takua Pa - Phang Nga and Muang Ranong.

Table 1: Cost function in the supply chain of computer waste management system

| Types of Cost | Cost (bath/year) |
|---|---|
| **Cost for raw material node** | 24,674,075 |
| **Cost for junk shop node** | |
| - Segregating cost of computer | 782,738 |
| - Transportation cost of plastic | 1,475,912 |
| - Transportation cost of iron | 727,591 |
| - Transportation cost of copper | 248,127 |
| - Transportation cost of monitor | 2,191,300 |
| **Cost for disposal node** | 191,149 |
| - landfill cost | 350,711 |
| **Cost for collection sites** | |
| fixed cost for new collection sites | 782,738 |
| **Operation cost of plastic** | |
| - Transportation cost of plastic | 9,339,873 |
| - Compression cost of plastic | 35,349 |
| - Inventory cost of plastic | 40,422 |
| **Operation cost of iron** | |
| - Transportation cost of iron | 587,194 |
| - Compression cost of iron | 13,302 |
| - Inventory cost of iron | 106,481 |
| **Operation cost of copper** | |
| - Transportation cost of copper | 231,650 |
| - Compression cost of copper | 14,140 |
| - Inventory cost of copper | 2,182,814 |

| Types of Cost | Cost (bath/year) |
|---|---|
| **Operation cost of monitor** | |
| - Transportation cost of monitor | 17,765,107 |
| - Inventory cost of monitor | 177,859 |
| **Total costs** | 61,477,291 |

## 6. CONCLUSION

In this paper, This paper presents a mathematical model for strategic design of reverse supply chains system of computer waste management system in the South of Thailand. The decisions considered in this model include the total cost of the reverse logistics and to investigate the location of collection sites in order to minimize the total cost of reverse logistics. The mixed integer programming has been developed in accordance with the data that collected from various members in this supply chain. The result reveals that total cost of computer waste, considering from upstream to downstream in the southern part of Thailand is about 61.5 million baht.

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