A reverse logistics model for plastic bottle recycling in Bank Sampah Malang

A K Garside¹, U B Farida¹ and I Masudin¹

¹Industrial Engineering Department, Faculty of Technic, University of Muhammadiyah Malang, Jl. Raya Tlogomas 246, Malang 65144, Indonesia

Abstract. Malang city government created Bank Sampah Malang (BSM) that offers 3R concept (reduce, reuse, and recycle). BSM is the institution which is oriented toward reducing plastic waste, but their recycling process still has not considered the environmental aspect yet. In this paper, we developed a reverse logistics model for plastic bottle recycling in Bank Sampah Malang (BSM) with consideration minimizing the costs of reverse logistics and environmental impacts. The proposed model takes into account various parameters, including kinds of costs, availability of used plastic bottle, storage capacity, disassembling capacity, vehicle capacity, and demand of chopped plastic. Goal programming is used to formulate mathematical model and LINGO is applied to solve the model. Lingo results indicate the two goals have been achieved because the value of the positive deviation variable associated with the two goals are equal to zero. In addition, we got several decision variable solutions including: number of plastic bottles purchased from depot, number of bottle bodies moved to recycling area, number of bottle bodies recycled, and amount of chopped plastics delivered to firm. Keywords: goal programming, plastic bottle, recycling, reverse logistics.

1. Introduction
Reverse logistics (RL) is a research topic that has evolved during the last two decades but at the present time can be considered a consolidated topic of research [1]. Several definitions have been suggested for the definition of RL [2], [3]. However, [4] stated the definition of RL from the European Working Group, REVLOG is more complete than the previous definitions. This research group defined RL as ‘the process of planning, implementing and controlling backward flows of raw materials, in process inventory, packaging and finished goods, from a manufacturing, distribution or use point, to a point of recovery or point of proper disposal’. Researches on RL have grown over many years and literature review related to RL can be examined in [5]–[10]. Reverse logistics is concerned with distribution activities involving product returns, recycling, substitution, reuse, disposal, refurbishment, repair, and remanufacturing. We can see several research studies that discuss product returns in [11], [12], recycling in[13]–[15], and remanufacturing in[16], [17].

Many quantitative models on reverse logistics have been proposed, amongst others are linear programming, non-linear programming, and goal programming [18]. Pati et al. [19] have formulated a mixed integer goal programming for paper recycling system management in India. Wongthatasakorn [20] also proposed a goal programming model for recycling system in Thailand. Indrianti and Rustikasari [21] developed a reverse logistics model for battery recycling in Indonesia using linear programming, which is considered economic and environmental aspects. More recently, Masudin et al.
[15] proposed a more comprehensive model than Indrianti and Rustikasari [21], they added inventory costs and enhanced the planning horizon to multi-period.

Malang city’s government created Bank Sampah Malang (BSM) that offers 3R concept. BSM is oriented toward reducing plastic waste, but their recycling process still has not considered the environmental aspect yet. The environmental aspect refers to the impact of the use of diesel fuel and the byproduct of Polyethylene Terephthalate (PET), which is the chemical compound of plastic bottles. On the other hand, the uncertainty on the number of used plastic bottles from the community, the demand of chopped plastic from the firms, and decision on how many bottles to be recycled will impact the reverse logistics cost. This paper proposes a goal programming model for the plastic bottle recycling conducted by BSM by minimizing reverse logistics cost and environmental impact.

2. Methods
2.1 Reverse logistics network for plastic bottle recycling at BSM
There are six entities in the reverse logistics network for plastic bottle recycling at BSM: 1) depot is the location where used plastic bottles is taken, 2) weighing and disassembling area is located at BSM, 3) landfill is the location to dump non-selling component which is the bottle label, 4) craftsman is the party who will buy the bottle caps to be processed into handicraft, 5) production area is the location to recycle the plastic bottles into chopped plastics, and 6) firms are the party who will buy the chopped plastics as a raw material for their production.

2.2 Notation
The following is the notation that will be used in our mathematical model:

Indices
- $d$: index for depots, $d = \{1, \ldots, D\}$
- $b$: index for production/recycling areas, $b = \{1, \ldots, B\}$
- $m$: index for craftsmen, $m = \{1, \ldots, M\}$
- $i$: index for landfills, $i = \{1, \ldots, I\}$
- $t$: index for time periods, $t = \{1, \ldots, T\}$
- $f$: index for firms, $f = \{1, \ldots, F\}$
- $a$: index for weighing and disassembling areas, $a = \{1, \ldots, A\}$
- $vb$: index for vehicle that carry used plastic bottles
- $vl$: index for vehicle that carry plastic labels
- $vr$: index for vehicle that carry chopped plastic

$b, l, c, o$ : index for material type, where $b$: used plastic bottle, $l$: plastic label, $c$: bottle cap, $o$: bottle body, $r$: chopped plastic from recycling

Decision variables
- $X_{da}^b$: Number of used plastic bottles purchased from depot $d$ by area $a$ at period $t$
- $X_{da}^b$: Number of used plastic bottles delivered from depot $d$ by area $a$ at period $t$
- $X_{da}^b$: Number of used plastic bottles weighed from depot $d$ by area $a$ at period $t$
- $X_{da}^b$: Number of used plastic bottles disassembled in area $a$ at period $t$
- $I_{da}^b$: Inventory of used plastic bottles stored in area $a$ at period $t$
- $X_{da}^b$: Number of bottle bodies disassembled in area $a$ at period $t$
- $I_{da}^b$: Number of bottle bodies stored in area $a$ at period $t$
- $X_{da}^b$: Number of bottle bodies moved from area $a$ to area $b$ at period $t$
- $X_{da}^b$: Number of bottle caps disassembled in area $a$ at period $t$
- $X_{da}^b$: Number of bottle caps sold to craftsman $m$ in area $a$ at period $t$
- $I_{da}^b$: Inventory of bottle caps stored in area $a$ at period $t$
- $I_{da}^b$: Inventory of plastic labels stored in area $a$ at period $t$
- $X_{da}^b$: Number of plastic labels disassembled in area $a$ at period $t$
- $X_{da}^b$: Number of plastic labels delivered by area $a$ to landfill $i$ at period $t$
2.3 Mathematical model formulation

In this research, the goal programming model has two goals. These are the minimizing reverse logistics cost and minimizing environmental impacts.

2.3.1 Minimizing reverse logistics cost. Bank Sampah Malang (BSM) expects minimum cost incurred for reverse logistics activity and therefore, the objective to minimize the cost. Total reverse logistics cost (TRLC) is the whole cost incurred during plastic bottle recycling in the weighing and disassembling area and production area.

\[
T = \sum_{t} \left( \sum_{b} X_{b}^{d} C_{d}^{b} + \sum_{b} X_{b}^{f} C_{f}^{b} \right) + \sum_{t} \left( \sum_{b} X_{b}^{f} C_{f}^{d} + \sum_{b} X_{b}^{f} C_{f}^{d} \right)
\]

(1)

2.3.2 Minimizing environmental impacts. In [9], the environmental impact of recycling process is obtained from EPS (Environmental Priority Strategy). The environmental impact from the use of diesel fuel (EIF) is computed from the emission per 1 kg fuel, the distance traveled by vehicle during delivery, the amount of material being delivered, and vehicle capacity as expressed in Equation (2). The environmental impact formulation by considering abiotic stock resource value from transportation and recycling process (EIA) is expressed in Equation (3).

\[
E = \frac{55,987.02}{d_{a}} \left( \sum_{t} X_{b}^{d} \frac{d_{a}}{c_{l}^{b}} \right) + \left( \sum_{t} X_{b}^{f} \frac{d_{a}}{c_{l}^{b}} \right) + \left( \sum_{t} X_{b}^{f} \frac{d_{a}}{c_{l}^{b}} \right) + 173,906 X_{b}^{r}
\]

(2)

\[
E = \frac{17,799.5}{d_{a}} \left( \sum_{t} X_{b}^{d} \frac{d_{a}}{c_{l}^{b}} \right) + \left( \sum_{t} X_{b}^{f} \frac{d_{a}}{c_{l}^{b}} \right) + \left( \sum_{t} X_{b}^{f} \frac{d_{a}}{c_{l}^{b}} \right) + 173,906 X_{b}^{r}
\]

(3)

Goal Programming model for plastic bottle recycling is expressed in Equation (4) to (35).

Lexicographically minimize: \(\{d_{e}^{+}, d_{e}^{-}, d_{e}^{+}\}\)

Subject to

\[
TRLC + d_{e}^{-} - d_{e}^{+} = TRLC_{\text{target}}
\]

(5)

\[
{EIF + d_{e}^{-} - d_{e}^{+} = EIF_{t}}
\]

(6)

\[
EI + d_{e}^{-} - d_{e}^{+} = EI_{t}
\]

(7)

\[
\sum_{b} X_{b}^{d} \leq \frac{A_{b}}{d_{a}} \forall a, t
\]

(8)

\[
l_{b} \leq \frac{f_{b}}{d_{a}} \forall a, t
\]

(9)

\[
X_{b}^{f} \leq \frac{S_{b}}{d_{a}} \forall a, t
\]

(10)

\[
X_{b}^{f} \leq 0.19 X_{b}^{d} \forall a, t
\]

(12)

\[
X_{b}^{f} \leq 0.07 X_{b}^{d} \forall a, t
\]

(13)

\[
X_{b}^{f} \leq 0.74 X_{b}^{d} \forall a, t
\]

(14)
\[
X^b_i \leq L^b_i \quad \forall u \forall t \\
I^0_t = I^0_{t-1} + X^b_i - \sum_{m} X^c_m \quad \forall u \forall t \\
I^0_i \leq I^0 \quad \forall u \forall t \\
I^0_t = I^0_{t-1} + X^0_i - \sum_{b} X^c_m \quad \forall u \forall t \\
I^0_i \leq I^0 \quad \forall u \forall t \\
\sum_{m} X^b_m \leq C \quad \forall u \forall t \\
C \leq \sum_{m} X^c_m \leq 1C^d \quad \forall u \forall t \\
I^0_t = I^0_{t-1} - X^0_i + \sum_{u} X^c_i \quad \forall E \forall t \\
I^0_i \leq 1C^d \quad \forall E \forall t \\
\sum_{m} X^0_i \leq K \quad \forall E \forall t \\
l^e_t = l^e_{t-1} + \sum_{m} X^c_i \quad \forall E \forall t \\
I^0_t \leq I^0 \quad \forall E \forall t \\
\sum_{m} X^c_i \leq C \quad \forall J \forall t \\
X^0_i, X^b_i, X^c_i, X^d_i, X^c_i, X^c_i, X^c_i, X^c_i, X^c_i \geq 0 \forall u \forall v \forall w \forall f \forall t \\
da^*_i - da^*_i - da_i + da^*_i + da^*_i = 0 \\
da^*_i + da_i = 0, da^*_i + da^*_i = 0, da^*_i + da^*_i = 0
\]

The first goal is to achieve a smaller TRLC value than TRLC_{target}. We must minimize \( d^*_i \) to achieve the first goal, as shown in equation (4). The second goal is to achieve a smaller EIF value than EIF_{target} and a smaller EIA value than EIA_{target}. We must minimize \( d^*_i \) and \( d^*_i \), as shown in Equation (4). Equation (5) express the goal constraint that shows the relationship between TRLC, TRLC_{target}, and the deviation variables. The goal constraint that shows the relationship between EIF, EIF_{target}, and the deviation variables is expressed in equation (6).The goal constraint that shows the relationship between EIA, EIA_{target}, and the deviation variables is expressed in equation (7).

Equation (8) states that the number of used plastic bottles purchased should not be more than the bottle availability in depot. Equation (9) states the inventory balance in the weighing and disassembling area and equation (10) guarantees the storage capacity in the weighing and disassembling area. Equation (11) guarantees the weighing capacity. Then equation (12) makes sure that the number of used plastic bottles being disassembled will not be greater than the number of used plastic bottles weighed. Equation (13)-(15) states that the number of bottle caps, plastic labels, and bottle bodies from bottle bodies disassembling are in accordance with the product structure. Equation (16) expresses the number of used
plastic bottles to be disassembled should not go over the disassembling capacity. Equation (17) expresses the inventory balance of bottle cap in the in the weighing and disassembling area. Equation (18) guarantees storage capacity in weighing and disassembly area. Equation (19) states the inventory balance of bottle bodies in the weighing and disassembling area. Equation (20) guarantees that the number of bottle bodies stored will not exceed its storage capacity. Equation (21) states the inventory balance of plastic labels in the weighing and disassembling area while equation (22) guarantees that the number of plastic labels stored will not exceed its storage capacity in the area. The number of used plastic bottles being transported from the depot to the weighing and disassembling area should not exceed the vehicle capacity, as expressed in equation (23). Next, equation (24) assures that the number of plastic labels being transported will not exceed the vehicle capacity and landfill's storage capacity. Equation (25) expresses the inventory balance of bottle bodies in production area while equation (26) guarantees that the number of bottle bodies stored will not exceed its storage capacity in the production area. The number of bottle bodies to be recycled in the production area should not exceed recycling capacity and this is expressed in equation (27).

Equation (28) assures that the amount of chopped plastic is in accordance with the product structure. Equation (29) states the chopped plastics inventory balance in the production area. Meanwhile equation (30) guarantees that the amount of chopped plastics stored will not exceed its storage capacity. Equation (31) guarantees that the amount of chopped plastics delivered to firms will not fall below its demand. Equation (32) guarantees that the amount of chopped plastic delivered to firms should not exceed the vehicle capacity used to transport it. Equation (33)-(34) are the non-negativity constraints to ensure that all decision variables are positive. Equation (35) is complementary constraints to ensure that one of the negative and positive deviations is zero.

3. Result and analysis
The developed Goal Programming (GP) model was based on a real issue faced by Bank Sampah Malang (BSM). During the research period, there were 30 depots that could supply used plastic bottles, 5 craftsmen who bought the bottle caps with a total demand of 620 kg, and five firms that requested chopped plastics with a total demand of 3,000 kg. At the early period, BSM had used 800 kg of plastic bottles stock, 2200 kg of bottle bodies in the weighing and disassembling area, 80 kg of bottle bodies in the production area, 90 kg of bottle caps, 20 kg of plastic labels, and 800 kg of chopped plastics.

GP model run in Lingo software resulted number of used plastic bottles delivered and number of used plastic bottles weighed matching with the number of used plastic bottles purchased from the depot which is 2,000 kg. Then the disassembled bottles of 2,800 kg were obtained from the number of used plastic bottles purchased added with 800 kg of stock from the previous period. The number of bottle caps produced was 532 kg. Added with the previous period stock of 88 kg, in total, 620 kg of bottle caps were sold to the craftsmen. The plastic labels from the disassembling process were 196 kg and the previous period stock was 20 kg. In total, 116 kg of plastic labels were to be dumped to the landfill. The bottle bodies produced in the weighing and disassembling 2,072 kg. The amount moved to production area is 2,272 kg after being added with the previous period stock of 2200 kg, and thus the leftover of bottle bodies in the weighing and disassembling area is 2,000 kg.

The quantity of bottle bodies to be recycled was 2,352 kg, from the number of bottle bodies moved plus the bottle bodies stock from the previous period in the production area of 80 kg. The amount of chopped plastics produced from recycling process was 2,267 kg. Added with the previous period inventory of 800 kg, a total of 3,000 kg of chopped plastics were sold to companies, thus giving the next period inventory of 67 kg. Deviation $d^n_1$, $d^n_2$, $d^n_3$ were 0; thus, the objective function to minimize reverse logistics cost and minimize environmental impact had been achieved. The output from LINGO showed a TRLC value of IDR 30,009,860 and was below the target set by BSM of IDR 40,000,000.

4. Conclusions
The Goal Programming model proposed in this research was able to solve the problem of used plastic bottle recycling. The solution has already considered the economic and environmental aspect of the
problem. The following research can be directed to apply weighted to existing goals so the goal priority can be better measured quantitatively.

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