A Mixed-Integer Robust Programming Model for Reverse Logistics Network Design of Plastic Waste Management in Indonesia

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Abstract

Plastic is a wear resistance, easy to use, and cheap material. It was required by so many industries, so the quantity of plastic production in Indonesia increases every year. The increase in plastic production makes the volume of plastic waste generated by households. The unmanaged plastics waste releases various harmful substances for humans and the environment. To reduce this negative impact, a reverse logistics network for plastic waste, the recovery flows of plastic waste, is designed. This study constructed mixed-integer linear programming (MILP) for reverse logistics network design for plastic waste management in Indonesia to minimize the total cost from opened facilities cost, processing cost, and transportation cost. Then, due to uncertainty of the quantity of returned plastic from the consumer, the first MILP model is reformulated into mixed-integer robust programming (MIRP). The MIRP model also figured out the optimal location of selected facilities and the quantity of plastic transported from one facility to the others, under uncertainty.

Keywords
Reverse Logistics Network Design, Plastics, Robust Optimization

1. Introduction
There were two million tons of plastic produced in 1950, and the amount continued to rise to 380 million tons in 2015 (Liang et al. 2021). The increase in plastic production can be influenced by economic growth and population. The growth of industries also influenced the number of plastic products produced (Hidayat et al. 2019). Besides that, the outbreak of the COVID-19 in 2020 further impacted the increasing demand for plastic production due to transformations in individual's behaviors and consumption patterns (Khoo et al. 2021). Changes in new habits increase demand for plastic, including masks and hand sanitizers, vitamins and medicines, and plastic for package wrap.

Rising plastic production increases the amount of plastic waste. The excess of global plastic waste produced reaches 1.6 million tons per day (Benson et al. 2021). About 9% of plastic waste goes through the recycling process, 12% goes through the incineration process, and 79% remains in landfills (Khoo et al. 2021). Plastic waste that is not appropriately managed can negatively impact the environment and humans. For example, piled up landfills, and if plastic waste is not managed correctly, it can release various harmful substances that pollute water, soil, and air.

Reverse logistics (RL) can be used to reduce the negative impact of the increasing amount of plastic waste (Kilic et al. 2015). RL is a series of planning, implementation, and management processes linked to the evaluation and proper allocation of waste to collect residual value from end of use or end of life products (Valenzuela et al. 2021). RL is different from forward logistics, where raw materials are converted into finished goods. In RL, the products that get returned will be remade into finished goods again. One of RL's decisions is to design the logistics network. Reverse logistics network design (RLND) is a strategic or long-term decision determining waste management facilities' number, location, and allocation (Valenzuela et al. 2021).

In the RLND decision-making process, data uncertainty on the parameters is unavoidable and essential to consider. The conditions of uncertainty are important to consider because of the lack of sufficient and accurate information in

RL (Rahimi & Ghezavati 2018). Furthermore, the decisions made in the RLND have a long-lasting impact over the next few years, where the values of the parameters change from time to time (Pishvaee et al. 2011). Conditions of uncertainty occur in the RL of Indonesian plastic waste. Data on plastic waste RLs in Indonesia is still limited in the availability and accuracy of the information (Ministry of Environment and Forestry 2020). The data also fluctuates or does not remain constant over time.

This study aims to present an appropriate model for the RLND of plastic waste management in Indonesia to minimize the total costs. RLND of plastic waste management is formulated by mixed-integer robust programming (MIRP) due to uncertainty of the quantity of returned plastic from the consumer. This study presented the optimization of a MIRP over a case study in Jakarta, Indonesia.

The rest of the paper is structured as follows. In Section 2, a literature review on RLND of plastic waste is provided. Section 3 explains the method that used in this study, i.e., Robust Optimization. Section 4 describes the RLND problem of plastic waste management in Indonesia. The MILP and MIRP for RLND of plastic waste management in Indonesia including notations, parameters, decision variables, and application of the model is presented in Section 5. Finally, Section 6 provides the conclusion and future research to address the limitations of the proposed model.

2. Literature Review

Since the 1970s, there has been an increase in research on reverse logistics network (RLN) (Tao & Yin 2014). In recent years, RLND and optimization have been a major focus. RLND determines the number of facilities needed, capacities of each facility, allocation of products to each facility, and the best locations for each facility. RLND has been designed for many products. For example, Bing et al. (2014) constructed MILP for RLND of household plastic waste in Netherlands. Liao (2018) design the RLN of bulk waste such as discarded chairs, tables, sofas, beds, desk, cabinets, and closets in Taiwan using mixed-integer nonlinear programming. Safdar et al. (2020) modelled MILP for RNLD of electronic waste management. Defalque et al. (2021) design RLN of paper waste recycling using goal programming. The paper waste can be in the form of loose material or low compaction bales.

For RNLD that discussed plastic, Bing et al. (2014) modelled the RLND of household plastic waste such as PET, PP, PE, film and mix of hard plastic (PVC and PS) in the Netherlands by deterministic MILP model. The model is constructed to get the optimal amount of product moved from one facility to another for several scenarios. Chari et al. (2016) constructed deterministic MILP for RLND of high-density plastic in Nova Scotia to uncover the optimal route and quantity of product moved. Sheriff et al. (2017) design RLN for plastic recycling using deterministic MILP model. The model determines the facility's location, the amount of product moved from and to each facility, and the optimal vehicle used to move product. Paydar & Olfati (2018) developed the RLND of PET bottles by deterministic MILP to find optimal locations and the number of products moved from one facility to another. Xu et al. (2021) determined the optimal location of selected facilities and the quantity of plastic transported from one facility to the others. The MIRP model of RLND for high-grade plastic waste in the global network is proposed with uncertainty on maritime freight rates, currency exchange rates, and carbon costs in both exporting and importing countries.

From the previous studies in RNLD of plastic waste, decisions in RLND are in the form of basic decisions such as selecting the optimal facilities and the quantity of plastic that move from one facility to another. In RLND of plastic waste, mixed-integer programming is often used. This occurs because the decisions on the selected waste management facilities are made in the form of integers, while the allocation is made in the form of real numbers, resulting in mixed-integer decisions. Moreover, in previous studies of RLND of plastic waste, only a few studies consider the uncertainty in the model, although uncertainty is often in optimization and essential in RLND. Therefore, this study proposes a MIRP model with the uncertain quantity of returned plastic from the consumer for RLND of plastic waste management in Indonesia. The quantity of returned plastic from the consumer does not follow a probability distribution, but changes in robust uncertainty sets, and the MIRP model closer to the real situation.

3. Methods

Robust optimization is a method for dealing with data uncertainty where the uncertainty is assumed to resides in the uncertainty set (Gorissen et al. 2015). In Robust Optimization, the true probability distribution of uncertain data is not required. Robust Optimization can work "robust" even in bad conditions, i.e., the solution is the best in the worst-case scenario (Ben-Tal et al. 2009).

The following is the general linear programming (LP) model:

$$\min_x\{c^T x : Ax \leq b\}$$

where $c \in \mathbb{R}^n, x \in \mathbb{R}^n, A \in \mathbb{R}^{m\times n}, b \in \mathbb{R}^m$. According to Ben-Tal et al. (2009) and discussed by Gorissen et al. (2015), in Robust Optimization, the general form of LP with uncertainty is defined by assuming all the parameters (c, A, b) are uncertain and the parameters are in a primitive uncertainty set $\mathcal{U}$. Then, the general uncertain LP is as follows:

$$\min_{\mathrm{x}}\{c^T x + d: Ax \leq b\}_{(c,d,A,b)\in\mathcal{U}}.$$

Assume that each uncertain parameter is reside in box uncertainty set $\mathcal{U}_{box} = \{\zeta: \|\zeta\|_\infty \leq \mu \mid \mu > 0\}$ where $\zeta \in \mathbb{R}^L$. Robust Optimization eliminates uncertainty from uncertain issues, resulting in a single deterministic problem known as robust counterpart. For this study, robust counterpart also can called MIRP model. Thus, robust counterpart for uncertain LP problem is as follows:

$$\min_x\{c^T x : a^T x + \mu\|D^T x\|_1 \leq b\}.$$

4. Problem Description

According to Ministry of Environment and Forestry (2020) and validated with ADUPI (Indonesian Plastic Recycling Association), a RL of plastic waste management network for Indonesia in Figure 1 is considered in this study. The plastic waste from end user transported to Temporary Shelter – *Tempat Penampungan Sementara* (TPS) or Integrated Waste Processing Site with 3R Waste Management – *Tempat Pengolahan Sampah 3R* (TPS3R). At TPS3R, plastic waste is collected, sorted, and recycled on a regional scale. The plastic waste is then compacted and cut into small pieces before sending it to the collector. The leftover from the process is transferred to the Final Processing Site – *Tempat Pemrosesan Akhir* (TPA). As the final process, the waste is buried with soil or performed incineration. In addition, plastic waste from end-users is also transferred to the Waste Bank. Waste Bank is a system established and managed by the community, business entities, and the government for managing waste following the 3R principles. For the Waste Bank processing activities, plastic waste is reused as crafts for sale and compacted or shredded before being sold to the collector. The collector then moved the waste to the recycler to transform it into new materials.

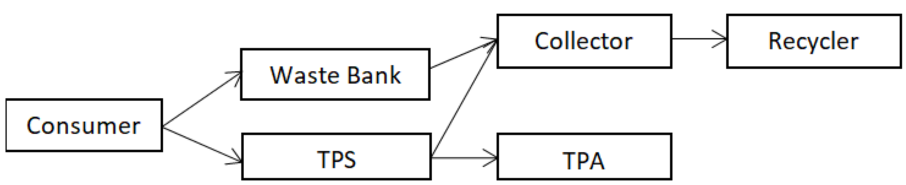

Figure 1. RL Network of Plastic Waste Management in Indonesia

5. Model Formulation

5.1 Notations, Parameters, and Variables

The following sets, parameters, and decision variables are used in the model.

Sets	
P	Plastic; indexed by p
K	Customer; indexed by k
B	Waste Bank; indexed by b
T	TPS/TPS3R; indexed by t
C	Collector; indexed by c
U	Recycler; indexed by u
A	TPA; indexed by a

Parameters

Q_{pk}	Quantity of returned plastic p from customer k
BP_{pb}	Processing cost of plastic p in Waste Bank b
BP_{pt}	Processing cost of plastic p in TPS/TPS3R t
BP_{pc}	Processing cost of plastic p in Collector c
BP_{pu}	Processing cost of plastic p in Recycler u
BP_{pa}	Processing cost of plastic p in TPA a
KK	Capacity of vehicle
J_{kb}	Distance between customer k and Waste Bank b
J_{kt}	Distance between customer k and TPS/TPS3R t
J_{bc}	Distance between Waste Bank b and Collector c
J_{tc}	Distance between TPS/TPS3R t ke Collector c
J_{ta}	Distance between TPS/TPS3R t and TPA a
J_{cu}	Distance between Collector c and Recycler u
BF_b	Cost of selecting the Waste Bank b
BF_t	Cost of selecting the TPS/TPS3R t
BF_c	Cost of selecting the Collector c
BF_u	Cost of selecting Recycler u
BF_a	Cost of selecting TPA a
KF_b	Capacity of Waste Bank b
KF_t	Capacity of TPS/TPS3R t
KF_c	Capacity of Collector c
KF_u	Capacity of Recycler u
KF_a	Capacity of TPA a (kg)
α_{pta}	Fraction of product p that allowed to be transported from TPS/TPS3R t to TPA a
BT	Transportation cost

Decision Variables	
x_b	$x_b = \begin{cases} 1, & \text{if Waste Bank } b \text{ is selected} \\ 0, & \text{otherwise.} \end{cases}$
x_t	$x_t = \begin{cases} 1, & \text{if TPS/TPS3R } t \text{ is selected} \\ 0, & \text{otherwise.} \end{cases}$
x_c	$x_c = \begin{cases} 1, & \text{if Collector } c \text{ is selected} \\ 0, & \text{otherwise.} \end{cases}$
x_u	$x_u = \begin{cases} 1, & \text{if Recycler } u \text{ is selected} \\ 0, & \text{otherwise.} \end{cases}$
x_a	$x_a = \begin{cases} 1, & \text{if TPA } a \text{ is selected} \\ 0, & \text{otherwise.} \end{cases}$
x_{kb}	$x_{kb} = \begin{cases} 1, & \text{if Waste Bank } b \text{ serves customer } k \\ 0, & \text{otherwise.} \end{cases}$
x_{kt}	$x_{kt} = \begin{cases} 1, & \text{if TPS/TPS3R } t \text{ serves customer } k \\ 0, & \text{otherwise.} \end{cases}$
q_{pkb}	Quantity of product p transported from customer k to Waste Bank b
q_{pkt}	Quantity of product p transported from customer k to TPS/TPS3R t
q_{pbc}	Quantity of product p transported from Waste Bank b to Collector c
q_{ptc}	Quantity of product p transported from TPS/TPS3R t to Collector c
q_{pta}	Quantity of product p transported from TPS/TPS3R t to TPA a
q_{pcu}	Quantity of product p transported from Collector c to Recycler u

5.2 MILP for RLND of Plastic Waste Management in Indonesia

The conceptual model for RL network of plastic waste management in Indonesia is shown in Figure 2.

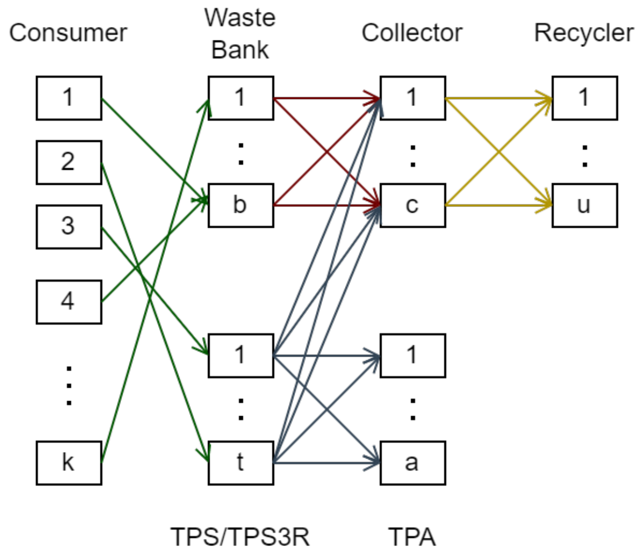

Figure 2. The Conceptual Model for RL Network of Plastic Waste Management in Indonesia

The goal of this model is to find optimal location of selected facilities and the quantity of plastic transported from one facility to the others that minimize the total cost. The total cost is made of the cost of the selected facility, the process at the facility, and transportation between facilities.

$$\min \{\sum_b BF_b x_b + \sum_t BF_t x_t + \sum_c BF_c x_c + \sum_u BF_u x_u + \sum_a BF_a x_a + \sum_p \sum_k \sum_b BP_{pb} q_{pkb} + \sum_p \sum_k \sum_t BP_{pt} q_{pkt} + \sum_p \sum_b \sum_t \sum_c BP_{pc}(q_{pbc} + q_{ptc}) + \sum_p \sum_t \sum_a BP_{pa} q_{pta} + \sum_p \sum_c \sum_u BP_{pu} q_{pcu} + \sum_p \sum_k \sum_b \frac{q_{pkb}}{KK} J_{kb} BT + \sum_p \sum_k \sum_t \frac{q_{pkt}}{KK} J_{kt} BT + \sum_p \sum_b \sum_c \frac{q_{pbc}}{KK} J_{bc} BT + \sum_p \sum_t \sum_c \frac{q_{ptc}}{KK} J_{tc} BT + \sum_p \sum_t \sum_a \frac{q_{pta}}{KK} J_{ta} BT + \sum_p \sum_c \sum_u \frac{q_{pcu}}{KK} J_{cu} BT\}$$

The first constraint is each consumer is only allowed to have one relationship with Waste Bank or TPS/TPS3R.

$$\sum_k \sum_b x_{kb} + \sum_k \sum_t x_{kt} = 1 \quad \forall k \in K$$
$$\sum_k \sum_b x_{kb} \leq M x_b \quad \forall b \in B$$
$$\sum_k \sum_t x_{kt} \leq M x_t \quad \forall t \in T$$

The second constraint is transhipment constraints. The quantity of returned product transported from one facility to the others should be equal to the one next facility to the others.

$$\sum_k \sum_b Q_{pk} x_{kb} = \sum_k \sum_b q_{pkb} \quad \forall p \in P$$
$$\sum_k \sum_t Q_{pk} x_{kt} = \sum_k \sum_t q_{pkt} \quad \forall p \in P$$
$$\sum_c q_{pbc} = \sum_k q_{pkb} \quad \forall p \in P, b \in B$$
$$\sum_c q_{ptc} = (1 - \alpha_{pta}) \sum_k q_{pkt} \quad \forall p \in P, t \in T$$
$$\sum_a q_{pta} = \alpha_{pta} \sum_k q_{pkt} \quad \forall p \in P, t \in T$$
$$\sum_u q_{pcu} = \left(\sum_b q_{pbc} + \sum_t q_{ptc}\right) \forall p \in P, c \in C$$

The following constraint is capacity constraints. The quantity of returned products transported from one facility to the others should be less than or equal to the capacity of the product at the facility.

$$\sum_p \sum_k q_{pkb} \leq KF_b x_b \quad \forall b \in B$$
$$\sum_p \sum_k q_{pkt} \leq KF_t x_t \quad \forall t \in T$$
$$\sum_p \sum_b q_{pbc} + \sum_p \sum_t q_{ptc} \leq KF_c x_c \quad \forall c \in C$$
$$\sum_p \sum_t q_{pta} \leq KF_a x_a \quad \forall a \in A$$
$$\sum_p \sum_c q_{pcu} \leq KF_u x_u \quad \forall u \in U$$

Lastly, the constraints for the definition of the decision variables are binary and continuous.

$$x_b, x_t, x_c, x_u, x_a, x_{kb}, x_{kt} \in \{0, 1\}$$
$$q_{pkb}, q_{pkt}, q_{pbc}, q_{ptc}, q_{pta}, q_{pcu} \geq 0$$

5.3 MIRP for RLND of Plastic Waste Management in Indonesia

A MIRP is proposed in this study because the RLND of plastic waste management in Indonesia contains a set of uncertain parameters i.e., the quantity of returned plastic from the consumer. According to Ben-Tal et al. (2009) and discussed by Gorissen et al. (2015), using Robust Optimization, thus robust counterpart by box uncertainty set is as follows:

$$\min \{\sum_b BF_b x_b + \sum_t BF_t x_t + \sum_c BF_c x_c + \sum_u BF_u x_u + \sum_a BF_a x_a + \sum_p \sum_k \sum_b BP_{pb} q_{pkb} + \sum_p \sum_k \sum_t BP_{pt} q_{pkt} +$$
$$\sum_p \sum_b \sum_t \sum_c BP_{pc}\left(q_{pbc} + q_{ptc}\right) + \sum_p \sum_t \sum_a BP_{pa} q_{pta} + \sum_p \sum_c \sum_u BP_{pu} q_{pcu} + \sum_p \sum_k \sum_b \frac{q_{pkb}}{KK} J_{kb} BT +$$
$$\sum_p \sum_k \sum_t \frac{q_{pkt}}{KK} J_{kt} BT + \sum_p \sum_b \sum_c \frac{q_{pbc}}{KK} J_{bc} BT + \sum_p \sum_t \sum_c \frac{q_{ptc}}{KK} J_{tc} BT + \sum_p \sum_t \sum_a \frac{q_{pta}}{KK} J_{ta} BT + \sum_p \sum_c \sum_u \frac{q_{pcu}}{KK} J_{cu} BT\}$$

$s.t.$

$$\sum_k \sum_b x_{kb} + \sum_k \sum_t x_{kt} = 1 \ \ \forall k \in K$$
$$\sum_k \sum_b x_{kb} \le M x_b \ \ \forall b \in B$$
$$\sum_k \sum_t x_{kt} \le M x_t \ \ \forall t \in T$$
$$\sum_k \sum_b Q_{pk} x_{kb} + \mu \sum_k \sum_b x_{kb} \sum_{l \in L} (D)_{kbl} - \sum_k \sum_b q_{pkb} = 0, \ \forall p \in P$$
$$\sum_k \sum_t Q_{pk} x_{kt} + \mu \sum_k \sum_t x_{kt} \sum_{l \in L} (D)_{ktl} - \sum_k \sum_t q_{pkt} = 0, \forall p \in P$$
$$\sum_c q_{pbc} = \sum_k q_{pkb} \ \ \forall p \in P, b \in B$$
$$\sum_c q_{ptc} = \left(1 - \alpha_{pta}\right) \sum_k q_{pkt} \ \ \forall p \in P, t \in T$$
$$\sum_a q_{pta} = \alpha_{pta} \sum_k q_{pkt} \ \ \forall p \in P, t \in T$$
$$\sum_u q_{pcu} = \left(\sum_b q_{pbc} + \sum_t q_{ptc}\right) \forall p \in P, c \in C$$
$$\sum_p \sum_k q_{pkb} \le KF_b x_b \ \ \forall b \in B$$
$$\sum_p \sum_k q_{pkt} \le KF_t x_t \ \ \forall t \in T$$
$$\sum_p \sum_b q_{pbc} + \sum_p \sum_t q_{ptc} \le KF_c x_c \ \ \forall c \in C$$
$$\sum_p \sum_t q_{pta} \le KF_a x_a \ \ \forall a \in A$$
$$\sum_p \sum_c q_{pcu} \le KF_u x_u \ \ \forall u \in U$$
$$x_b, x_t, x_c, x_u, x_a, x_{kb}, x_{kt} \in \{0, 1\}$$
$$q_{pkb}, q_{pkt}, q_{pbc}, q_{ptc}, q_{pta}, q_{pcu} \ge 0$$

5.4 Application of the Model

In this study, the MIRP model is implemented using a case study of plastic waste management in Jakarta, Indonesia. A set of P of one type of plastic waste is considered. The RL network of plastic waste management in Indonesia is defined by a set K of ten Consumers, a set B of five Waste Banks, a set T of four TPS/TPS3R, a set A of one TPA, a set C of five Collectors, and a set U of three Recyclers. The number of facility points is based on the municipalities in Jakarta (SIPSN – Sistem Informasi Pengelolaan Sampah Nasional 2022).

There are five different data on the quantity of returned plastic from the consumer for each consumer. These data are collected from the Ministry of Environment and Forestry Indonesia official website. Due to the uncertainty of this data, the quantity of returned plastic from the consumer is assumed to reside in the box uncertainty set, so the data for case study of plastic waste management in Jakarta can be solved. Based on data obtained from the official website of the Ministry of Environment and Forestry, the median value between the highest and lowest quantity of returned plastic for each consumer is used as nominal data in the MIRP model with box uncertainty set. The nominal data is then disturbed with uncertainty. The uncertainty is obtained from the difference between the nominal value and the quantity of returned plastic data from each consumer. Figure 3 shows the box uncertainty set for the quantity of returned plastic from each consumer. Then, the MIRP model is solved using Python MIP on a personal computer with Intel Core i3 7th generation and 4.0 GB RAM to find the optimal solution.

From the case study, the solution of optimal location of selected facilities and the quantity of plastic transported from one facility to the others are obtained while minimizing the total cost of selected facility, process at the facility, and transportation between facilities. The selected Waste Bank are Waste Bank 1, Waste Bank 2, Waste Bank 3, Waste Bank 4, and Waste Bank 5. The selected TPS/TPS3R are TPS/TPS3R 1, TPS/TPS3R 3, and TPS/TPS3R 4. The selected TPA is TPA 1. The selected Collector is Collector 4 and the selected Recycler is Recycler 3. The plastic waste from each consumer is only transported to one Waste Bank or TPS/TPS3R.

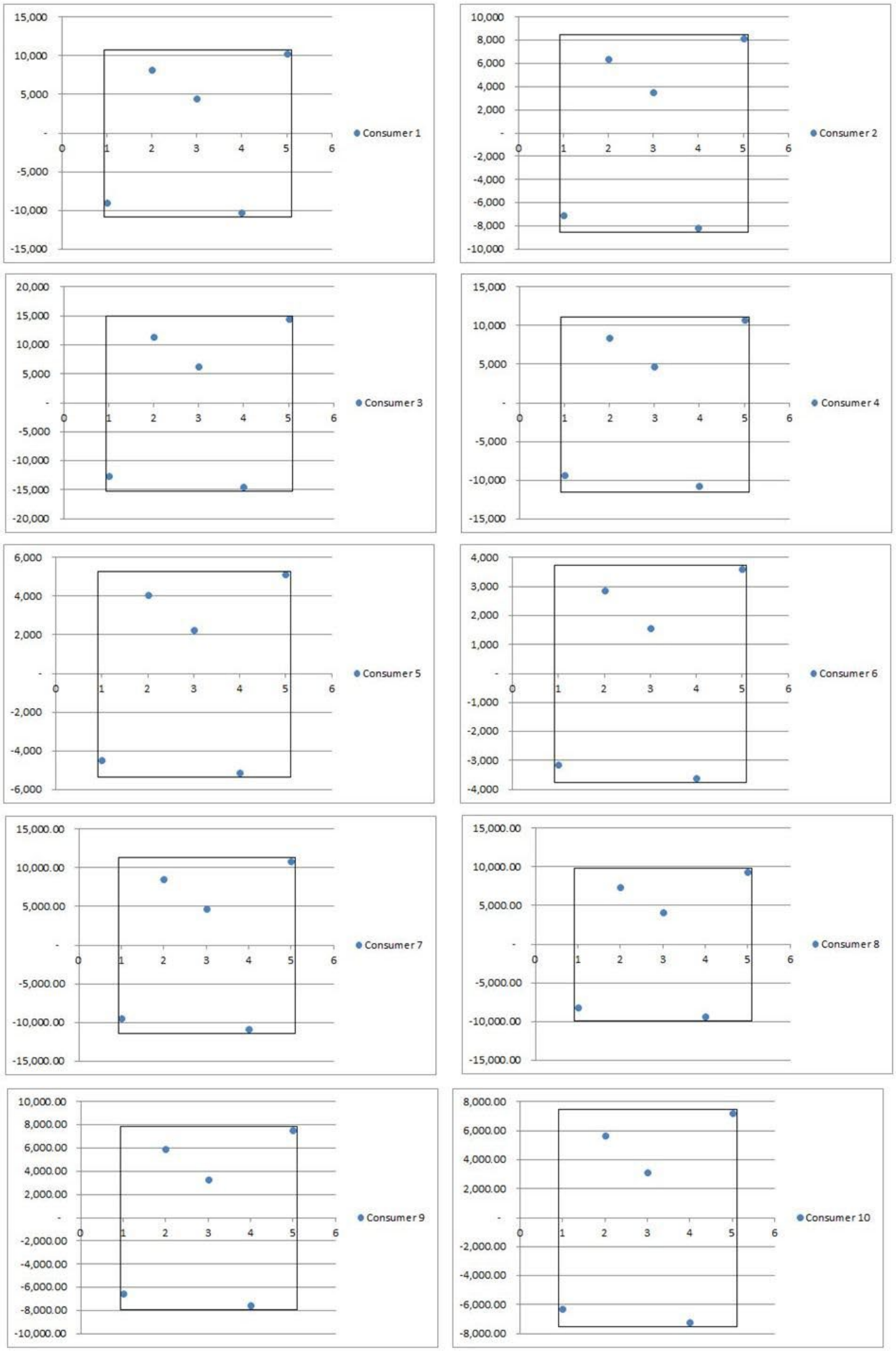

Figure 3. Box Uncertainty Sets for The Quantity of Returned Plastic from The Consumer

Table 1 shows the quantity of plastic transported from one selected facility to the others in ton. From Consumer 1, 45756 tons of plastic waste is transported to TPS/TPS3R 3. From Consumer 2, 36079 tons of plastic waste is moved to Waste Bank 3 and so on. From Waste Bank 1, 47600 tons of plastic waste is transported to Collector 4 and so on. From TPS/TPS3R 1, 29007 tons of plastic waste is moved to Collector 4 and 12432 tons of plastic waste is transported to TPA 1, and so on. Lastly, 317843 tons of plastic waste is transported from Collector 4 to Recycler 3. Also, the optimal RL network of the case study is depicted in Figure 4.

Table 1. Robust Solution of the Case Study in Jakarta

From	To	Quantity (ton)
Consumer 1	TPS/TPS3R 3	45756
Consumer 2	Waste Bank 3	36079
Consumer 3	TPS/TPS3R 4	64050
Consumer 4	Waste Bank 1	47600
Consumer 5	Waste Bank 2	22822
Consumer 6	Waste Bank 4	16038
Consumer 7	TPS/TPS3R 4	48044
Consumer 8	TPS/TPS3R 1	41438
Consumer 9	Waste Bank 5	33465
Consumer 10	TPS/TPS3R 4	31910
Waste Bank 1	Collector 4	47600
Waste Bank 2	Collector 4	22822
Waste Bank 3	Collector 4	36079
Waste Bank 4	Collector 4	16038
Waste Bank 5	Collector 4	33465
TPS/TPS3R 1	Collector 4	29007
TPS/TPS3R 3	Collector 4	32030
TPS/TPS3R 4	Collector 4	100803
TPS/TPS3R 1	TPA 1	12432
TPS/TPS3R 3	TPA 1	13727
TPS/TPS3R 4	TPA 1	43202
Collector 4	Recycler 3	317843

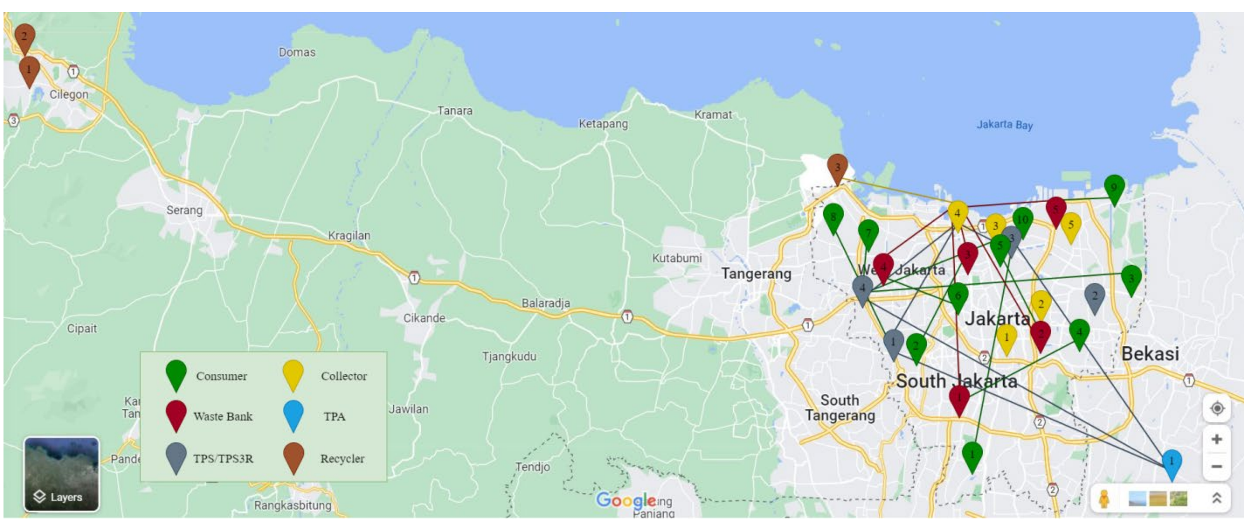

Figure 4. The Optimal RL Network of the Case Study in Jakarta

The MIRP model is tested and validated using a case study of plastic waste management in Jakarta. From the MIRP model, the optimal location of selected facilities and the quantity of plastic transported from one facility to the others that minimize the total cost are obtained. The solution minimizes the total cost with uncertainty in the quantity of returned plastic from the consumer.

6. Conclusion

Due to uncertainty in RLND of plastic waste management in Indonesia, a MIRP model is proposed using Robust Optimization. In this study, RL network of plastic waste management in Indonesia consider consumer, Waste Bank, TPS/TPS3R, TPA, Collector, and Recycler. The objective of the model is to minimize the total cost from the cost of the selected facility, the process at the facility, and transportation between facilities. First, a MILP model for RLND for plastic waste management in Indonesia is constructed. To cope with uncertain parameters in MILP model, the quantity of returned plastic from the consumer is assumed to reside in the box uncertainty set. Then, a robust counterpart of the uncertain MILP model is formulated to find an optimal robust solution. For application of the model, the optimal robust solutions, i.e., the optimal location of selected facilities and the quantity of plastic transported from one facility to the others, are obtained from the MIRP model by a plastic waste management case study in Jakarta.

This study can be developed in the future to address the limitations. For example, the model considers another form of uncertainty sets for the uncertain parameters. Also, because uncertainty in optimization problems is often, other parameters such as transportation cost, processing costs at the facility, and capacity of the facility can be considered in the model.

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