The Optimization of Facility Location-Routing Decision Model for Municipal Solid Waste Network

Cahaya Annisaa' Fathonah and Suparno
Department Industrial and Systems Engineering
Institut Teknologi Sepuluh Nopember
Surabaya, Indonesia
annisaacahaya@gmail.com, suparno@ie.its.ac.id

Abstract

Solid waste management is still being a problem in many regions. Yogyakarta, one of the cities in Indonesia want to optimize waste management. Evaluation is carried out on two main things in waste management, namely routing activities and placement of waste collection point (TPS). The evaluations are conducted because many small TPS existence that affected the cost of routing activities. Therefore, a Multi-Objective Integer Linear Programming (MOILP) model is developed to solve these problems. The objective of the propose model to simultaneously minimize the cost of routing activities and maximize the amount of waste that can be temporarily accommodated in that existed waste collection point. The propose model is considered an operational-strategy model because includes facility location and vehicle routing problem. This model is a hybrid of fuzzy theory, maximum covering problem, and vehicle routing problem. The model solve as single objective by Fuzzy Goal Programming. The results obtained from implementing the model using real-world data. Furthermore, sensitivity analysis has been done on some parameter in order to determine how the parameters changes can affect the objective functions.

Keywords
Solid Waste Management, Facility Location - Routing Problem, Fuzzy Goal Programming

1. Introduction
Solid waste is still being a problem in several countries (Mesjasz 2019). Solid waste management in urban areas is known as Municipal Solid Waste Management (MSWM). The main target is to protect public health, to maintain and improve environmental quality, and to give support to economic productivity through recycled products that are produced in the form of goods or fuels (Alam and Ahmade 2013). Municipal Solid Waste Management (MSWM) consists of generation, storage, collection, transfer-transport processing, and disposal (Sharholy et al. 2008, Hoornweg et al. 2012, Joseph 2008). MSWM in each country is different, in Indonesia MSWM is managed by government agencies, namely the Ministry of Public Works at the national level and the Environment Department (*Dinas Lingkungan Hidup*) at the regional and municipal levels.

Yogyakarta, one of the big cities in Indonesia, is still has the solid waste problem. The waste management in Yogyakarta has several problems in the implemented waste transportation activities network, which causing inequality that affects the high operational costs of transporting waste. Based on the preliminary observations results and the results of the discussions with the Yogyakarta Environment Department (DLH), these problems happened due to the high number of small waste collection point (TPS) existences that have an impact on the routing activities time.

Two fundamental issues of concern in solid waste collection are the locations of initial collection and the period of collection by the dedicated vehicles. Location for waste collection point can allocate use facility location theory. Location theory or facility location is a method for determining the location of a facility with four basic factors, they are how many facilities will be allocated, where the location is, how much the capacity is and how much demand will be served (Daskin 1995). Research by Adeleke and Olukanni (2020) has reviewed several facility location methods that can be applied in waste management. Waste collection point which keep maintained will be formed a directed graph that will form arcs and affect its transportation. The arc is used in determining the route for transporting waste. The determination of routes and networks for Municipal Solid Waste Management (MSWM) activities to optimize waste transportation activities have been carried out by (Zsigraiova et al. 2013, Das and Bhattacharyya 2015, Markov and Verone 2015, Assaf and Saleh 2017, Banyai et al. 2019, Sulemana et al. 2019). In addition, there is research that integrates the determination of routes and facility locations that have been conducted on solid waste management by (Mohammad et al. 2017, Ouhader and Kyal 2017, Veenstra et al. 2018, Farahbakhsh 2019, Zandkarimkhani et al. 2020, Mamashli and Javadian 2021).

This research focus to optimizing the waste management network in urban areas. The propose model simultaneously integrate facility location and vehicle routing to minimize waste management costs and maximize the amount of waste that can be accommodated by TPS, it is considered an operational-strategy model. The development of this model combines strategic and operational decisions since in some problems strategic decisions are influenced by operational decisions or vice versa (Zandkarimkhani et al. 2020). In waste management, the decision to determine the location strategy will give effects on waste transportation activities. This research develop a model with the characteristics of Multi-Objective Integer Linear Programming (MOILP) which is solved as single model by the fuzzy goal programming method. This research will later be able to support the Environment Department (DLH) in planning strategic decisions in determining the number of waste collention point facilities that will be maintained and routes for transporting solid waste on solid waste management at Krasak Sector, Yogyakarta.

2. Optimization Model

2.1 Overview

A novel hybrid approach facility location method, vehicle routing problem and fuzzy theory. TPS in Yogyakarta consists of three types, namely depo, container and TPSS. In facility location, the facilities to be maintained will serve demand point that have a maximum distance of 2000 m from the facilites point and are adjusted to the maximum capacity of each type of TPS so that distance and capacity constraint are developed to determine the TPS location. The demand point in this research is the central point of an area (Alsalloum and Rand 2006, Farahani and Hekmatfar 2012). Furthermore, in the maintained TPS, the waste will be transported by vehicles provided with a fixed container system. In the real of disposal waste, services consider the capacity of the TPS. In addition, according to (Xue et al. 2015) in general, waste transportation to final disposal considers the capacity of the facility, so the capacity of the facility is a demand in waste disposal. It also takes into development of a model with maximum covering problem where the capacity of the facility will be use maximized. In the disposal waste activity, the vehicle departs from the DLH Office then goes to the TPS according to the sector where the vehicle is assigned and carries out solid waste. When the vehicle is full, the waste will be taken to Piyungan TPA and the vehicle return to the nearest TPS that has not been served in the sector where it is assigned to bring back the solid waste until the vehicle working hours are over. This research assumed if there are disposal waste activities at the trip, the vehicle will trip to Piyungan TPA with travel time as measured from the center point of the waste management sector and if there is transportation back in the next trip there will be a return trip from Piyungan TPA to the center point waste management sector. The assumption is considering on real condition the center point of waste management sector represents a regional which have considered radians in facility location. A set of facilities has a center point that forms radians (Farahani and Hekmatfar 2012). Therefore, travel time will not much different from the distance and time from Piyungan TPA to a waste collection point in sector Krasak and vice versa as shown in figure 1.

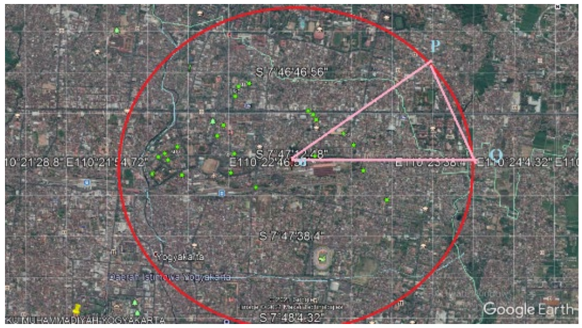

Figure 1. Facility Region

The study belongs to Xue et al. (2015) also accommodated the similar assumption where facility also has the region and there was a central point. In this study, the number of a trip for every vehicle is already known to refer to research of (Cattaruzza et al. 2016, Lei et al. 2006, Azi et al. 2007). The number of trips determined the ability of the vehicle to Piyungan TPA every day and from Piyungan TPA to vehicle storage Depot (DLH Office). In order to better understand and simplify the proposed model, the main following assumptions are given:

1. The distance calculation will be used using straight line LB / LS with the location point obtained from Google Earth for location determination.
2. The time of the routing activity comes from measuring the distance on google maps and multiplied with the dump truck speed.
3. Dump truck speed of 40 km / hour with 7 hours working hours from 06.00 WIB.
4. Ignoring traffic jams and incidental activities on the way to pick up the solid waste.
5. Ignoring vehicles that are not routinely used to transport solid waste, so this research just uses dump truck with volume 6 m^3 as a vehicle.
6. There is a maximum number of vehicles that can serve the same waste collection point on the same trip because we have limitation land.

2.2 Model Development

The developed model in this study was conducted by developing a Multi-Objective Integer Linear Programming mathematical model from several previous studies. The constraint for determine the TPS location were developed from research (Alsalloum and Rand 2006, Daskin 2008). Meanwhile, the constraint for vehicle routing problem were developed from research (Angelelli and Speranza 2002, Lei et al., 2006, Azi et al. 2007, Markov et al. 2015, Cattaruzza et al. 2016, Ouhader and Kyal 2017). Markov et al (2015) developed the Vehicle Routing Problem (VRP) model by adding an intermediate facility. Meanwhile (Lei et al. 2006, Azi et al. 2007, Cattaruzza et al 2016) developed a multi-trip VRP model where the maximum trip for each vehicle can be determined by the decision maker. Research by (Speranza et al. 2008, Ouhader and Kyal 2017) developed a split delivery that considers vehicle capacity, so that facilities that have a capacity of more than the vehicle capacity can be served more than once with one-time service can fulling vehicle capacity.

The model development is conducted to solve the problems that have been described in the research background. The mathematical model is solved by using the fuzzy goal programming method. The following models have been developed and will be used for problem solving in this study.

2.2.1 Notation

The mathematical model in this study uses the following notations:

I = Set of demand point points from the community with index *i*{I=1,2,3.....*i*}
K = Set of alternative TPS locations points in the form of depots with index *k* {k=1,2,3.....*k*}
L = Set of alternative TPS locations points in the form of containers with index *l* {l=1,2,3.....*l*}
M = Set of alternative TPS location points in the form of TPSS with index *m* {m=1,2,3.....*m*}
E = $\{(ka,kb,la,lb,ma,mb) | ka,kb,la,lb,ma,mb,d,b,s \in E,\ ka \neq kb,\ la \neq lb,$ and $ma \neq mb\}$ = set of directed edge
C_k = The capacity of Depo locations with index *k* (m^3/day)
C_l = The capacity of Container locations with index *l* (m^3/day)
C_m = The capacity of TPSS location with index *m* (m^3/day)
V_i = The volume of waste demand point from the community with index *i* (m^3/day)
D_{ik} = The distance between the demand point of waste with index i with the alternative location of TPS with index *k* (m)
D_{il} = The distance between the demand point of waste with index i with the alternative location of TPS with index *l* (m)
D_{im} = The distance between the demand point of waste with index i with the alternative location of TPS with index *m* (m)
D_{max} = The maximum distance or distance coverage (m)
CB = Waste transport worker costs (IDR / person)
B_v = The number of carrying waste workers with index (person)
= The capacity of waste transport vehicles with index *v* on trip *t*
V = The association of vehicles with index *v* {v = 1,2,3 ..., v}
T = The collection of waste transportation trips does not include TPA trips to the depot with an index *t* {t = 1,2,3 ..., t-1}
NV_v = The cost of vehicle fuel in the waste collection activity for each vehicle with index *v* (Rupiah)
$TP_{ka, kb}$ = The travel time from k facility to other k facilities (minutes)
$TP_{ka, lb}$ = The travel time from facility *k* to facility *l* (minutes)
$TP_{ka, mb}$ = The travel time from facility *k* to facility *m* (minutes)
$TP_{la, kb}$ = The travel time from facility *l* to facility *k* (minutes)
$TP_{la, lb}$ = The travel time from facility *l* to other facility *l* (minutes)
$TP_{la, mb}$ = The travel time from facility *l* to facility *m* (minutes)
$TP_{ma, kb}$ = The travel time from facility *m* to facility *k* (minutes)
$TP_{ma, lb}$ = The travel time from facility *m* to facility *l* (minutes)
$TP_{ma, mb}$ = The travel time from facility *m* to another facility *m* (minutes)
M_{vt} = The number of facilities *k, l,* and ^{m} served in one trip *t*
TPBS = The travel time from TPA to Sector (minutes)
TPSB = The travel time from Sector to TPA (minutes)
TPBD = The travel time from TPA to Depot (minutes)
J_{mat} = The maximum number of vehicles visiting *ma* on the trip *t*
J_{lat} = Maximum number of vehicles visiting *la* on trip *t*
J_{kat} = The maximum number of vehicles visiting the *ka* on the trip *t*

The decision variables:

A_{vt} = The amount of waste carried by vehicle *v* on trip *t*
X_k = (*1*, if facility *k* is the location for placing waste and 0, if facility *k* is not a location for placing waste)
X_l = (*1*, if facility *l* is the location for placing waste and 0, if facility *l* is not the location for placing waste)
X_m = (*1*, if facility m is the location for placing waste and 0, if facility *m* is not the location for placing waste)
X_{vt} = (*1*, if vehicle *v* on trip *t* carries out waste transportation and 0, otherwise)
Y_{ik} = (*1*, if the waste from demand point *i* can be covered by facility *k* and 0, if the demand point *i* cannot be fulfilled by facility *k*)
Y_{il} = (*1*, if the waste from demand point *i* can be covered by facility *l* and 0, if the demand point *i* cannot be fulfilled by facility l)
Y_{im} = (*1*, if the waste from demand point *i* can be covered by facility *m* and 0, if the demand point *i* cannot be fulfilled by facility m)
W_v = (*1*, if vehicle *v* use for waste disposal and 0, if not)
Z_{katv} = (*1*, if the waste from facility *k* can be transported using vehicle *v* on trip *t* and 0, if not)
Z_{tatv} = (*1*, if the waste from facility *l* can be transported using vehicle *v* on trip *t* and 0, if not)
Z_{matv} = (*1*, if the waste from facility *m* can be transported using vehicle *v* on trips *t* and 0, if not)
$P_{ka.kb.t.v}$ = (*1*, if there is a trip from facility *k* to another facility k using vehicle v on trip t and 0, if not)
$P_{ka.lb.t.v}$ = (*1*, if there is a trip from facility *k* to facility *l* using vehicle *v* on trip *t* and 0, if not)
$P_{ka.mb.t.v}$ = (*1*, if there is a trip from facility *k* to facility *m* using vehicle *v* on trip *t* and 0, if not)
$P_{la.lb.t.v}$ = (*1*, if there is a trip from facility *l* to another *l* facility using vehicle *v* on trip *t* and 0, if not)
$P_{ta.lb.t.v}$ = (*1*, if there is a trip from facility *l* to facility *k* using vehicle *v* on trip *t* and 0, if not)
$P_{la.mb.t.v}$ = (*1*, if there is a trip from facility *l* to facility *m* using vehicle *v* on trip *t* and 0, if not)
$P_{ma.mb.t.v}$ = (*1*, if there is a trip from facility *m* to another *m* facility using vehicle *v* on trip *t* and 0, if not)
$P_{ma.kb.t.v}$ = (*1*, if there is a trip from facility *m* to facility *k* using vehicle *v* on trip *t* and 0, if not)
$P_{ma.lb.t.v}$ = (*1*, if there is a trip from facility *m* to the facility *l* using vehicle *v* on trip *t* and 0, if not)
$P_{d,ka,1,v}$ = (*1*, if there is a trip from depot to facility *k* using vehicle *v* on trip *1* and 0, if not)
$P_{d,la,1,v}$ = (*1*, if there is a trip from depot to facility *l* using vehicle *v* on trip *1* and 0, if not)
$P_{d,ma,1,v}$ = (*1*, if there is a trip from depot to facility m using vehicle *v* on trip *1* and 0, if not)

2.2.2 Mathematic Models

Objective Function

$$\text{Min } \sum_V CB\ B_V\ W_v + \sum_v CN_v \quad (1)$$

$$\text{Max } \sum_i \sum_k Y_{ik} + \sum_i \sum_l Y_{il} + \sum_i \sum_m Y_{im} \quad (2)$$

Subject to

$$d_{max}\ X_k \geq D_{ik} Y_{ik} \qquad \forall\ k \epsilon K,\ i \epsilon I \quad (3)$$

$$\sum_{k \in K} Y_{ik} + \sum_{l \in L} Y_{il} + \sum_{m \in M} Y_{im} \geq 1 \qquad \forall\ i \in I \quad (4)$$

$$\sum_{i \epsilon I} V_i Y_{ik} \leq C_k X_k \qquad \forall\ k \epsilon K \quad (5)$$

$$\sum_k X_k \leq P_k \quad (6)$$

$$\sum_{t=1} \sum_d \sum_{ka} P_{dkatv} + \sum_{t=1} \sum_d \sum_{la} P_{dlatv} + \sum_{t=1} \sum_d \sum_{ma} P_{dmatv} = 1\ W_v \qquad \forall\ v \in V \quad (7)$$

$$Z_{katv} \geq P_{dkatv}\ \forall\ ka \in Ka,\ v \in V,\ t = 1 \quad (8)$$

$$\sum_{ka} \sum_t Z_{katv} + \sum_{la} \sum_t Z_{latv} + \sum_{ma} \sum_t Z_{matv} \geq \sum_{ka} \sum_{t+1} Z_{katv} + \sum_{la} \sum_{t+1} Z_{latv} + \sum_{ma} \sum_{t+1} Z_{matv}\ \forall\ v \epsilon V \quad (9)$$

$$A_{vt} \leq C_{vt}\ X_{vt} \qquad \forall\ v \epsilon V, t \epsilon T \quad (10)$$

$$A_{vt} = \sum_{ka \epsilon Ka} C_{ka}\ Z_{katv} + \sum_{la \epsilon La} C_{la}\ Z_{latv} + \sum_{ma \epsilon Ma} C_{ma}\ Z_{matv} \quad (11)$$

$$\sum_{kb} P_{ka,kb,t,v} + \sum_{lb} P_{ka,lb,t,v} + \sum_{mb} P_{ka,mb,t,v} \leq 1 \qquad \forall\ v \epsilon V,\ ka \epsilon Ka,\ ka \neq kb,\ t \epsilon T \quad (12)$$

$\sum_{ka} P_{ka,kb,t,v} + \sum_{la} P_{la,kb,t,v} + \sum_{ma} P_{ma,kb,t,v} - \sum_{ka} P_{kb,ka,t,v} - \sum_{la} P_{kb,la,t,v} - \sum_{ma} P_{kb,ma,t,v} = 0$

$\forall\, v \in V,\ kb \in Kb,\ ka \neq Kb,\ t \in T$ (3.13)

$Z_{katv} - Z_{kbtv} + P_{kakbtv} \leq 1 \quad \forall\, v \in V,\ ka \in Ka,\ kb \in Kb,\ ka \neq kb,\ t \in T$ (14)

$-Z_{katv} - Z_{kbtv} + 2 \times P_{kakbtv} \leq 0 \quad \forall\, v \in V,\ ka \in Ka,\ kb \in Kb, ka \neq kb,\ t \in T$ (15)

$\sum_t X_{vt} \geq W_v \quad \forall\, v \in V$ (16)

$\sum_{ka} Z_{katv} + \sum_{la} Z_{latv} + \sum_{ma} Z_{matv} \geq X_{vt} \quad \forall\, v \in V,\ t \in T$ (17)

$$\sum_{v}\sum_{t} Z_{katv} = \frac{C_{ka}}{C_{vt}} X_{ka} \quad \forall ka \in Ka, C_{ka} > C_{vt} \qquad (18)$$

$$\sum_{v} Z_{matv} \leq J_{mat} \qquad \forall\, ma \in Ma, t \in T \qquad (19)$$

$$\sum_v W_v \leq V_{max} \qquad (20)$$

$$\sum_{t=1} X_{vt} \leq 1 \ \forall\, v \in V \qquad (21)$$

TPSBT= $\sum_v \sum_t TPSB \times X_{vt} \quad \forall\, v \in V$ (22)

TPBST= $\sum_v \sum_t TPBS \times X_{vt} \quad \forall\, v \in V,\ t \neq 1$ (23)

Service Time = $TS_{ka} \times Z_{katv} + TS_{la} \times Z_{latv} + TS_{ma} \times Z_{matv} \quad \forall\, v \in V$ (24)

Departure Time = $TP_{dka} \times P_{dkatv} + TP_{dla} \times P_{dlatv} + TP_{dma} \times P_{dmatv} \quad \forall\, v \in V$ (25)

Travel Time = $TP_{kakb} \times P_{kakbtv} + TP_{kalb} \times P_{klbtv} + TP_{kamb} \times P_{kambtv} + TP_{lakb} \times P_{lakbtv} + TP_{lalb} \times P_{lalbtv} + TP_{lamb} \times P_{lambtv} + TP_{makb} \times P_{makbtv} + TP_{malb} \times P_{malbtv} + TP_{mamb} \times P_{mambtv} \quad \forall\, v \in V$ (26)

Travel Time + Sevice Time+ Departure Time + TPSBT + TPBST +TPBD $\leq T_{max} \quad \forall\, v \in V$ (27)

CNv = (Travel Time + Departure Time + TPBD+TPSBT+TPBD) x K_v x BB $\quad \forall\, v \in V$ (28)

Decision Variabel

$X_k, X_l, X_m, X_{vt}, Y_{ik}, Y_{il}, Y_{im}, W_v, Z_{kv}, Z_{lv}, Z_{mv}, P_{d,ka,v,t}, P_{d,la,v,t}, P_{d,ma,v,t}, P_{ka,kb,v,t}, P_{ka,lb,v,t}, P_{ka,mb,v,t}, P_{la,kb,v,t}, P_{la,lb,v,t}, P_{la,mb,v,t}, P_{ma,kb,v,t}, P_{ma,lb,v,t}, P_{ma,mb,v,t}, P_{kb,ka,v,t}, P_{kb,la,v,t}$
$P_{kb,ma,v,t}, P_{lb,ka,v,t}, P_{lb,la,v,t}, P_{lb,ma,v,t}, P_{mb,ka,v,t}, P_{mb,la,v,t}, P_{mb,ma,v,t} \in \{0,1\}$ (29)

$A_{vt} \geq 0$ and integer (30)

The first objective function in equation (3.1) is to minimize transportation costs for waste transportation which consists of labor and fuel costs. Next, the second objective function (3.2) is to maximize the waste that can be colected by the TPS facilities that are maintained. The allocation of waste from the demand point has a maximum distance limit so that the distance from the demand point to the TPS that will accommodate the waste is not more than the maximum distance for disposal if the TPS is maintained so that equation (3.3) is formed. This constraint applies to each demand point of waste for each type of TPS. The next constraint that waste can be covered by at least one facility is shown by equation (3.4). This equation shows that the demand point of waste can be allocated to the depo, container and TPSS. Equation (3.5) shows that in the waste allocation to TPS, the volume of waste that will be allocated from the demand point does not exceed the capacity of each type of TPS. Equation (3.6) shows that the facilities to be maintained for each type of TPS will not exceed the maximum TPS that will be maintained according to the decision maker. Each vehicle that will be used can visit one of the TPS after leaving the depot as shown in equations (3.7) and (3.8). Furthermore, a continuity equation is needed where the vehicle will serve from the first trip shown by equation (3.9). Equations (3.10) and (3.11) show that the amount of waste carried by the vehicle for each trip will not exceed the vehicle capacity for each trip. Equations (3.12) and (3.13) show that if the vehicle capacity is still sufficient there will be a trip to another TPS point and shows that after serving a TPS it will leave these TPS. The following equations apply to each type of TPS. The next TPS to be visited is the TPS which is also served in the same trip as shown by equations (3.14) and (3.15). This constraint applies to each type of TPS to the same type of TPS and to other types of TPS. Equations (3.16) and (3.17) show that there will be services when the vehicle is used. Constraint (3.18) shows split delivery where the TPS will be served more than once when the capacity exceeds the vehicle capacity so that the vehicle will carry garbage at these TPS until its capacity is full. Limited land affected this model need constraint for the number of vehicles that can service TPS on the same trip as shown in equation (3.19). Constraint (3.20) and (3.21) Furthermore equations (3.22) and (3.23) show that if there is transportation activity on a trip then there will be a trip from the TPA to the center point of the sector or vice versa, but for the first trip there will only be trips from the center point of sector to the landfill so it is necessary to calculate the travel time. This is based on the assumption that the center point of the sector can represent other TPS facilities in thi area because of the radius in the covering of a facility. Equations (3.24) to (3.27) show the time limit that does not exceed the working hours of the vehicle. Meanwhile, the equation (3.28) shows that the total cost of fuel is determined by the amount of time each vehicle travels, vehicle speed and fuel cost per meter. A decision in the mathematical model is shown in the equation (3.29) to (3.30).

2.3 Equivalent Single Objective Model

The Multi Objective Integer Linear Programming model will be solved by Single Objective model use Fuzzy Goal Programming. The development of the Fuzzy Goal Programming model builds on the mathematical model of previous research, namely (Zimmermann 1978, Li et al. 2004, Biswas and De 2016, Mamashli and Javadian 2021) with the following membership functions.

If $F_i(x) \geq f_i$, so

$$\mu_{fi}(x) = \begin{cases} 1 & F_i(x) \geq f_{imax} \\ \frac{F_i(x) - L_i}{f_{imax} - L_i} & L_i \leq F_i(x) \leq f_{imax} \\ 0 & f_i(x) \leq L_i \end{cases} \tag{31}$$

If $F_i(x) \leq f_i$, so

$$\mu_{fi}(x) = \begin{cases} 1 & F_i(x) \leq f_{imin} \\ \frac{U_i - F_i(x)}{U_i - f_{imin}} & f_{imin} \leq F_i(x) \leq U_i \\ 0 & F_i(x) \geq U_i \end{cases} \tag{32}$$

U_i and L_i are the lower and upper limits of the desired decision maker preferences, while f_{imax} and f_{imin} are the optimal values of the mathematical model. So that the fuzzy goal programming equation that will be used is as follows.

$$\text{Max } \lambda \tag{33}$$

Subject to

$$\sum_V CB \;\; B_V \, W_v + \sum_v CN_v + (\overline{Z_1} - Z_1^*)\lambda \leq \overline{Z_1} \tag{34}$$

$$\sum_i \sum_k Y_{ik} + \sum_i \sum_l Y_{il} + \sum_i \sum_m Y_{im} - (Z_2^* - \overline{Z_2})\lambda \geq \overline{Z_2} \tag{35}$$

3. Data Collection

This research used data from google maps application, google earth application, direct observation and secondary data Yogyakarta Environment Department (DLH) and other departement. The detail is:

1. The number of each type of TPS along with the volume.
2. The location of the 23 TPSs (1 Depo, 1 Container, 21 TPSS) and its capacities.
3. Vehicle capacity and its working hours.
4. Distance between demand point and facility.
5. Distance between facilities.
6. Distance between final disposal and center point of sector.

7. Volume of solid waste calculate by multiplying the number of people each area with the waste can be produced by each individu (0,00188 m^3/day).
8. Loading and unloading time of vehicles in waste disposal is assumed, the loading time is assumed to be 4 minutes/m^3 and unloading is 2 minutes/m^3.

4. Results and Discussion

4.1 Numerical Result

MSW consists of generation, storage, collection, transfer-transport processing, and disposal (Sharholy et al. 2008, Hoornweg and Bhada 2012). The development of this model focuses on collecting activities at waste collection points and transportation activities to final disposal because Indonesia has not maximally used recycling facilities, compost plants, and incinerators in several cities so that waste management is still dominated by waste collection point (TPS) and then continued with Final Disposal (TPA). The decision space for determining the location can be divided into three, they are discrete space, network space, and continuous space (Karimifar et al. 2009). This research provides a discrete decision space with maximal covering problem. Regarding Daskin (2008) the Maximal Covering Location Problem is a method that has objective to maximize the number of covered demand points at a coverage distance from the facility points. Maximum covering problem can use to allocation the obxious facility like waste collection point to maximize the demand (Farahani et al. 2012, Medrano-Gomez et al. 2020, Hartini et al. 2021, Wang et al. 2020). Beside use a constraint from maximum covering problem to facility location decision, this model use constraint drom vehicle routing problem. VRP is needed in waste management for optimizing waste transportation (Zsigraiova 2013, Huang and Lin 2015, Assaf and Saleh 2017, Sulemana et al 2019, Asefi et al. 2019). The constraint in this model is from Vehicle Routing Problem with Multiple Trips and Intermediate Facility (VRPMTIF). Vehicle Routing Problem with Multiple Trips and Intermediate Facility is a variation of the Vehicle Routing Problem (VRP) problem that is added by multiple trips and intermediate facility constraints (Fitria and Susanty 2009, K Syahputri et al. 2019). The VRPMTIF model can be applied to the waste transportation system in the Yogyakarta, because the vehicle will be allocated to go on a trip, they are the departure trip from the depot, the delivering service between TPS and disposal trip to the TPA (intermediate facility) to unloading the waste or return from the TPA to the depot or to the TPS for another transportation. Furthermore, the model to be developed is characterized by Multi-Objective Integer Linear Programming and solve by fuzzy goal programming. Fuzzy goal programming used because in goal programming, deterministic assumptions are applied so that if the parameters are fuzzy or stochastic, the decision will be difficult to get (Aouni et al. 2010, Diaz-Madroñero et al. 2014, Mamashli and Javadian 2021).

This mathematical model was coded in Lingo 11.0 software and Microsoft Excel to obtain optimum global results. First, the optimal value is determined for each objective function with branches and bound using Lingo 11.0 software. The optimal value for the first objective function is IDR 1.431.608,00 and the second objective function is 103,08 m^3/day. Maximal solid waste management cost is IDR 1.605.000,00 from labor costs and 15 liters of diesel fuel costs for each vehicle. Minimal waste can be covered 74% of the total waste is in accordance with Yogyakarta Mayor Regulation Number 67 of 2018. Based on this, the fuzzy membership for each objective function is as shown in Figure 2.

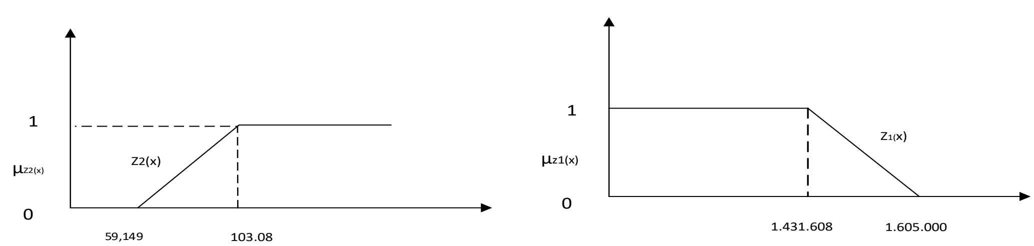

Figure 2. Fuzzy Membership

Furthermore, the optimal value used for solving the model with fuzzy goal programming. The result shows the value of λ is 0, 47. In consequence, the result had not approached the optimum value yet for each objective function. The value of fuzzy membership is as follows.

$$\mu_{z1} = \frac{1605000 - 1431608}{1605000 - 1431608} = 1 \quad (36)$$

$$\mu_{z2} = \frac{79{,}93 - 59{,}149}{103{,}08 - 59{,}149} = 0{,}473 \quad (37)$$

The results of solving the model with Lingo 11.0 software can be seen in Table 1 and Table 2.

Table 1. TPS Facilities that are Maintained and demand point that will be covered

No.	TPS	TPS Capacity (m^3/day)	Demand Point	Solid Waste Volume (m^3/day)
1.	TPSS Kusbini I	24	Kotabaru Klitren	5,16 17,98
2.	Depo Sagan	24	Baciro	23,13
3.	TPSS Pengok	36	Demangan Terban	16,37 17,27

Table 1 shows the facilities that will be maintained along with the waste that can be covered by these facilities. To accommodate waste from 5 demand point with volume 79,93 m^3/day need 3 TPS from 23 TPS in sector Krasak with total capacity 84 m^3/day. So, after the waste collected at waste collection point it will transport to final disposal. This model asummed provide 5 vehicles because in Yogyakarta use 40 dumptrucks to dispose the solid waste from 8 sectors. Meanwhile, the routes for waste disposal at TPS are as follows.

Table 2. The Results of Data Processing Routing

No.	Vehicle	Route	Total Trip	The total time (minute)	Waste can be transported (m^3/day)
1.	1st Vehicle	Depot - Depo Sagan – TPA Piyungan - Depo Sagan – TPA Piyungan – TPSS Pengok - TPA Piyungan - Depo Sagan – TPA Piyungan – Depot	5	339,3	24
2.	2nd Vehicle	Depot – TPSS Kusbini I - TPA Piyungan – Depot	2	85,47	6
3.	3rd Vehicle	Depot – TPSS Pengok – TPA Piyungan – TPSS Kusbini I – TPA Piyungan - TPSS Kusbini I – TPA Piyungan - Depo Sagan – TPA Piyungan – Depot	5	336,03	24
4.	4th Vehicle	Depot – TPSS Pengok – TPA Piyungan – Depot	2	84,03	6
5.	5th Vehicle	Depot – TPSS Kusbini I - TPA Piyungan – TPSS Pengok - TPA Piyungan - TPSS Pengok - TPA Piyungan - TPSS Pengok - TPA Piyungan – Depot	5	337,47	24
			19	1182,3	84

Table 2 shows that to transport waste from TPS which is still maintained in the Krasak sector, it requires 5 vehicles in 19 trips with total routing time of 1182,3 minutes for all vehicle. Based on tables 1 and 2, the developed model can reduce the number of facilities that will be maintained so that the facilities visited by vehicles are slightly less and each vehicle will work under the maximum working hours of the vehicle (420 minutes).

4.2 Sensitivity Analysis

Sensitivity analysis use to determine how the parameters changes can affect the objective functions. The sensitivity analysis was carried out on the parameter of the volume of waste by increasing and decreasing it by 5% and 15%, the presentation considers the increase volume of waste in some conditions. The results of the analysis are shown in Table 3.

Tabel 3. Sensitivity Analysis

No.	Condition	TPS will be Covered the Solid waste	Vehicle	Transportation Cost	The maximum amount of waste that can be covered at the TPS	λ
1.	Real Data	Depo Sagan TPSS Pengok TPSS Kubini I	5 Vehicles, 19 Trips	IDR 1.431.608,00	79,93 m^3/day	0,473
2.	Waste volume increased by 5%	Depo Sagan TPSS Pengok TPSS Kubini I	5 Vehicles, 19 Trips	IDR 1.431.608,00	83,39 m^3/day	0,54
3.	Waste volume increased by 15%	The value of the first objective IDR 1,619,702.00 and the second objective 97,85 m^3/day				
4.	Waste volume reduced by 5%	Depo Sagan TPSS Pengok TPSS Kubini I	5 Vehicles, 19 Trips	IDR 1.431.608,00	75,93 m^3/day	0,38
5.	Waste volume reduced by 15%	Container RRI TPSS Pengok TPSS Kubini I	5 Vehicles, 20 Trips	IDR 1.472.069,00	83,22 m^3/day	0,58

When the volume of waste is increased, the waste that can be covered will increase so the waste collection point that will be maintain can be changed and the transportation costs depends on the TPS that will be used when the volume is increased or decreased. Increasing 15 % waste volume make the optimal value of each destination function changes to exceed the maximum value of the target cost of transportation in real conditions, so it is necessary to provide more budget to anticipate transportation when the volume of waste increases or increase the vehicle to be used.

6. Conclusion

These hybrid mathematical models of fuzzy theory, max covering problem, and vehicle routing problem can simultaneously solve the problems on network waste management at Krasak Sector, Yogyakarta. The development of this model can reduce the number of TPS that will be maintained from 23 TPSs to 5 TPSs and it affects the routing activity. The TPS that will be maintained to accommodate waste from 5 urban areas in Gondomanan are Sagan Depot, Kusbini I TPSS, and Pengok TPSS with maximum waste that can be accommodated is 79,93 m^3/day. Meanwhile, from its TPS, disposal route by 5 vehicles in 19 trips with the total cost of disposal activity is IDR 1.431.608,00 and maximal routing time 339,3 minute. The sensitivity analysis results showed that by increasing the waste volume can make increasing in the amount of total collected waste and change the waste collection point that will be maintain that affected waste transportation activity to final disposal. Further research can develop the model into a continuous model using the Geographic Information System (GIS) and develop the model into a heterogeneous fleet (using more than one vehicle type).

References

Adeleke, O. J., and Olukanni, D. O, Facility location problems : models, techniques, and applications in waste management, *MDPI*, pp. 1–20, 2020.

Alsalloum, O. I., and Rand, G. K., Extensions to emergency vehicle location models, *Computers and Operations Research*, vol. 33, no. 9, pp. 2725–2743, 2006.

Aouni, B., Martel, J. M., and Hassaine, A., *Fuzzy goal programming model: an overview of the current*, vol. 16, pp. 149-161, 2010.

Asefi, H., Shahparvari, S., Chettri, P., and Lim, S. Variable fleet size and mix VRP with fleet heterogeneity in Integrated solid waste management. *Journal of Cleaner Production*, vol. 230, pp. 1376–1395, 2019.

Assaf, R., and Saleh, Y., Vehicle-routing optimization for municipal solid waste collection using genetic algorithm : the case of southern nablus city, *Civil And Environmental Engineering Reports*, vol. 26, no. 3, pp. 57, 2017.

Azi, N., Gendreau, M., and Potvin, J. Y., An exact algorithm for a single-vehicle routing problem with time windows and multiple routes, *European Journal of Operational Research*, vol. 178, no. 3, pp. 755-756, 2007.

Banyai, T., Tamas, P., Illes, B., Stanvekiut, Z., and Banyai, A., Optimization of municipal waste collection routing : impact of industry 4.0 technologies on environmental awareness and sustainability, *International Journal of Environmental Research and Public Health Article*, vol. 16, no.4, pp. 1-24, 2019.

Biswas, A., and De, A. K., A fuzzy goal programming approach for solid waste management under multiple uncertainties, *Procedia Environmental Sciences*, vol. 35, pp. 245-256, 2016.

Cattaruzza, D., Absi, N., and Feillet, D., *Vehicle routing problems with multiple trips, HAL,* vol. 14, no. 3, pp. 223-259, 2016.

Das, S., and Bhattacharyya, B. K., Optimization of municipal solid waste collection and transportation routes. *Waste Management*, vol. 43, pp. 9-18, 2015.

Daskin, M. S. *Network and discrete location, models, algorithms, and applications*, New York: Willey, 1995.

Daskin, M. S., What you should know about location modelling. *Naval Research Logistics*, vol. 55,, pp 283-294, 2008.

Díaz-madroñero, M., Mula, J., and Jiménez, M., Fuzzy goal programming for material requirements planning under uncertainty and integrity conditions, *International Journal of Production Research,* vol. 52, no. 23, pp. 6971-6988, 2014.

Farahani, Reza Zanjirani., Hekmatfar, M, *Contributions to Management Science*, In Icclab, Nl, 2012.

Farahbakhsh, A., and Forghani, M. A., Sustainable location and route planning with GIS for waste sorting centers , case study : Kerman , Iran, *Waste Management & Research*, vol.37, no. 3, pp. 287-300, 2019.

Fitria, L., and Susanty, S. Penentuan rute truk pengumpulan dan pengangkutan sampah di bandung. *Jurnal Teknik Industri*, vol. 11, no. 1, pp. 51–60, 2009.

Hartini, S., Puspitasari, D., and Utami, A. A. Design of waste cooking oil collection center in Semarang City using maximal covering location problem: A finding from Semarang, Indonesia, *IOP Conference Series: Earth and Environmental Science*, vol. 623, pp. 1-8, 2021.

Hoornweg, Daniel., and Bhada, T., and Perinaz, *What a Waste a Global Review of Solid Waste Management*, 1st edition, Washington DC: World Bank, 2012.

Huang, S. H., and Lin, P. C., Vehicle routing-scheduling for municipal waste collection system under the "keep trash off the ground" policy, *Omega (United Kingdom)*, vol. 55, pp. 24–37, 2015.

Joseph, K., Perspective of solid waste management in india. *British Journal of Haematology*, vol. 143, no.2, 2008.

K, Syahputri., Rahmi M S, Indah R, Mangara M T, J. Determination of trash hauling routes using floyd warshall algorithm in medan barat district. *Journal of Physics: Conference Series*, 2019.

Karimifar, M. J., Sikarudi, M. K., Moradi, E., and Bidkhori, M., Competitive location problem. *Contributions to Management Science*, pp. 271-294, 2009.

Lei, L., Liu, S., Ruszczynski, A., and Park, S., On the integrated production, inventory, and distribution routing problem. *IIE Transactions (Institute of Industrial Engineers)*, vol.38, no. 11, 2006.

Mamashli, Z., and Javadian, N., Sustainable design modifications municipal solid waste management network and better optimization for risk reduction analyses. *Journal of Cleaner Production*, vol. 279, pp. 1-22, 2021.

Markov, I., Varone, S., and Micle, B., The waste collection VRP with intermediate facilities, a heterogeneous fixed fleet and a flexible assignment of origin and destination depot, *Transp-OR, Ecole Polytechnique Fédérale de Lausanne,* pp. 1-27, 2015.

Mesjasz-Lech, A., Reverse logistics of municipal solid waste - Towards zero waste cities, *Transportation Research Procedia*, vol. 39, pp. 320-332, 2019.

Ouhader, H., and Kyal, M., Combining Facility Location and Routing Decisions in Sustainable Urban Freight

Distribution under Horizontal Collaboration : How Can Shippers Be Benefited?*, Mathematical Problems in Engineering*, vol. 2017, pp. 1-18, 2017.

Sharholy, M., Ahmad, K., Mahmood, G., and Trivedi, R. C., Municipal solid waste management in Indian cities - A review. *Waste Management*, vol. 28, no. 2, 2008.

Speranza, C. A. and M. G., *The Split Delivery Vehicle Routing Problem: A Survey*. 1st edition, Springer Science + Business Media, LLC 2008, 2008.

Sulemana, A., Donkor, E. A., Forkuo, E. K., and Oduro, S., Effect of optimal routing on travel distance , travel time and fuel consumption of waste collection trucks. *Emerald Insight*. Vol. 30, no. 4, pp. 803-832, 2019.

Veenstra, M., Roodbergen, K. J., Coelho, L. C., and Zhu, S. X., A simultaneous facility location and vehicle routing problem arising in health care logistics in the Netherlands. *European Journal of Operational Research*, vol. 268, no. 2, pp. 703-715, 2018.

Wang, Z., Duan, Y., & Huo, J., Maximal covering location problem of smart recycling infrastructure for recyclable waste in an uncertain environment. *Waste Management and Research*, vol. 39, no. 2, pp. 396–404, 2021.

Xue, W., Cao, K., and Li, W., Municipal solid waste collection optimization in Singapore, *Applied Geography*, vol. 62, pp. 182-190, 2015.

Zandkarimkhani, S., Mina, H., Biuki, M., and Govindan, K., A chance constrained fuzzy goal programming approach for perishable pharmaceutical supply chain network design. *Annals of Operations Research*, vol. 295, no. 1, pp. 425-452, 2020.

Zimmermann, H. J., Fuzzy programming and linear programming with several objective functions, *Fuzzy Sets And Systems*, vol. 1, no. 1, pp. 45-55, 1978.

Zsigraiova, Z., Semiao, V., and Beijoco, F., Operation costs and pollutant emissions reduction by definition of new collection scheduling and optimization of msw collection routes using GIS., the case study of barreiro, Portugal, *Waste Mangement*, vol. 33, no. 4, pp. 793-806, 2013.

Biographies

Cahaya Annisaa is the graduate student in logistics and supply chain concentration in the Department of Industrial and Systems Engineering, Sepuluh Nopember Institute of Technology. Ms. Cahaya holds a Bachelor of Engineering degree in Departemen Industrial Engineering, Universitas Ahmad Dahlan.

Suparno is one of the Professor in the Industrial and Systems Engineering Department, Institut Teknologi Sepuluh Nopember, Surabaya. He earned BS in Industrial Engineering from Institut Teknologi Bandung, Indonesia, Master degree in Industrial Engineering from University of Wisconsin Madison, USA, and Ph. D in Engineering Management from University of Strathclyde, UK. His research interest includes operations management and supply chain management.