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RESEARCH PAPER

Positioning household waste transfer points: A municipality government-organized waste perspective

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Abstract. In response to growing importance of household waste management issue, this article deals with the positioning of household waste transfer points from a government-organized waste perspective. By taking Surakarta, a municipality in Central Java, Indonesia as an example, the problem in the municipality is formulated as an MILP, is approached with a capacity-weighted set covering method, and finally is solved by using software LINGO 11. The article concludes that the transfer point alternatives of Sondakan Kuburan, Norowangsan, SPSA, Pajang Rel, Bonoloyo and Kedung Tungkul should be selected in order to be able to serve all the household waste producers for the maximum household waste generated. On the contrary, the selection of Sondakan Kuburan, Bonoloyo and Kedung Tungkul only should be able to provide service to all of the household waste produced for the scenario of minimum amount of household waste.

Keywords: household waste; location-allocation; set covering; waste transfer point

1. Introduction

Waste is an issue of which importance and emergence grows over time (Kennes, 1998; Krook *et al.*, 2012; Mccunney, 1986; Wang *et al.*, 2016; Yu & Solvang, 2017; Yuan & Shen, 2011; Zaman, 2015). Lack of good waste management results in serious problems such as landslide (Defu *et al.*, 2013), disturbance to microhydro power station (Parlan, 2013) and negative impacts to land resources and environment (Wang *et al.*, 2010), to name a few. More specifically, poor management of household waste leads to a variety of mishaps (Giusti, 2009; Laurent *et al.*, 2014; Tai *et al.*, 2011). The mishaps are even critical in developing countries (Al-khatib *et al.*, 2007; Henry *et al.*, 2006; Oteng-ababio *et al.*, 2013; Owusu, 2010; Pasang *et al.*, 2007; Troschinetz & Mihelcic, 2009).

Recently, waste produced by households in Indonesia is organized as follows: The waste comes from households or industries, sanitary workers pick up the waste, the waste is collected at transfer points, the waste is transported to disposal sites by trucks, and

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landfilling to disposal sites (Djunaidi et al., 2015). From the scheme, it is clear that the household waste is transported from waste generators to transfer points. In many areas in the country, the transportation is carried out by third parties working for a set of waste generators.

The Municipality of Surakarta – or Surakarta in short –, located in Central Java Province, took a slightly different way of managing its waste from its counterparts. Before the waste is sent to the only disposal site of Putri Cempo, the waste goes from households trough two different routes (Nugrahadi, 2017): it goes to transfer points with the assistance of third parties, or collected by the third parties, the waste is brought to meet mobile transfer points and subsequently is transported to the Putri Cempo disposal site. This is not easy to do as whether the third parties bring the waste to the transfer points or to the mobile ones is uncertain in nature. As a consequence, the number of each type of waste transportation vehicles is not easy to determine. In the meantime, there exists in Indonesia the fact that authority owned by municipalities or districts increases duo to autonomy (President of Republic of Indonesia, 2014). Taking this fact into consideration, it seems logic to think that the household management in Surakarta should be carried out fully by the municipal government.

It is yet crystal clear that most of Indonesian governments at all levels exist in a situation where there are limited budgets. Within Surakarta context, the waste authority in the municipality is trying to reduce its 9 transfer points to a smaller number of them.

Taking all these factors into consideration, this article proposes the use of a simpler, more practical approach to the household waste management. More specifically, the household waste is proposed to be served by transfer points to which particular transportation means bring the waste and from which the household waste is sent to disposal site by separate transportation devices with larger capacities. Breaking down the waste management into two layers of logistics will, in turn, make the management simpler and easier to handle.

In order to do that, the problem under concern is formulated as a mixed integer linear programming (MILP) and is approached with a capacity-weighted set covering model. Using data obtained from the field, the model is solved by utilizing software LINGO 11.

The development of set covering models, to our best knowledge, can be traced back to the year 1971 (Bellmore & Ratfliff, 1971). Since then, the academic communities see an escalating number of research and publications on the application of set covering models (Farahani et al., 2012; Farahani et al., 2010). This includes those to waste management (Eiselt & Marianov, 2015; Purkayastha et al., 2015).

The rest of the article is organized as follows. Introduction is presented first. Details of the experiment is presented afterwards, followed by results and discussion. The article ends with conclusions.

2. Experimental details

The set covering model of the MILP under concern is as follows:

Minimize $\sum_{j \in J} c_j x_j$ (1)

Subject to:

$$\sum_{j \in N} y_{ij} \geq 1 \quad \forall_i \in I \tag{2}$$

$$\sum_{i \in I} v_i y_{ij} \leq c_j x_j \quad \forall_j \in J \tag{3}$$

$$x_j \{0,1\} \quad \forall_j \in J \tag{4}$$

$$x_{ij} \{0,1\} \quad \forall_i \in J \tag{5}$$

Where:

I = set of household waste producers (in the unit of Kelurahan)
J = set of alternative locations for waste transfer points
c_j = capacity of transfer point *j* (m^3/month)
v_i = household waste produced by producer *i* (m^3/month)
t_{ij} = travelling time from producer *i* to transfer point *j*
T_c = maximum covering time
$N_i = \{j | t_{ij} \leq T_c\}$
= all alternative locations of transfer point which are able to serve waste producer *i*

$$x_j = \begin{cases} 1, \text{if alternative } j \text{ is selected as transfer point} \\ 0, \text{otherwise} \end{cases}$$

$$y_{ij} = \begin{cases} 1, \text{if producer } i \text{ is served by point } j \\ 0, \text{otherwise} \end{cases}$$

Function (1) minimizes the total number of capacity-weighted transfer point to open. Constraints (2) set the requirements that each waste producer should be served by at least 1 transfer points. The requirement that each open transfer point can only serve waste producers at its capacity is reflected by constraints (3). The constraints also necessitate that a waste producer can only be served by an open transfer point. Finally, constraints (4) and (5) relate to yes-no decisions.

Surakarta consists of 5 Kecamatan, i.e. Banjarsari, Jebres, Pasar Kliwon, Serengan and Laweyan, and 52 kelurahan (a kelurahan is similar with a village). With a total area of 44 km^2, in 2014 the city has 585,486 inhabitants. Despite small in size, Surakarta is regarded as one of important regions in Central Java. With the density of 13,294 inhabitants/km^2 (2014) (BPS Kota Surakarta, 2104), the city falls into one of the most populous cities in the province.

Taking the density into account and considering the fact that the settlements in the city are close to each other, the waste authority in the municipality is seriously considering to lessen its 9 existing transfer points to a fewer number of them. With this reason and by applying criteria of distance from human settlements or public facilities, the authors dropped 3 of the existing transfer points off from location alternatives.

Data on alternative locations for transfer points and their capacity, household waste producers and waste resulted, and maximum covering time were collected from the

Environment Agency. The data were verified by field observation. On the other hand, google map was used to gain data on travelling times between location nodes.

Table 1 provides data on alternative locations for transfer points and their daily capacity. Data on household producers is available in Table 2. From January 2016 to January 2017, it is found that waste produced in January 2016 and January 2017 constitute the minimum and maximum amount of waste resulted during the time period. These two are selected as data going into further processing and analysis, and are provided in Table 2. Figure 1, in the meantime, provides the locations in map of Surakarta. The authority gives information that the maximum covering time is exactly the working hours during a day, that is, 8 hours. Using the equations (1)-(5), the data were subsequently processed by utilizing optimization software LINGO 11.

Table 1. Data on alternative locations for transfer points

Alternative	Capacity (m^3/day)
Sondakan Kuburan	150.00
Norowangsan	15.00
SPSA	48.00
Pajang Rel	50.00
Bonoloyo	250.00
Kedung Tungkul	200.00

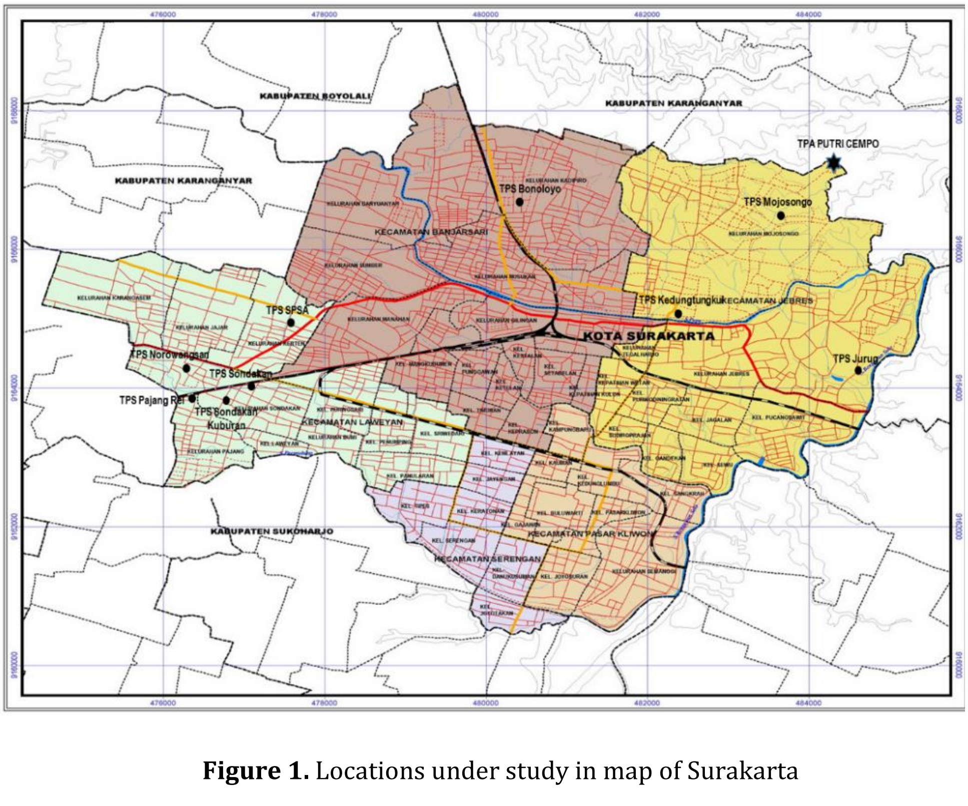

Figure 1. Locations under study in map of Surakarta

Table 2. Data on household waste producers

Subdistrict	No.	Village	Volume (m^3/ month)	
			January 2016	January 2017
Banjarsari	1	Banyu Anyar	562.60	773.24
	2	Gilingan	649.48	654.52
	3	Kadipiro	131.32	580.80
	4	Kestalan	265.32	271.24
	5	Ketelan	233.92	232.36
	6	Keprabon	199.36	204.20
	7	Manahan	646.96	788.48
	8	Mangkubumen	518.00	550.95
	9	Nusukan	652.08	736.56
	10	Punggawan	312.00	341.60
	11	Stabelan	349.04	364.92
	12	Sumber	485.40	572.84
	13	Timuran	163.68	218.92
Jebres	14	Gandekan	354.88	409.92
	15	Jagalan	510.68	555.60
	16	Jebres	784.24	928.56
	17	Kampung Sewu	233.16	285.76
	18	Kepatihan Kulon	154.56	117.12
	19	Kepatihan Wetan	166.44	182.24
	20	Mojosongo	203.04	511.96
	21	Pucang Sawit	528.40	603.88
	22	Purwodiningrat	269.40	252.88
	23	Sudiro Prajan	143.48	198.48
	24	Tegal Harjo	186.44	230.28
Pasar Kliwon	25	Balaikota 1270	54.64	49.40
	26	Baluwarti	317.20	342.12
	27	Gajahan	211.08	258.28
	28	Joyosuran	423.72	515.84
	29	Kampung Baru	218.08	249.96
	30	Kauman	165.36	218.28
	31	Kedung Lumbu	311.64	340.32
	32	Pasar Kliwon	238.04	391.12
	33	Sangkrah	430.36	561.40
	34	Semanggi	1349.72	1806.72
Serengan	35	Danusuman	441.28	505.08
	36	Jayengan	260.96	253.68
	37	Joyotakan	331.36	340.88
	38	Kemlayan	221.00	210.44
	39	Kratonan	290.08	341.04
	40	Serengan	431.68	504.16
	41	Tipes	544.60	600.72
Laweya	42	Bumi	240.08	209.48
	43	Jajar	382.28	459.96
	44	Karangasem	380.32	510.68
	45	Laweyan	117.68	116.40
	46	Kerten	336.12	293.52
	47	Pajang	260.88	405.32
	48	Panularan	324.16	478.00
	49	Penumping	298.88	359.08
	50	Purwosari	437.60	424.00
	51	Sondakan	174.40	196.08
	52	Sriwedari	300.00	311.00
		Total	18,197.08	21,820.27

3. Result and discussion

This article deals with the positioning of disposal sites in Surakarta from the viewpoint of the municipality and by taking into account capacity constraints. Formulated as an MILP, the problem under concern is approached by a set covering method and is solved with software LINGO 11. Table 3 presents the result in brief.

Table 3. Summary of the results

	Time period	**January 2017**	**January 2016**
	Waste volume (m^3)	21,820.27	18,197.08
	Transfer points selected	Sondakan Kuburan, Norowangsan, SPSA, Pajang Rel, Bonoloyo and Kedung Tungkul	Sondakan Kuburan, Bonoloyo and Kedung Tungkul
	Capacity of transfer points selected (m^3)	22,103.00	18,600.00
		Household waste producers served by the transfer points:	
Transfer point:	Sondakan Kuburan	Gilingan, Ketelan, Mangkubumen, Nusukan, Punggawan, Jagalan, Sudiroprajan, Sangkrah, Bumi, Sondakan	Kadipiro, Keprabon, Stabelan, Timuran, Gandekan, Jebres, Kepatihan Kulon, Kepatihan Wetan, Mojosongo, Sudiroprajan, Tegalharjo, Balai Kota 1270, Kauman, Joyotakan, Jajar, Karangasem, Laweyan, Sondakan
	Norowangsan	Kepatihan Wetan, Balai Kota 1270, Kauman	-
	SPSA	Banyuanyar, Kadipiro, Kepatihan Kulon	-
	Pajang Rel	Pucang Sawit, Baluwarti, Tipes	-
	Bonoloyo	Kestalan, Keprabon, Manahan, Stabelan, Sumber, Timuran, Gandekan, Jebres, Kampung Sewu, Purwodiningrat, Tegalharjo, Kampung Baru, Kedung Lumbu, Pasar Kliwon, Joyotakan, Kemlayan, Kratonan, Laweyan, Pajang, Penumping, Purwosari	Banyuanyar, Ketelan, Mangkubumen, Sumber, Jagalan, Kampung Sewu, Pucang Sawit, Purwodiningrat, Gajahan, Joyosuran, Kampung Baru, Pasar Kliwon, Sangkrah, Danusuman, Jayengan, Kemlayan, Serengan, Tipes, Bumi, Pajang, Purwosari
	Kedung Tungkul	Mojosongo, Gajahan, Joyosuran, Semanggi, Danusuman, Jayengan, Serengan, Jajar, Karangasem, Kerten, Panularan, Sriwedari	Gilingan, Kestalan, Manahan, Nusukan, Punggawan, Baluwarti, Kedung Lumbu, Semanggi, Kratonan, Kerten, Panularan, Penumping, Sriwedari

Table 3 gives clear information that, in order to be able to serve all the waste sources at its maximum production, the 6 alternatives for disposal site should be all selected. This makes the number of capacity-weighted disposal sites under study be minimized, with a total value of 22,103.00.

Given all the alternative sites been selected, the allocation of the chosen sites to the household waste producers in January 2017 is also available in Table 3. The table provides evidence that, among all sites, the Bonoloyo disposal site is assigned to household waste producers at the very most, that is, 21 household waste producers. On the contrary, each of the Norowangsan disposal site, the SPSA disposal site and the Pajang Rel disposal site only serve 3 different household waste producers. Finally, each of the sites of Sondakan Kuburan and Kedung Tungkul serves 10 and 12 household waste producers, respectively.

The use of smaller amount of waste, in this case, waste produced in January 2016, leads to different result of location-allocation scenario. From Table 3, the transfer points of Sondakan Kuburan, Bonoloyo and Kedung Tungkul only are sufficient to serve all the household waste producers. In this case, each of Sondakan Kuburan, Bonoloyo and Kedung Tungkul serves 18, 21 and 13 household waste producers, respectively.

Looking deeper at the solution, it can be seen that all the chosen transfer points have larger capacities relative to their counterparts. This should be associated with the objective of minimizing the total number of capacity-weighted transfer points. In this sense, the total capacity of the 3 transfer points in 1 January 2016 is (600.00 m^3/day) x 31 days = 18,600.00 m^3, whereas the total amount of waste produced in the same month is 18,197.08 m^3.

The problem under concern is approached by a type of set covering model. The solutions, however, may not seem appropriate from different perspectives. For example, Kelurahan of Gandekan, Jebres, Kepatihan Kulon, Kepatihan Wetan, Mojosongo, Sudiroprajan and Tegalharjo (all of them are within Kecamatan Jebres) are allocated to The Sondakan Kuburan transfer point in January 2016. In contrast, Kerten, Panularan and Sriwedari (all of these kelurahan are located in Kecamatan Laweyan) are allocated to the transfer point of Kedung Tungkul both in January 2017 and January 2016 scenarios. Looking at the map in Figure 1, the 2 transfer points are distant from the household waste producers allocated to each of them. The use of 8 working hours as the maximum travelling time makes any household waste producer be able to be served by any alternative of transfer points. In other words, constraints on maximum travelling time or maximum travelling distance simply do not exist. When the collection of waste is carried out by the community through the third parties, this creates another problem of fairness, since some waste producers should pay more to the third parties than the other household waste producers.

Regarding the abovementioned suitability of the solutions proposed, there are at least two ways of improvements that can be conducted. Firstly, it seems more suitable to use a psychological time limit set by the household waste producers (for example, due to their tolerance in paying the third parties) or owned by the their parties in association with their maximum travelling time preferences. Secondly, the use of other models of location-allocation taking fairness issues (for example, p-centre models (Thomas *et al.*, 2002) or dispersion models (Fernández *et al.*, 2013; Sayah & Irnich, 2017) into account also seems possible. These ways will give the solutions relatively fair for all the household waste producers despite the household waste organized by the municipality government.

The research presented in this article also uses deterministic values of travelling times between nodes. This raises another concern as, generally speaking, travelling times between any nodes fluctuate over time and inexact to some degree. To deal with this issue, the travelling times maybe more appropriate to be provided by implementing fuzzy logic as well (Hwang *et al.*, 2004; Ishii *et al.*, 2011; Kalantari *et al.*, 2014). Taking the fact that household waste produced tends to increase as time goes on (Karak *et al.*, 2013) into account should also be accommodated into the calculation. This way will make the solution obtained apply for a longer, reasonable period of planning horizon.

4. Conclusion

This article examines the positioning of household waste transfer points and household waste allocation to the points from the perspective of a municipality government-organized waste. Taking the municipality of Surakarta as a context, the article concludes that, for the scenario of maximum waste generated, all the alternatives of transfer points of Sondakan Kuburan, Norowangsan, SPSA, Pajang Rel, Bonoloyo and Kedung Tungkul should be selected in order to be able to serve all the household waste producers. In contrast, the service to all of the household waste produced for the scenario of minimum amount of waste are able to be carried out by the transfer points of Sondakan Kuburan, Bonoloyo and Kedung Tungkul only.

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