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RECYCLING FACILITY LOCATION-ALLOCATION MODEL IN REVERSE LOGISTICS OF MUNICIPAL SOLID WASTE MANAGEMENT - A CONCEPTUAL FRAMEWORK

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Abstract: Unsustainable waste management system threatens individual health level, environmental structure, infrastructure of municipalities, and quality of life. In line with the Sustainable Development Goals (SDG) 12, by 2030 the generated waste must be reduced substantially through prevention, reduction, recycling, and reuse. Hence, providing adequate number of recycling facilities at strategic locations that are accessible by all, is a must. Bridging the current information on recycling facility location problem, this study highlights the structure on developing the state-of-the-art information and knowledge for recycling facilities location model. The paper also presents on the conceptual framework in attaining this model using renowned facility location problem concept with spatial analysis approach.

Keywords: facility location, municipal waste, recycling. waste management system, sustainable development goals

1. Introduction

Municipal waste system management (MSWM) in urban area is challenging (Choon et al., 2017). Inefficient MSWM can results in harmful public health and environmental impacts. Thus, sustainable MSWM design and approaches is required to address related economic, environmental, and social aspects for better sanitary infrastructure and services and life quality of the communities. Landfill, incineration, composting, and recycling non-organic waste are among commonly accepted methods for solid wastes disposal. Landfilling is the most preferred method for municipal solid waste disposal, by either developing or developed countries (Nanda & Berruti, 2021). However, it has disadvantages including emission of greenhouse gases (GHGs) that contributes to climate change (Noor et al., 2013) and source of pollutions (air, groundwater, and soil pollutions) and natural environment degradation (Vaverková, 2019).

Nowadays, many manufacturers have produced eco-friendly and recyclable goods, yet strong support from respective authorities in managing these wastes is very much needed. Recycling and reusability can preserve natural resources, reduce amount of waste produced by households and foster the transition towards a Circular Economy (Zaharudin et al., 2021). These moves are in line with the Sustainable Development Goals (SDG),

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which is one of the targets of Goal 12 (Responsible Consumption and Production), which stated that by 2030, the generated waste must be reduced substantially through prevention, reduction, recycling, and reuse. Thus, the implementation of reverse logistics in MSWM is consistent with the SDG. However, inconsistency in regulations by local authorities could results in low participation in recycling and waste separation behaviour among households. People, especially households, play a prominent part in MSWM (Babaei et al., 2015) thus, recycling must be stimulated among the households since they are the highest generators of solid waste (Razali et al., 2019). Establishment of recycling centres that includes determining the number of these facilities and appropriate locations are among critical success factors of MSWM, but extensive challenges such as limited resources, budgets and operational costs are obstacles for proper implementation (Asefi et al., 2015). Optimal locations of recycling centres generate different impacts not just to MSWM and selected areas in general, but most importantly to recycling activities in the areas, thus locations' selection should involve various stakeholders including reverse logistics experts, local or state government and related businesses (Tadić et al., 2019).

Household waste recycling is a vital process towards reducing waste disposal and realizing the zero waste cities. Looking into this perspective, this paper emphasizes on discussing current studies concerning recycling facility location problem. The remaining of this paper is organised as the following. Section 2 presents a structured review of past studies on recycling facility location problem, covering from year 2018 until 2021. Section 3 proposes a mathematical programming model formulation for the recycling facility location-allocation problem. Section 4 concludes this paper by highlighting the significance of the proposed concept and our future works.

2. Structured Review of Past Studies on Recycling Facility Location Models

The method employed in coming up with the conceptual framework and preliminary mathematical model for the recycling facility location-allocation model is through a structured review of past related studies. The literature for our study is gathered using the SCOPUS search engine, focus within the "Article title, Abstract, Keywords" by using the keywords of "waste" AND "recycling" AND "facility location". As results, only 52 articles are related to recycling facility location problem and from year 2018 until 2021, there are only 12 published articles. The publication years of these articles are as presented in Table 1. Clearly, the interest in improving recycling facility location problems is a growing topic. However, despite recycling has been a topic of interest in current world issue, surprisingly limited articles were found on those focusing on improving the recycling rates by improving facility location network.

Table 1. Number of published articles per year

Year	2021	2020	2019	2018	Before 2018
Number of articles	1	6	2	3	40
Total	12				

Table 2 summarizes the information on type of recyclable wastes, area of case studies and, the mathematical models proposed on the articles published from 2018 until 2021. Based on this table, it can be stated that most mathematical models of these studies have been formulated as mixed-integer linear programming (MILP) and multi-objective (MO) mathematical programming (MP) model (having multiple objective functions).

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Table 2: Details on the selected articles

Authors (Year)	Type of MP			Solution Approach		Type of Waste	Country
	MILP	IP	MO	MCDM	MLP		
Yu and Tong (2021)	x					Metal	China
Utku and Erol (2020)	x					Hazardous	Turkey
Guan and Yang (2020)	x		x			Hazardous	-
Alarcon-Gerbier and Buscher (2020)	x				x	-	-
Kaya, Çiçekalan and Çebi (2020)				x		WEEE	Turkey
Caramia and Dalla Costa (2020)					x	-	-
Kumar *et al.* (2020)				x		WEEE	India
Šomplák *et al.* (2019)	x		x			-	Czech Rep.
Herrera-Granda *et al.* (2019)	x		x			-	Ecuador
Hrabec *et al.* (2018)	x		x			-	-
Rentizelas, Shpakova and Mašek (2018)	x					Plastic	UK
Aydemir-Karadag (2018)	x			x		Hazardous	China

MILP: mixed-integer linear programming; IP: Integer Programming; MO: multi-objective; MCDM=multi criteria decision making; MLP=multi-level programming.

Yu and Tong (2021) solved their proposed MILP model to find capacitated location of recycling facilities for end-of-life photovoltaic (PV) in Zhejiang province, China. The model minimizes the total cost based on two scenarios: (i) municipal waste recycling facilities provided by the authorities, (ii) recycling facilities provided by the PV producers. An MILP model was formulated by Rentizelas, Shpakova and Mašek (2018) to optimise locations and supply network of the pyrolysis plants (plant that uses pyrolysis technology for agricultural plastic recycling) of Scottish agricultural sector. Model's results highlight potential benefits of the plants and the MILP model as tool for decision making on agricultural plastic waste recycling that leads to waste reduction and circular economy. The MILP model was also used by Utku and Erol (2020) to determine recycling facilities, waste treatment and disposal facility locations for hazardous wastes in Marmara region, Turkey.

Guan and Yang (2020) formulated a bi-objective (MO) linear programming model for determining the location of recycling facility for hazardous waste, focusing on power batteries waste. The model considers social negative effects which expressed as a direct proportion to the number of transport power batteries between the facility nodes. Meanwhile, Aydemir-Karadag (2018) formulated an MILP model and applied the multi-criteria decision making (MCDM) for locating-routing problem of the hazardous waste management system for several regions in Turkey by considering several types of waste management facilities including recycling centres, treatment facilities (incineration and sterilization centres), and disposal centres. MILP was also utilised by Alarcon-Gerbier and Buscher (2020) who formulated an MILP model for the dynamic location problem of mobile recycling facilities in which a bilevel decomposition algorithm as multi-level programming (MLP) approach was proposed to solve the model. Caramia and Dalla Costa (2020) also used bilevel optimization model (MLP approach), for solving the waste collection centres location problem involving a hierarchical structure of one leader and a multi-follower where leader controls facility installation and capacities while followers assign customers to facilities.

The aims of the study by Hrabec et al. (2018) are to reduce waste produced, to attain the highest recycle rate and to use resulting residual waste for energy recovery in Czech Republic. A multi-objective (MO) MILP with two objective functions which are to

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minimize total GHG emission and to minimize cost has been proposed. The study by Šomplák et al. (2019) is an extension of the study of Hrabec et al. (2018) where the proposed MILP model considers integration of circular economy strategies in MSWM. The aims and objective functions of MILP model are similar to those in the earlier study. Herrera-Granda et al. (2019) applied a MO, MILP model in determining locations of urban municipal solid waste containers of Ibarra City, Ecuador, where model's objective functions concerns with minimizing investment cost and minimizing total distance from users to recycling containers.

Kaya et al. (2020) and Kumar et al. (2020) used MCDM approach to locate the Waste Electric and Electronic Equipment (WEEE) recycling plant. Kaya et al. (2020) ranked the criteria and sub-criteria as outlined by three experts working of the area of WEEE recycling by using Pythagorean fuzzy AHP (PFAHP) method. The MCDM approach was applied in Istanbul, Turkey. Meanwhile, Kumar et al. (2020) used Best-Worst Method (BWM) for ranking the criteria for a sustainable recycling plant location while the VIKOR method was applied for ranking recycling candidate locations. The presented MCDM model was applied in India.

Based on our review of past studies, it can be noted that most studies mainly concern with determining locations of recycling facilities for assorted materials (multi-types) solid waste where this would be advantageous as recyclable solid wastes can be classified into several types, such as metal, WEEE, plastic, and many more. Moreover, focusing only on specific type of recycling waste or facilities would only reduce household's participation in recycling activity. Based on the reviews also, it is found that studies focusing on establishing and improving recycling facilities locations in Malaysia by using mathematical programming models are still lacking. Thus, the gap analysis can be summarized into two-fold namely, i) studies involving mathematical modelling for recycling facility location-allocation problem especially in the context of Malaysia are non-existence and should be given attention, and ii) studies that are focusing on improving waste recycling facility in Malaysia are still lacking despite the fact that establishment of optimal recycling facilities location is imperative to improve recycling behaviour among public and to increase recycling rates.

2.1 A covering facility location model

Generally, facility location problems concern with a number of facilities to be located on a given network to satisfy a set of demand subject to some constraints such as population density in an area, facility-demand distances, and facility capacity, to guarantee availability and accessibility for all demand (Marín, Nickel & Velten, 2010).

Traditional covering is one the approaches that is embedded in facility location model to predetermine the accessibility of users to any potential facility location. The covering or coverability could be presented in coverage gap or radius (Zarrinpoor et al., 2017). The earliest models include Location Set Covering Model (LSCM) by Toregas et al. (1971) that determines the suitable facility locations to cover all demands within pre-specified time and distance while limiting the number of sets of provided facilities. Later, Church and ReVelle (1974) proposed the Maximum Coverage Location Problem (MCLP) to determine facility locations by maximizing demand covered for a fixed number of facilities. Daskin (1983) introduced an extension to MCLP, called the Maximum Expected Covering Location Problem (MEXCLP) that considers probability of server (facility) being busy when maximizing demand covered, where the probability was determined by using a heuristic procedure. Facility location model is applicable to any

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problems provided that two stakeholders exists: the users (demands) and the organizers (suppliers). Thus, problem of determining the number and locations of waste-disposal facilities definitely can be formulated as covering problems (Francis, White, & McGinnis, 1974) where any facility location models can be adapted and modified to solve recycling bins location-allocation problem in an urban area.

3. A mathematical model for recycling facility location-allocation

The proposed model of our study is based on *covering-like* model, as to ensure maximum demand can be covered within pre-specified distances or times between facilities and demand points. In this study, locations for recycling facilities within the municipalities urban area will be proposed. Unlike most covering-like models, the demand in our context is redefined as amount of waste generated per municipal area and for that reason, capacity constraint must be included to cope with real-life situation where every facility has limited space. Further enhancement of the capacity constraint could be done by adding the busyness likelihood or in our context, recycling facility reliability. In addition, since households generate multi-type of recyclable wastes, thus the model is added with an additional dimensional index to represent types of wastes. Combining the availability concept in defining the capacity and multi-type of recyclable waste results in an additional constraint to be required in defining the limitation of each recyclable wastes' containers in a recycling facility. Adaptation of conventional covering-like model for recycling facility location-allocation problem is presented as the following.

Notation – Sets, Indices, Parameters, and Input Variables:

i	:	index of municipal nodes, $i = 1, 2, \dots, m$
j	:	index of potential recycling facility location nodes, j$= 1, 2, \dots, n$
k	:	index of types of recyclable wastes, $k = 1, 2, \dots, t$
P	:	maximum number of recycling facility in a municipal area
U	:	maximum capacity of containers for each k waste in a facility *j*
d_{ik}	:	amount of *k* waste generated at each location i
c_j	:	fixed cost of locating facility at node *j*
q_{jk}	:	availability level of *k* waste container at each facility *j*
a_{ij}	:	1 if distance between municipal nodes and recycling facility location is less than prespecified distance *D*, 0 otherwise.

Decision variables:

$$x_j = \begin{cases} 1, \text{ if recycling facility is located at node } j \\ 0, \text{ otherwise} \end{cases}$$

$$y_{jk} = \begin{cases} 1, \text{ if facility } j \text{ is allocated with } k \text{ containers} \\ 0, \text{ otherwise} \end{cases}$$

w_{jk} = a non-negative proportion for containers of recyclable wastes k in a facility *j*

Model Formulation:

$$\text{Maximize} \quad \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{t} d_{ik} q_{jk} y_{jk} \tag{1}$$

subject to:

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$$\sum_{k=1}^{t} y_{jk} - \sum_{i=1}^{m} a_{ij} x_j \leq 0 \qquad , \ j = 1, 2, \ldots, n \tag{2}$$

$$\sum_{k=1}^{t} k y_{jk} \leq U \qquad , j = 1, 2, \ldots, n \tag{3}$$

$$y_{jk} - \sum_{k=1}^{t} w_{jk} \leq 1 \qquad , j = 1, 2, \ldots, n \tag{4}$$

$$\sum_{j=1}^{n} x_j \leq P \qquad , j = 1, 2, \ldots, n \tag{5}$$

$$y_{jk}, x_j \in \{0.1\} \qquad , j = 1, 2, \ldots, n \tag{6}$$

Equation (1) represents the objective function of the model that is to maximize total amount of generated waste covered by a facility j. Constraints of the model are presented by inequalities (2) – (6). Constraint (2) ensures all waste generated from municipalities area i is covered by at least one recycling facility j. Constraint (3) limits the amount of waste per facility j, with respect to waste type k, and constraint (4) ensures the availability of containers for each k type. Meanwhile, Constraint (5) restricts the number of facilities in an area to at most P locations. Lastly, Constraint (6) restricts the values of the decision variables to be either 0 or 1 (binary). In the proposed model, the availability concept in objective function (1) is adapted from Shuib and Zaharudin (2011) where,

$$q_{jk} = 1 - (b_j)^k \qquad , j = 1,2, \ldots, n \qquad (6).$$

The $(b_j)^k$ indicates the busyness level of facility j with type of k waste. This value is gained from $b_j = \frac{\sum_{i=1}^{m} d_i a_{ij}}{\sum_{i=1}^{m} d_i}$ i.e., the capability of facility j to cover waste from municipalities i. Besides, the 0-1 value of a_{ij}, further improvement could be implemented such as by using gravity model (see: Zaharudin et al., 2021) or fuzzy set theory approach (see: Kaya et al., 2020). The model is expected to be able to provide an information on potential recycling facility locations, concurrently assigned the waste generated from municipality areas to these facilities. With the capacity constraint, the availability of containers for different type of recyclable wastes can be guaranteed.

4. Conclusions and future works

The paper has presented the review of recent studies on mathematical programming models in solving recycling facilities location problem. Even though the number of literatures is growing, it seems that studies concerning the recycling facilities location-allocation problem has not received substantial attention from academic world, especially from those in developing countries, despite the importance of recycling in MSWM towards contributing for achievement of the respective SDG. In fact, many MSWM studies focused more on analysing, evaluating, and synthesizing the current recycling participation or behaviour among the public or for municipalities areas whereas attention should be given on improving recycling rates which could be accomplished by determining the optimal locations for recycling facilities. Traditional facility location

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model emphasised on this concept where the methodology has been widely used either in public or private organizations. Our study enunciates on the applicability of conventional facility location problem with some refinement on input's definitions. The proposed mathematical model, a covering-like model, is enriched with MSWM system characteristics as presented in earlier section. It has also been found that studies focusing on improving Malaysia's MSWM recycling system by using mathematical modelling and optimisation approach are still lacking. Thus, in our future work, the proposed model will be applied in improving recycling facility network in Malaysia, focusing on urban municipalities by significantly reducing generated waste via 3Rs with higher participation from households largely contributed by the strategic optimal locations of the waste recycling centres.

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