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Location-Allocation Model of Recycling Facilities – A Case Study of Seremban, Malaysia

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Abstract

Sustainable municipal solid waste management (MSWM) is a necessity in any country. One of the modules is recycling practice, where this would directly reduce the amount of waste sent to landfill. Recycling represents the reverse logistic module that requires high engagement from municipal waste generators, especially at the residential level. This engagement could be gained by providing an optimal number of recycling facilities at the strategic location. These recycling facilities, such as public recycling bins, could improve the recycling rates. At the same time, it reduced the operational costs of the respective authorities to sort the collected waste. For this reason, this study proposed a recycling facility location-allocation model in an urban area. The model is developed by utilizing the classic facility location problem approach, i.e., covering the model with capacity consideration. The proposed model is then applied in Seremban, i.e., an urban area in Malaysia. As result, it is found that the proposed model can determine the optimal location-allocation for the recycling bins to cover the area of study.

Keywords: Facility Location, Waste Management, Recycling, Circular Economy, Sustainable Development Goals

Introduction

Municipal solid waste management (MSWM) is the system that manages the municipal solid waste (MSW), which includes the collection, transportation, processing, recycling or disposal, and monitoring of waste materials (Demirbas, 2011), where several stages with several types of facilities are involved. The MSWM requires its respective authority to manage all the operations of these waste facilities, while ensuring and improving each facility's targeted performance level. The amount of MSW produced increases proportionately with the global population. Improper waste management will create numerous environmental issues, such as water pollution, air pollution and health problems (Tiew et al., 2019). Landfilling is the most prevalent waste disposal option; however, it will unfortunately increase greenhouse gas emissions, which subsequently leads to global warming. Incineration is another waste disposal method, but it can also cause environmental damage. Through sustainable waste management, the amount of waste that is sent to landfill can be reduced.

One of the highest solid waste producers are the households (Razali et al., 2019), thus it is important to promote and encourage waste separation at the source program. Besides that, the local authority can encourage people to engage in recycling practices in prominent areas by ensuring the accessibility and availability of recycling facilities, such as drop-off bins or recycling points, in strategic locations. Hence, a clean development mechanism can also be integrated into the waste management model (Potdar et al., 2016) and benefit the government financially especially in reducing the amount of managed waste to be sent to landfill (Razali et al., 2020). This practice also represents the zero-waste principles, which are the key to develop a smart and sustainable city, in accordance with the two Sustainable Development Goals (SDGs), which are SDG 11 and SDG 12. SDG 11 focuses on making cities more inclusive, safe, resilient, and sustainable, whereas SDG 12 focuses on responsible consumption and production. For this reason, the establishment of optimal recycling facility locations is required in order to encourage households to recycle.

Literature Review

Facility location studies are not a new field of research; they have been established for decades in both the public and private sectors. Facility location challenges, generally, include a number of facilities that must be positioned on a network in accordance to satisfy a set of demands while following to particular constraints (Marín et al., 2010) that assure the facilities' availability and accessibility. Traditional coverage variable is one of the ways contained in the facility location model to predetermine user accessibility to each proposed facility location.

A coverage gap or a radius can be used to represent the covering or coverability (Zarrinpoor et al., 2017); Daskin (1983) proposed one of the most well-known facility location models, the Maximum Expected Covering Location Problem (MEXCLP). It investigates the likelihood of a server (facility) being busy, where the probability was derived using a heuristic technique when maximizing the demand covered. Daskin (1983) used the MEXCLP to solve the ambulance location problem, taking into account the probability of ambulance busyness when computing the covering level. Much recent works, Jamiron et al (2021) expands the MEXCLP model to address the problem of recycling facility location. The model is then implemented in an urban municipality in Malaysia. Aside from MEXCLP, various models have been developed to address the problem of recycling facility location. In reality, any form of facility location problem model, including the location-allocation problem for recycling bins in a municipality, may be changed and adjusted to match the specific focal problem.

To the utmost of our knowledge, there has not been any study conducted on the main notion of the location model in establishing the recycling bin's location. In fact, most earlier studies concentrated on resolving problems on multi-type waste (not just recyclable waste), multi-facility and multi-stage location. For instance, Olapiriyakul (2017); Olapiriyakul et al (2019) used a multi-objective (MO) model to identify various types of waste facilities in the MSWM network, such as sorting facilities where recyclable goods were collected by local private enterprises. Both studies differed in terms of public health impacts measurement, where Olapiriyakul (2017) measured the impacts based on the extent of the residential area that was affected by the unpleasant sanitary effects of waste sites, which were gathered using the geographic information system (GIS). Meanwhile, Olapiriyakul et al (2019) use the life-cycle impact assessment (LCIA) technique to calculate the impacts using disability-adjusted life years (DALYs).

Gilardino et al (2017) suggested a mixed integer linear programming (MILP) technique to determine the needed placement and number of recyclable waste and general waste bins, including collection routes, in Lima, Peru, by reducing the total number of general and recyclable waste collection sites. Rathore and Sarmah (2019) presented a MILP with GIS for identifying transfer station locations in Bilaspur, India. Similar approach and area of study were considered by Rathore et al (2020) used a similar approach and research area to allocate and locate the number of two MSW bins types, organic (compostable) and inorganic (recyclables, plastics, and inert). GIS was also used by Nowakowski and Mrówczyńska (2018) to detect the best electrical and electronic equipment (WEEE) collection places, designate vehicle collection routes, as well as establish the containers optimal quantity at each prospective facility point in Sfax, Tunisia.

Harijani et al (2017) suggested a MOMILP relying on social, environmental, and economic factors to locate MSW in Tehran, Iran, with an emphasis on the disposal and recycling network. Moreover, Harijani et al (2017) took a similar method, employing a multi-period element to portray and cope with the dynamic quantity of operational costs, transportation, as well as generated waste. The same factors were considered by Asefi and Lim (2017) to determine the routing, capacities, and locations_of MSWM facilities several types by merging a multi criteria decision making (MCDM) technique (for example, Delphi-Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)) into the GIS environment.

Blazquez and Paredes-Belmar (2020) assigned location for waste collection bins and planned the optimal waste collection service route in Renca, Santiago, by using MILP with Large Neighborhood Search (LNS) heuristic through a two-stage methodology approach. In the same area of study, Letelier et al (2021) considered the same approach to tackle the bin location-allocation problem with regards to recyclable and household waste separately, with the use of the MILP model and GIS. The authors also considered the municipality's and users' preferences in the decision-making process. Moreover, the preference of the users and the municipalities was also used in the gravity model by Zaharudin et al (2021) in providing an empirical analysis for understanding the effects of closures, downsizing and expansion of the recycling centres network.

This paper proposes an approach to reducing waste sent to landfills by establishing optimal recycling facility location and allocation within urban municipalities, focusing on households' areas. Besides Jamiron et al (2021), studies that used Malaysia as a case study are hardly found. Hence, the goals of this paper are to: (i) address a deficiency in the literature by establishing a mathematical model for identifying and allocating recycling bins for urban areas, and (ii) apply the model to a Malaysian municipality area. To do so, we utilized improved a mathematical model for facility location-allocation. The remaining sections of the paper are organized as follows: Section 2 highlights the current waste management system in the case study area, i.e., Seremban, Malaysia. Section 3 demonstrates and discusses the developed model and Section 4 discussed the case study's findings. Conclusions and recommendations for future research are presented in Section 5.

Case Study: Waste Management System (WMS) in Malaysia

Malaysia is a developing country with a growing population and a steadily increasing MSW generation. MSW in Malaysia was in a period of transition from 1960 until the official solid waste management legislation was fully implemented in 2011 (Abas & Wee, 2016). Statistically, the average amount of generated MSW in Malaysia for 2018 was about 38,200 tons per day (1.12 kg/cap/day) (Imran et al., 2019) and it was predicted that Malaysia will generate approximately 14 million tonnes of waste by 2022 due to population growth (Hassan et al., 2021). Currently, low public participation are among the biggest challenges in establishing a substantial MSWM system (Khamaruddin et al., 2019), where more than 80% of these disposed wastes are recyclables (Devadoss et al., 2021).

Waste disposal in Malaysia still relies on landfilling approach to manage solid waste due to its low cost (Imran et al., 2019), even though this is the least preferred waste disposal method (Moh & Abd Manaf, 2017). Soon, Malaysia will be incapable of holding the rising amount of waste (Rahim et al., 2021). Furthermore, it was reported that about 10,000 tons of good food and plastic were disposed in a day and these will disrupt the drainage system, which will eventually lead to flash floods (Ab Malek, 2021). Clearly, there is a need to emphasize on sustainable MWSM, especially crucial practices, such as recycling at the source, i.e., household.

Recycling rates in Malaysia were reported to be at 28.1% for 2019, which exceeded the targeted rate of 22% ("Compendium of Environment Statistics, Malaysia 2020," 2020). This shows that the Malaysian government is always committed to improve the MSWM system, besides implementing SDGs in both private and public sectors. Besides, recycling rates are expected to reach 40% by 2025 (BERNAMA, 2020). This is relevant as in 2018, Malaysians discarded RM476 million worth of recyclables to landfills (Tarmiji, 2020). In the Comprehensive Action Plan of Solid Waste Management 2015–2020, one of the proposed strategies on source separation and recycling is by providing more recycling facilities in public locations (Moh & Abd Manaf, 2017). Thus, by providing recycling bins at locations with excellent accessibility, it is not only practical to encourage waste separation at the household level, but it is also beneficial to reduce government expenditures to manage solid waste, especially in urban municipalities. For this reason, a mathematical model to locate and allocate recycling bins is proposed in the following section.

The Location-Allocation Model for Recycling Facility

We modified an existing set-covering facility location model, i.e., the MEXCLP by Daskin (1983), to ensure demand for or household willingness to participate in recycling practises in the case study area. To fit the MSWM to the problem, two improvements are introduced. First, the factor that is related to notations, sets, and parameters of the facility is defined as the recycling bin locations. We assume the demands of users are represented by the number of households. Second, the availability constraint is introduced to ensure there is sufficient capacity in the allocated recycling bins for each demand.

Let $I = \{1, 2, 3, \dots, n\}$ denotes the set of demand locations, indexed by *i*, and let $J = \{1, 2, 3, \dots, m\}$ denotes the set of potential recycling bin locations, indexed by *j*. The number of recycling bins allocated at each location *j* is represented by *k*, with a total number of bins allocation of at most M bins. Let d_i be the number of demands at location i and $dist_{ij}$ be the shortest travel distance between demand and recycling bin location, with a maximum travel distance of at most D units. The binary a_{ij} is used to indicate if the travel distance is less than or equal to D units, then $a_{ij} = 1$, otherwise $a_{ij} = 0$. Lastly, the busyness level of having k bins at each recycling bin location j is signify as q_{jk}. Meanwhile, the decision variables and the model formulation as follows:

Decision Variables

$$x_j = \begin{cases} 1 & \text{if a recycling bin is allocated at } j \\ 0 & \text{otherwise} \end{cases}$$

$$y_{ik} = \begin{cases} 1 & \text{if demand at location } i \text{ is covered with } k \text{ bins} \\ 0 & \text{otherwise} \end{cases}$$

Model Formulation

$$Maximize \sum_{i}^{n}\sum_{j}^{m}\sum_{k}^{K} d_i q_{jk} y_{ik} \tag{1}$$

subject to:

$$\sum_{k}^{K} y_{ik} - \sum_{j}^{m} a_{ij}x_j \leq 0 \quad , \forall i = 1, 2, \dots, n \tag{2}$$

$$\sum_{j=1}^{m} x_j \leq P \tag{3}$$

$$\sum_{k}^{K} y_{ik} \leq 1 \quad , \forall i = 1, 2, \dots, n \tag{4}$$

The objective function of the model is presented by equation (1), i.e., maximizes the amount of demand at *i* featured by the chosen facilities *j*, given that *j* is allocated with *k* bins. Constraints of the model as presented by the inequalities of (2) – (4). Inequalities (2) ensure the covered demands are able to reach the selected facility location within the allocated distance *D*. Inequalities (3) constrain the total number of selected facilities at most *M* locations. Meanwhile, (4) ensures the coverability of *k* bins for demand at every location. Moreover, this constraint also symbolises the distribution of the number of bins per chosen recycling facility location *j*, which guarantees the availability of sufficient bin capacity for each demand *i*. The availability, i.e., q_{jk}, is adopted from Shuib and Zaharudin (2011), in which

$$q_{jk} = 1 - (b_j)^k \quad , \forall j = 1,2, \dots, m. \tag{5}$$

where the $(b_j)^k$ has been modified to suit our study characteristics, where it now indicates the facility business level with the number of bins *k*. The b_j denotes the capacity of a facility to comprise the demand for a region, i.e. $b_j = \frac{\sum_{i=1}^{n} d_i a_{ij}}{\sum_{i=1}^{n} d_i}$. We assumed that there are no financial integrations, such as operating or transportation costs, and that the specified node of potential bin locations is perpetually available to the public in this model. We also assumed that the waste generation for each household are equal.

Area of Study – Seremban, Malaysia

Seremban, one of Malaysia's urban municipalities, was chosen as our case study. The location of Seremban as shown in figure 1. Seremban had 221,529 households with a population of 630,299 in 2019, which was equivalent to three (3) individuals per household[1]. This also

[1] Average number of individuals per household = population/ number of households.

means that the amount of solid waste produced by a household was 3.36 kg[2] or almost 750,000 kg of waste[3] per day. Currently, only one landfill is used to dispose Seremban's waste, and it is expected to last for another 20 years. However, as the population of Seremban grows, so does the need to enhance recycling rates to build a sustainable and smart city for the future. Thus, having sufficient recycling facilities, such as recycle drop-off bins, in optimal locations can greatly improve the Seremban MSWM efficiency.

Figure 1: Seremban location

Figure 2: Selected household areas in Seremban, with potential recycling bin location

Six (6) households' areas (approximately 125,000 people) in Seremban are chosen, i.e., n = 6. Five (5) potential recycling bin locations, i.e., m = 6, are identified based on the accessibility

[2] Assuming the waste produced is 1.12 kg/cap/day (Imran et al., 2019), i.e., 1.12kg*3 = 3.36kg.

[3] 3.36kg*number of households in Seremban = 3.36 kg * 221,529 = 744,337 kg.

to the public and the spaciousness of the area. Figure 2 highlights these locations. There are commercial centres, groceries, and other public facilities such as clinics and schools in this area of study. Meanwhile, Google Maps was used to calculate the travel times between these locations. The availability concept value was calculated by multiplying the fraction of demand *i* that each potential location *j* can cover within *D* minutes with the number of recycling bins *k*, as the consideration. The model was solved using CPLEX 20.1 on a computer with a 2.5GHz processor speed.

Results and Discussion

The findings of the study are presented in this section. A calibration procedure was conducted to obtain the optimal location allocation for the recycling bin in the case study area. Parameters *D*, *M*, and *k* were subjected to a calibration procedure. The value of *D* was chosen at random, i.e., 3, 5, and 10 minutes, to represent the range of allowable travel times. *M* was varied from 1 to 5, with 5 being the maximum number of potential recycling bin locations for the study area. At each recycling station, *k* represents the number of bins allocated, where *k* = 1, 2, or 3 bins. The relationship between these parameters is depicted in Figure 4.

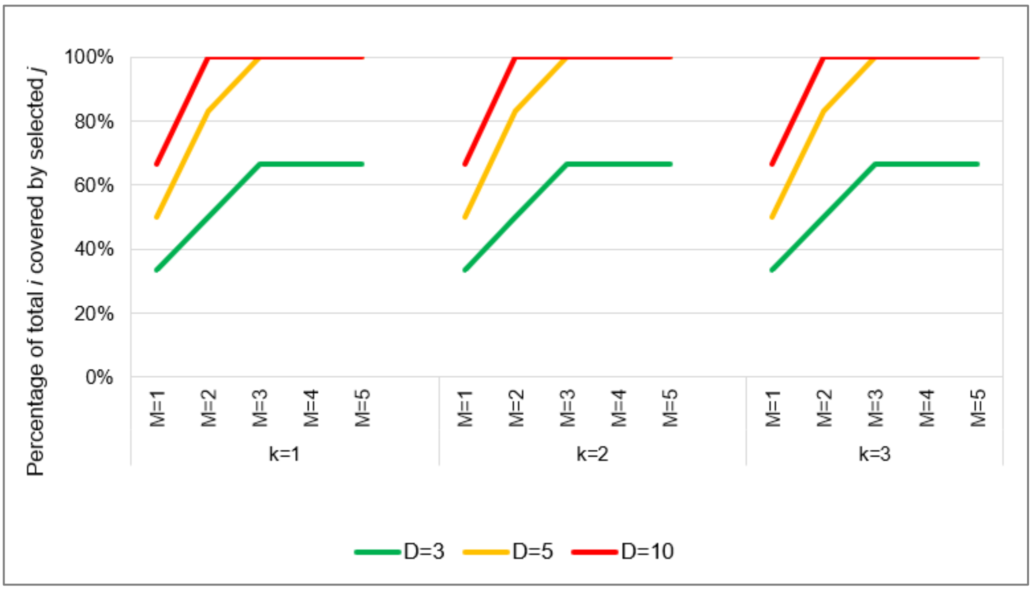

Figure 3: Percentage of total demand locations *i* covered by the chosen recycling bin locations *j* with varying *k* and *M* values

As seen from figure 3, the proposed model is relatively sensitive to the value of *D*, i.e., the maximum travel distance between the demand area *i* and the recycling bin location *j*. This is expected since the coverability is increased, hence, the expected demand is also increased. From this figure, it can be seen that all demand locations are completely covered when *M* = 2, and *D* = 10 minutes. Meaning, a total of two (2) recycling bin locations are needed to cover all the demand in the area of study, with *D* = 10 minutes. Meanwhile, it was observed that calibration in *k* values did not affect the model's coverability. As seen, all demand is expected to be covered when *k* had an optimal value of 1. Specifically, this implies that having one (1) bin is adequate to cover the specified demand at location *i*. This means that each demand site, *i,* should be allocated at least one recycling bin, thus ensuring that all study areas are covered. Meanwhile, Table 1 shows the details of the selected recycling bin locations, which are represented by *j*; the number of allocated bins, which are represented by *k*; and the demand locations that are covered by each selected *j*, which are represented by *i*. From this table, the selected recycling bin's locations are *j* = 4 and 5, with an allocation of six (6) bins in total. This value is significant as the selected area of study in Seremban has a population of approximately 125,000.

Table 1
Recycling bin locations and allocations within the selected residential areas of Mutiara Rini, Johor Bahru, with k=1

j	Demand *i* that can be covered by each *j*	Total number of bins allocation for each *j**	Total number of bins allocation for the area of study
4	1,2,4	3	6
5	3,5,6	3	

*For each *i* that are covered by a *j*, one bin is needed.

Based on Figure 3 and Table 1, the respective authorities can allocate a minimum of six (6) recycling bins at two (2) optimal locations to cover the study area. However, this depends on the authority's financial allocation. More recycling bins can be allocated at the suggested optimal locations if the authority wants to enhance Seremban's recycling rates. But as seen in Figure 3 earlier, adding more bins would not increase the percentage of expected demand covered. Remarkably, although the financial implications are not taken into account in the proposed model, it can be used to understand the impact of local authority decisions on demand coverability.

Similarly, the authorities might have their own preferences in locating recycling bins. This scenario is also helpful in assisting local authorities that have financial restrictions or have limited selection on potential recycling bin locations. Using the proposed model, we further investigate this scenario by assuming only one (1) preferred recycling bin location, i.e., $M = 1$, with one bin allocation for each *I*, i.e., $k = 1$. For this scenario, value *D* is varied.

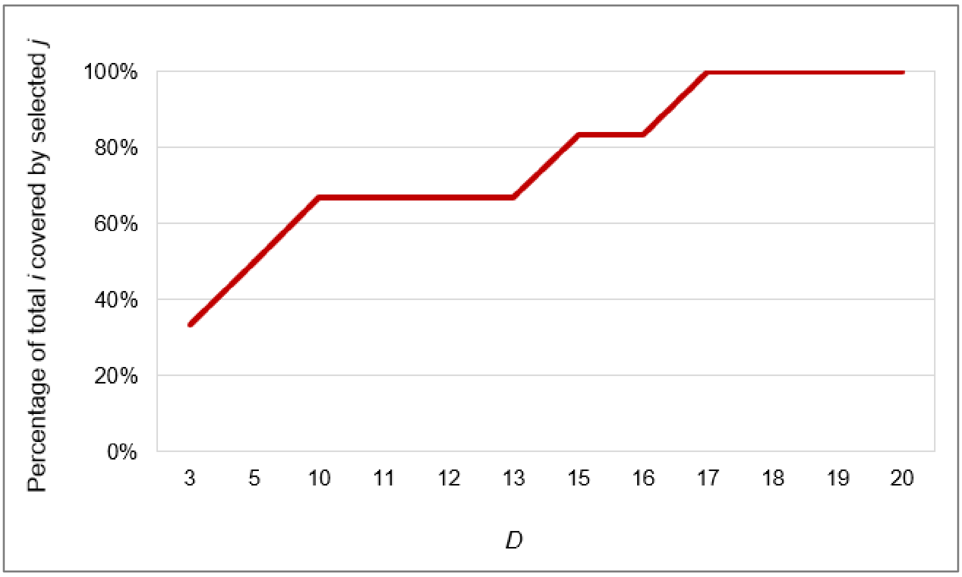

Figure 4: Percentage of total demand locations *i* covered by the chosen recycling bin location *j* with varying *D* value.

Figure 4 displays the percentage of area *i* covered by selected *j* when the *D* value varies while keeping the *M* at value 1. The 100% coverage level is reached when the distance travelled is

D = 17. In other words, households must travel at most 17 minutes to drop off recyclable waste. Based on the proposed model, the recycling bin location is at j = 5. meaning that if the local authority would like to have only one recycling bin location, the optimal location would be j = 5. However, the downturn of having only one recycling bin location requires a long commute from each household to the recycling facility. This might reduce households' interest and willingness to recycle and would eventually reduce the recycling rates in the future.

The model proposed in this paper provides authorities with an attentive decision to optimally locate and allocate recycling bins by focusing on maximizing the expected demand covered while taking availability and reachability limits into account. Furthermore, the suggested model can deliver dynamic solutions to decision makers based on their preferences and constraints.

Conclusions and Future Works

This study focused on determining the optimal location and placement of recycling bins in urban areas using the conventional facility location model, MEXCLP. To the best of our knowledge, there is a lack of past studies that adapted the conventional facility location model to determine the recycling bin location and allocation. Our study adapted the MEXCLP to the MSWM problem by incorporating concepts on the availability and accessibility of recycling bins. The modified model was then applied to one of Malaysia's urban areas, Seremban. From the results obtained, only six (6) recycling bins at two (2) locations were needed to cover the area of study. We also looked into the scenario of having only one potential recycling bin location. As a result, it is established that having a bin at j = 5 would provide full demand coverage. However, demand needs to travel at most 17 minutes to drop off their recyclables, which would affect households' participation level because of the long-distance travel required to drop off their recyclable materials.

To the best of our knowledge, there were few studies on locating recycling facilities in Malaysia using a mathematical approach, our research is able to fill a gap in the literature by developing a mathematical model for locating and allocating recycling bins in a Malaysian municipality, especially, for the urban area. Hence, from this study, contributions from mathematical modelling for recycling facilities and the implementation of the suggested model in the Malaysian urban area may be acknowledged. Several enhancements are possible in the future. To assure practical outcomes in future work, the volume or weight of the waste may be used as one of the input factors. The updated MEXCLP model currently uses a 0-1 value as an input parameter; however, further improvements can be made by utilizing a gravity model (see: Zaharudin et al., 2021) or a fuzzy set theory approach (see: Kaya et al., 2020). Meanwhile, financial implications such as operating expenditures or travel expenses might be added to the model and incorporated into future work.

References

Ab Malek, R. (2021). *10,000 Tonnes of Food, Plastic Waste Thrown Away Daily*. New Straits Times. https://www.nst.com.my/news/nation/2021/04/683032/10000-tonnes-food-plastic-waste-thrown-away-daily

Abas, M. A., & Wee, S. T. (2016). Municipal Solid Waste Management in Malaysia: An Insight Towards Sustainability. *SSRN Electronic Journal*, *January 2015*. https://doi.org/10.2139/ssrn.2714755

Tarmiji, A. M. F. (2020). *Membudayakan kitar semula dalam masyarakat*. KOSMO! https://www.kosmo.com.my/2020/08/12/membudayakan-kitar-semula-dalam-masyarakat/

Asefi, H., & Lim, S. (2017). A novel multi-dimensional modeling approach to integrated municipal solid waste management. *Journal of Cleaner Production*, *166*, 1131–1143. https://doi.org/10.1016/j.jclepro.2017.08.061

Awasthi, A., Chauhan, S. S., & Goyal, S. K. (2011). *A multi-criteria decision making approach for location planning for urban distribution centers under uncertainty*. *53*(1–2), 98–109. https://doi.org/10.1016/j.mcm.2010.07.023

BERNAMA. (2020). *SWCorp tingkat sasaran kadar kitar semula 40 peratus menjelang 2025*. Sinar Harian. https://www.bharian.com.my/berita/nasional/2020/08/717133/swcorp-tingkat-sasaran-kadar-kitar-semula-40-peratus-menjelang-2025

Blazquez, C., & Paredes-Belmar, G. (2020). Network design of a household waste collection system: A case study of the commune of Renca in Santiago, Chile. *Waste Management*, *116*(August), 179–189. https://doi.org/10.1016/j.wasman.2020.07.027

Bruno, G., & Genovese, A. (2012). A Spatial Interaction Model for the Representation of the Mobility of University Students on the Italian Territory. *Networks and Spatial Economics*, *12*(1), 41–57. https://doi.org/10.1007/s11067-010-9142-7

Compendium of Environment Statistics, Malaysia 2020. (2020). In *Department of Statistic, Malaysia* (Issue November). https://www.dosm.gov.my/v1/index.php?r=column/pdfPrev&id=TjM1ZlFxb3VOakdmMnozVms5dUlKZz09

Daskin, M. S. (1983). Maximum Expected Covering Location Model: Formulation, Properties and Heuristic Solution. *Transportation Science*, *17*(1), 48–70. https://doi.org/10.1287/trsc.17.1.48

Demirbas, A. (2011). Waste management, waste resource facilities and waste conversion processes. *Energy Conversion and Management*, *52*(2), 1280–1287. https://doi.org/https://doi.org/10.1016/j.enconman.2010.09.025

Gilardino, A., Rojas, J., Mattos, H., Larrea-Gallegos, G., & Vázquez-Rowe, I. (2017). Combining operational research and Life Cycle Assessment to optimize municipal solid waste collection in a district in Lima (Peru). *Journal of Cleaner Production*, *156*, 589–603. https://doi.org/https://doi.org/10.1016/j.jclepro.2017.04.005

Hassan, M. S., Mat, H. N., Ismail, M. R., & Mahmud, N. H. (2021, July 20). 14 juta tan sampah pada 2022. *Harian Metro*. https://www.hmetro.com.my/utama/2021/07/732770/14-juta-tan-sampah-pada-2022

Imran, A., Shreeshivadasan, C., Norhayati, A., & Danish, M. A. (2019). Sanitary Landfill is a Solution in Solid Waste Management or a Silent Threat to Environment: Malaysian Scenario Article history. *Open International Journal of Informatics (OIJI)*, *7*(Special Issue), 135–146.

Jamiron, N. F. H., Sarif, N. A. S., Abdul Rahman, N. S., & Zaharudin, Z. A. (2021). Establishing Recycling Bins Location and Allocation for Sustainable Urban Municipalities of Johor Bahru in Malaysia. *International Journal of Academic Research in Economics and Management and Sciences*, *10*(3), 459–472. https://doi.org/http://dx.doi.org/10.6007/IJAREMS/v10-i3/11344

Kaya, A., Çiçekalan, B., & Çebi, F. (2020). Location selection for WEEE recycling plant by using Pythagorean fuzzy AHP. *Journal of Intelligent and Fuzzy Systems*, *38*(1), 1097–1106. https://doi.org/10.3233/JIFS-179471

Khamaruddin, P. F., Tony, T. A., Alias, A. B., Aishah, S. A. S., & Suhaili, E. Q. (2019). Waste Characteristics Study and Recycling Practice Trend at Tuanku Abdul Halim Mu'adzam Shah Engineering Complex, UiTM. *Key Engineering Materials*, *797*(November), 65–73. https://doi.org/10.4028/www.scientific.net/KEM.797.65

Letelier, C., Blazquez, C., & Paredes-Belmar, G. (2021). Solving the bin location-allocation problem for household and recycle waste generated in the commune of Renca in Santiago, Chile. *Waste Management & Research : The Journal of the International Solid Wastes and Public Cleansing Association, ISWA*, 734242X20986610. https://doi.org/10.1177/0734242X20986610

Marín, A., Nickel, S., & Velten, S. (2010). An extended covering model for flexible discrete and equity location problems. *Mathematical Methods of Operations Research*, *71*(1), 125–163. https://doi.org/10.1007/s00186-009-0288-3

Devadoss, M. P. S., Agamuthu, P., Mehran, S. B., Santha, C., & Fauziah, S. H. (2021). Implications of municipal solid waste management on greenhouse gas emissions in Malaysia and the way forward. *Waste Management*, *119*, 135–144. https://doi.org/10.1016/j.wasman.2020.09.038

Harijani, M. A., Mansour, S., & Karimi, B. (2017). A multi-objective model for sustainable recycling of municipal solid waste. *Waste Management and Research*, *35*(4), 387–399. https://doi.org/10.1177/0734242X17693685

Harijani, M. A., Mansour, S., Karimi, B., & Lee, C. G. (2017). Multi-period sustainable and integrated recycling network for municipal solid waste – A case study in Tehran. *Journal of Cleaner Production*, *151*, 96–108. https://doi.org/10.1016/j.jclepro.2017.03.030

Moh, Y. C., & Abd Manaf, L. (2017). Solid waste management transformation and future challenges of source separation and recycling practice in Malaysia. *Resources, Conservation and Recycling*, *116*(2017), 1–14. https://doi.org/10.1016/j.resconrec.2016.09.012

Nowakowski, P., & Mrówczyńska, B. (2018). Towards sustainable WEEE collection and transportation methods in circular economy - Comparative study for rural and urban settlements. *Resources, Conservation and Recycling*, *135*(August 2017), 93–107. https://doi.org/10.1016/j.resconrec.2017.12.016

Olapiriyakul, S. (2017). Designing a sustainable municipal solid waste management system in Pathum Thani, Thailand. *International Journal of Environmental Technology and Management*, *20*(1–2), 37–59. https://doi.org/10.1504/IJETM.2017.086433

Olapiriyakul, S., Pannakkong, W., Kachapanya, W., & Starita, S. (2019). Multiobjective Optimization Model for Sustainable Waste Management Network Design. *Journal of Advanced Transportation*, *2019*. https://doi.org/10.1155/2019/3612809

Potdar, A., Singh, A., Unnikrishnan, S., Naik, N., Naik, M., Nimkar, I., & Patil, V. (2016). Innovation in Solid Waste Management through Clean Development Mechanism in Developing Countries. *Procedia Environmental Sciences*, *35*, 193–200. https://doi.org/10.1016/j.proenv.2016.07.078

Rahim, S., Rahman, N. I. A., Neng, C. H., & Khoiry, M. A. (2021). Perception of the public towards sustainable technology facilities in rest and service areas in Malaysia. *Environmental Engineering and Management Journal*, *20*(1), 97–108. https://doi.org/10.30638/eemj.2021.011

Rathore, P., & Sarmah, S. P. (2019). Modeling transfer station locations considering source separation of solid waste in urban centers: A case study of Bilaspur city, India. *Journal of Cleaner Production*, *211*, 44–60. https://doi.org/10.1016/j.jclepro.2018.11.100

Rathore, P., Sarmah, S. P., & Singh, A. (2020). Location–allocation of bins in urban solid waste management: a case study of Bilaspur city, India. *Environment, Development and Sustainability*, *22*(4), 3309–3331. https://doi.org/10.1007/s10668-019-00347-y

Razali, F., Wai, W. C., & Daud, D. (2019). a Review of Malaysia Solid Waste Management Policies To Improve Recycling Practice and Waste Separation Among Households. *International Journal of Built Environment and Sustainability*, *6*(1–2), 39–45. https://doi.org/10.11113/ijbes.v6.n1-2.381

Shuib, A., & Zaharudin, Z. A. (2011). TAZ_OPT: A goal programming model for ambulance location and allocation. *2011 IEEE Colloquium on Humanities, Science and Engineering*, 945–950. https://doi.org/10.1109/CHUSER.2011.6163878

Tiew, K. G., Basri, N. E. A., Watanabe, K., Zain, S. M., Er, A. C., & Deng, H. (2019). Higher educational institutions recycling management in Malaysia. *International Journal of Business and Society*, *20*(1), 277–285.

Zaharudin, Z. A., Brint, A., Genovese, A., & Piccolo, C. (2021). A spatial interaction model for the representation of user access to household waste recycling centres. *Resources, Conservation and Recycling*, *168*(December 2020), 105438. https://doi.org/10.1016/j.resconrec.2021.105438

Zaharudin, Z. A., Nordin, N. A. M., Tahir, H. M., Kamal, C. W. R. A. C. W., Ghani, N. H. A., & Halim, N. H. A. (2012). An application of MEXCLP model: A case study for mobile ambulance location. *CHUSER 2012 - 2012 IEEE Colloquium on Humanities, Science and Engineering Research*, 539–543. https://doi.org/10.1109/CHUSER.2012.6504372

Zarrinpoor, N., Fallahnezhad, M. S., & Pishvaee, M. S. (2017). Design of a reliable facility location model for health service networks. *International Journal of Engineering, Transactions A: Basics*, *30*(1), 75–84. https://doi.org/10.5829/idosi.ije.2017.30.01a.10