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Research Paper

Towards Sustainable City: A Covering Model for Recycling Facility Location-allocation in Nilai, Malaysia

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Abstract
Sustainable waste management is essential for any nation. To limit the amount of waste transported to landfills, it is critical to handle waste properly, notably by segregating recyclables from discarded waste. Waste separation at the source is critical to ensure that generated waste is not completely directed to landfill. The practice of waste separation would initiate the recycling process, which is able to reduce the amount of waste sent to the landfill. Recycling is critical to the achievement of two Sustainable Development Goals (SDGs), 11 and 12, for which Malaysian government has set the goal for recycling rates to reach 40% by 2025 in 2022, the rate has reached 33.17%. In Malaysia, recyclables are either collected on-site or sent to a designated facility. The separation at source activity is essential for developing recycling practices. Despite being the largest waste generator, public engagement, particularly at the household level, has remained low, most likely due to recycling facility availability and accessibility issues. Thus, improving public access to the facility would lead to increased recycling rates. In this study, a mixed integer linear programming model is proposed to locate recycling facilities in optimal locations that cover the most amount of waste generated by households. The capacity level is induced to ensure that the dropped-off recyclables are proportionate at the designated facility locations. Several experiments were conducted for validity purposes, and the proposed model was applied in a Malaysian urban area, namely Nilai. As a result, the proposed model was able to locate the optimal locations with the requisite capacity level while ensuring coverage for most Nilai households.

Keywords
Facility Location, Covering Model, Recycling, Sustainable Development Goals

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1. INTRODUCTION

Ineffective waste management has negative effects on the environment, economy, and society (Harbiankova and Kalinowski, 2023) therefore, a much sustainable strategy must be implemented. Reuse, recycling, conversion, and energy transformation are examples of waste treatment strategies that provide numerous waste treatment choices so that the environmental impact is minimized (D'Sa and Patnaik, 2022) and reduced the waste disposed to landfill. Despite the fact that landfilling is the least advised option for sustainable waste management (SWM) since it increases greenhouse gas emissions that contribute to global warming (Rosni et al., 2022) the majority of countries, including Malaysia, still adopt this approach because it is both time- and cost-effective (Ahmad et al., 2019). In 2016, Malaysia generated 1.17 kilogram/capita/day of waste, third in ASEAN (Ghani, 2021). In 2022, the national recycling rate is 33.17%, showing significant changed and remarking the enthusiast of Malaysian Government in improving recycling rate of the country.

Malaysian households have been required since 2015 to separate their waste into recyclable and non-recyclable (general wastes) materials (Rangga et al., 2022) however, more than 80% of recyclables are found in the landfills (Baba-Nalikant et al., 2023; Devadoss et al., 2021). Clearly, involvement of householders in the separation at source is important as they are the largest waste generator. Nonetheless, Malaysia have poor execution of the waste legislation (Khamaruddin et al., 2019) with lack of inadequate reduce, reuse and recycle (3R) facilities (such as material recovery and drop-off center) (Alias et al., 2018) and limited in innovative disposable facilities (Umar et al., 2021). The scarcity of such facilities would deter the public, particularly householders, from separating the generated waste. Therefore, householders must practicing separation of the generated waste so that the quantity of waste that can be recycled can be increased, significantly lower the overall amount of waste transferred to landfills (Razali and Wai, 2019).

In accordance with the Malaysian government's 2025 goals, which require recycling rates of at least 40% (Chin et al., 2023) and since households plays an important role in separation-at-source activity, a sustainable and efficient mechanism must be established to collect recyclables from households. Hence, this study's aim is to propose a framework for creating a mathematical model for determining the optimal sites for recycling facilities and the proper allocation of recycling containers using a modified set covering approach.

Covering concept refers to the provision of services to a user by a facility located within a predetermined distance, regardless of whether it is the nearest facility or based on the customer's proximity to such facilities (Farahani et al., 2012). Toregas et al. (1971) initially presented the Location Set Covering Problem (LSCP) as the basis for the location model that relied on covering as its key approach. The authors' main aim was to determine the minimum number of facilities required to satisfy a given set of demands. The concept of coverage was subsequently investigated by Church and ReVelle (1974) which proposed the Maximal Covering Location Problem (MCLP). The method aims to maximize the number of demands that can be satisfied within a specific coverage threshold between the demand locations and the set of facilities. Later, Daskin (1983) introduced a revised version of the MCLP, known as the Maximum Expected Covering Location Problem (MEXCLP), which integrates the use of multiple servers at each facility to enhance the coverage level. The coverage level was defined by the author based on the probability of a facility experiencing periods of idleness. Nevertheless, it is assumed that the probability is uniform across all facilities.

The covering model has been applied in a variety of contexts, including the waste-related problem. Much recent research conducted by Puspita et al. (2023) in South Sumatra, which employed the model to manage the locations of temporary waste disposal sites. Meanwhile, Letelier et al. (2022) addressed the management of both recyclable and non-recyclable waste in Chile through the implementation of optimized bins allocation strategy based on the modified LSCP. Hartini et al. (2021) employed the use of MCLP in order to formulate the design of a waste cooking oil collection center located in Semarang City, Indonesia. Sari et al. (2021) is also using Indonesia as the focal point of the study, namely, Yogjakarta. The authors used the MCLP, which integrates costs as a determining factor in the identification of optimal locations and numbers of e-waste collection centers. The application of the covering model was also employed in the process of identifying appropriate sites for the establishment of recycling facilities within a specified designated area. For example, Cubillos and Wøhlk (2021) proposed a bi-objective technique that employs the covering concept to tackle the recyclable drop-off facility location and routing problem that considers the cost of both objectives. The model was executed in five distinct regions of Denmark. Jamiron et al. (2021) and Rosni et al. (2022) employed the MEXCLP approach to derive most effective recycling bin locations in urban areas of Malaysia. Jamiron et al. (2021) limits on the number of bins allocated at each selected facility in Johor Bharu, whereas Rosni et al. (2022) relaxed this condition that allowing for greater demand coverage with a minimal number of facility locations. Rosni et al. (2022) implemented their research in the locality of Seremban. Meanwhile, Wang et al. (2021) employed an extended version of the MCLP to allocate recycling infrastructure in an uncertain environment. The aim was to ensure that a limited number of recycling infrastructure could cover a maximum number of demands. The authors incorporated uncertainty conditions into their model to achieve this objective. The uncertain MCLP model is further extended by the authors through the provision of an extended version.

Our study focused establishing several sites to locate drop-off recycling facility for the householders in Malaysia using the mathematical modelling approach, however, to the best of our knowledge, are still lacking. Many of the existing research, especially in Malaysia, concentrated more on analyzing, assessing, and synthesizing the current recycling participation or behavior among the public or for municipalities than enhancing recycling rates by establishing the optimal recycling facility locations (Zaharudin and Shuib, 2021).

The remainder of this paper is organized as follows. Section 2 describe the Nilai city, Malaysia and highlighting the current situation of recycling system of the city. On similar section, the adjusted covering model for determining recycling facility locations is presented. Section 3 demonstrates the results and discussion. Lastly, Section 4 concludes the paper with some recommendations for future research.

2. EXPERIMENTAL SECTION

2.1 Nilai City: Current Scenario

Nilai is located within Seremban of Negeri Sembilan, Malaysia. Seremban comprises of Seremban town, Setul, Labu, Rasah, Ampangan, Rantau, Pantai, and Lenggeng. Nilai is a city that is located within Seremban, within Setul district and at the border of Negeri Sembilan and Selangor. Nilai is called a satellite city since most workers that work in Kuala Lumpur or South of Selangor, reside in Nilai. Besides households' areas, Nilai has several high institutions and industrial areas. Currently, about 400,000 people reside in Nilai, hence the estimated amount of waste generated is almost 468,000 kg of waste per day. All of the households' waste of Nilai is currently disposed of the landfill in Port Dickson (another area located in Negeri Sembilan).

Currently, SWM Environment Sdn. Bhd., a private company and integrated waste management and public cleansing service provider in the southern region of Peninsular Malaysia, is in charge of MSW in Negeri Sembilan (Ahmad et al., 2019), namely, Seremban. This company was contracted by SWCorp to handle household waste, collect, and manage recyclables, and retain the waste under control and confinement. In 2018,

Table 1. The Cluster Demand Area with Population, Estimated Number of Households, and Estimated Recyclable Waste Generation

n	Area	Population	Estimated Number of Household*	Estimated Recyclable Waste Generation (kilograms)**
1	Tmn Desaria, Tmn Desa Saga	1051	265	10
2	Tmn Desa Seringin	750	189	7
3	Lmn Delfina, Lmn Akasia, Lmn Lili, Lmn Dillenia, Lmn Kekwa, Lmn Isora, Laman Lavenda, Lmn Jasmin, Lmn Dahlia	5962	1502	59
4	Tmn Teratai, Lmn Orkid, Lmn Anggerik, Lmn Azalea, Lmn Kenanga, Nilam & Camelia Court	6697	1687	67
5	Puncak Jati Apartment, Desa Jati, Anggerik Courts Apartment, Tmn Desa Anggerik & Nilai Spring Villas	13280	3345	132
6	Desa Palma Apartment, Desa Melati, Desa Casuarina, Nilai Spring Heights, Kasturi Height, Bayu Apartment 1 & 2	14999	3778	149
7	Desa Kasia, Desa Kolej	3053	769	30
8	Desa Indah, Impiana Resident, Sutera Indah Apartment, Tmn Nilai	4914	1238	49
9	Tmn Semarak 1 & 2	14614	3681	145
10	Tmn Warisan Villa, Cempakapuri Apartment 1, 2, & 3, Cempaka Court Apartment, Flat Cempaka 4, Desa Cempaka, Tmn Ban Aik	15730	3962	156
11	Tmn Desa Jasmin, Tmn Rosmerah, Impiana Villa, Nilai Santalia Apartment, Yadin Impiana	5006	1261	50
12	Tmn Nilai Perdana	4967	1251	49

*Assuming there are 3.97 persons per household (Source: Seremban City Council)
**Assuming a household generates 33.71% of recyclables (Source: Malaysia Department of Statistic)

SWM Environment Sdn. Bhd. together with SWCorp and Negeri Sembilan municipalities to set up KITARecycle, a drop-off facility for recyclables, is located in several designated areas (Munawar and Radzuan, 2022). The KITARecycle is located at the curb sides within the public accessible area and a cage-shaped facility. This initiative offers financial incentives for selected recyclables dropped by the public. Currently, according to the SWCorp, there are only two KITARecycle drop-off facilities to cover the entire Nilai city area that is located within the compound area of Seremban City Council (Nilai Branch), i.e., the local municipalities for the Nilai city. In the meantime, there are several recycling drop-off facilities that are provided by private companies and non-government organizations (NGOs) that are located within the Nilai area.

For our study, the drop-off facility that is provided by the Negeri Sembilan municipalities, namely the KITARecycle was focused on. Since only two facilities are provided by the municipalities, all households will use these limited capacity facilities, it is expected of not being able to accommodate the actual amount of recyclable waste produced by the householders of Nilai. Some householders may find the facility area is located rather far away, which some may find unattractive; consequently, the proportion of users who do not recycle will increase. The situation of current and desired assignment is depicted in Figure 1.

Figure 1 depicts the existing and desired demand assignment. The first illustrations show the current assignment, where demand does not have a particular disposal area (or location).

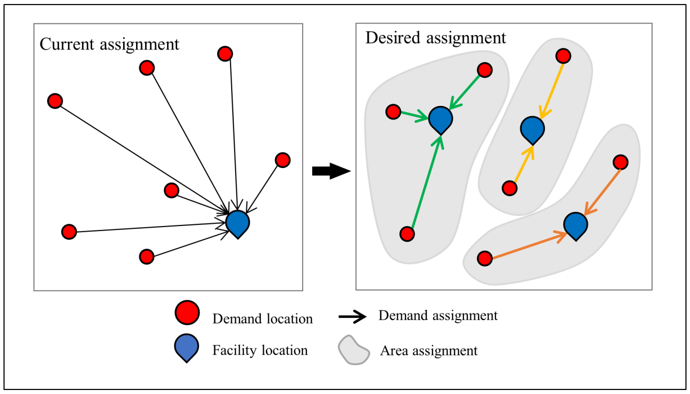

Figure 1. Demand Assignment of the Existing Condition and Desired Assignment

This would exacerbate the problem of congestion at the facility, especially for recyclables, which would result in spillage issues due to the facility's inadequate infrastructure. So, it is more sustainable to develop waste disposal locations for each demand group, as indicated in the second illustration of desired assignment. In the figure, demand orientation is based on an established facility location, which is determined by demand travel time (accessibility), spatiality, and coverability. Meanwhile, the appropriate capacity of the facility to serve neighboring demand must be estimated in order to solve overflow issues and collect more recyclable waste. Hence, the mathematical formulation with decisions on facility (recycling center) location, server (recyclable containers) allocation, and demand assignments to the potential facility location must be established in a manner that maximizes coverage level. The next part provides the mathematical formulation based on the covering model approach.

2.2 Mathematical Model for Recycling Facility Location of Nilai City, Malaysia

A mathematical model, namely the classical covering model with additive capacity constraint and system performance is used for finding recycling drop-off center within a set of candidate locations. Simultaneously, the proposed model allocated the optimal number of recycling containers to the established centers. The location-allocation process is carried out concurrently, indicating an improvement in the proposed tools. The model also proposes enhancing recycling rates through reachability (measured as the distance between household-centers) and coverability, by keeping the capacity at the optimal level, which is determined by the weight of recyclables. With this, it is anticipated that households will improve their separation at source activities, directly implying that more recyclables will be disposed of at the recycling center.

Consider a directed graph, $G = (N, A)$ containing a set of locations (N) and arcs (A). In this study, let, demand locations, denoted by $i = 1, 2, \ldots, n$ and locations of facility, denoted by $j = 1, 2, \ldots, m$. The arcs or vertices represent the path between two locations with the least weight, which could be represented via cost, travel time or distances. To achieve maximum coverage of recyclable waste deposited by each demand, the container allocations are represented by an additional dimension, k, where $k = 1, 2, ..., K$, such that the model of location of the facility and container allocation are calculated simultaneously. In this paper, demand, i.e., the amount of waste generated at location i is denoted as d_i, travel distance (in minutes) between location i and j denoted as t_{ij} where T indicates the maximum ones, and a binary parameter denoted as s_{ij} is values to 1 if $t_{ij} \leq T$, and 0 otherwise. Several parameters are introduced, which are the maximum capacity of a container for recyclables (Q), maximum total number of permissible facility locations within the study area (δ), maximum total possible allocations for recyclable containers in the study area is (ε), and minimum service level for the recycling system is (τ). For the proposed formulation, three decision variables are introduced, which are the x_j, i.e., a binary variable that values to 1 if a facility is operating at location j and 0 otherwise, the y_{kj}, i.e., a binary variable that values to 1 if facility at location j is allocated with k containers, and the q_{ij}, i.e., the amount of demand served at location i using the facility at location j.

Accordingly, the proposed mathematical model for determining the optimal location of a recycling facility and the allocation of containers can be established. The model proposed employs the MCLP method developed by Church and ReVelle in 1974, albeit with additional constraints pertaining to capacity levels. The model is as follows:

$$Max\left(\sum_{j=1}^{m}\sum_{i=1}^{n} q_{ij}\right) \tag{1}$$

subject to:

$$\sum_{j=1}^{m} s_{ij}x_j \geq 1; \forall i = 1, 2, ..., n \tag{2}$$

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

$$\sum_{j=1}^{m}\sum_{k=1}^{K} k y_{kj} \leq \varepsilon; \tag{4}$$

$$\sum_{k=1}^{K} y_{kj} \leq x_j; \forall j = 1, 2, ..., m \tag{5}$$

$$\sum_{i=1}^{n}\sum_{j=1}^{m} q_{ij} \geq \tau \sum_{i=1}^{n} d_i; \tag{6}$$

$$\sum_{j=1}^{m} q_{ij} \leq d_i; \forall i = 1, 2, ..., n \tag{7}$$

$$\sum_{i=1}^{n} q_{ij} \geq x_j; \forall j = 1, 2, ..., m \tag{8}$$

$$\sum_{i=1}^{n} q_{ij} \leq \sum_{k=1}^{K} kQy_{kj}; \forall j = 1, 2, ..., m \tag{9}$$

$$x_j, y_{kj} \in \{1, 0\}; \forall j = 1, 2, ..., m; \forall i = 1, 2, ..., n; \forall k = 1, 2, ..., K \tag{10}$$

$$q_{ij} \geq 0; \forall j = 1, 2, ..., m; \forall i = 1, 2, ..., n \tag{11}$$

The mathematical formulations are presented from (1) until (9). The purpose of this study is shown in (1) which is to maximize the amount of waste collected by the drop off facilities. The constraints of the proposed formulation are represented by the inequalities from (2) to (11). Inequalities (2) guarantee that every demand at location i will have at least one nearest recycling facility during acceptable travel times. Inequalities (3) and (4) impose budgetary and capacity management restrictions on the municipal authorities when managing the recycling system in a given area. (3) imply that the area should have not more than δ operational locations for recycling facility, while (4) limit the quantity of allocated containers for the area at most ε. However, if the system has no restriction on budgetary and on capacity, these constraints could be relaxed. Inequality (5) guarantees that the demand for each location i is covered by only the operational facility at location j. In the meantime, service performance is guaranteed by at least τ percent, as shown in (6). The constraint also portrays the accessibility of demand at location i to any operating facility at site j. Inequality (7) assuring the demand assignment to at least one facility that located at j. Inequality (8) ensures demand of location i are served by the operating facility only. Meanwhile, service capacity is represented by inequality (9). This inequality ensures the amount of demand at all locations i is less than the designated containers capacity. Finally, Equations (10) and (11) represent the constraints of the decision variables. The next section dedicates on the data acquisitions and input parameters setting.

2.3 Data Acquisition

The following part describes the data acquisition on Nilai city area. Figure 2 depicts the study area in Nilai with tabular locations representing the location of existing and potential recycling facilities and the demand area. These locations were

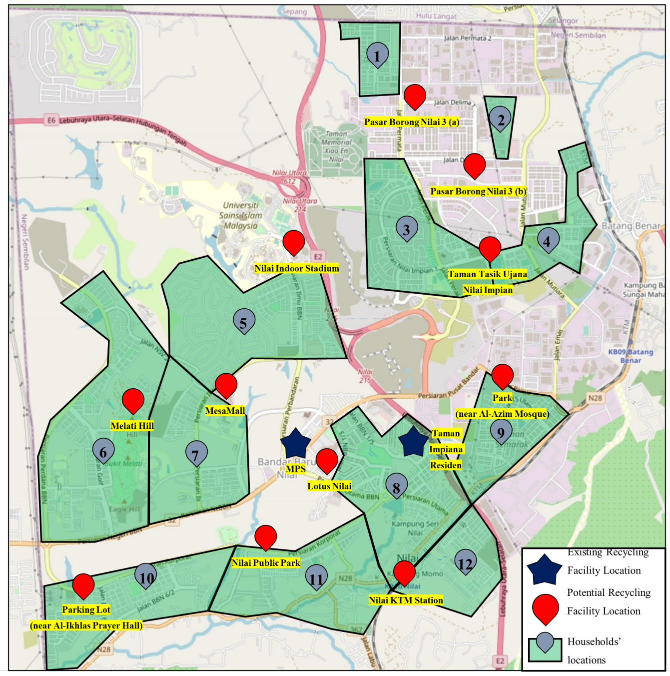

Figure 2. The Existing and the Potential Recycling Drop Off Locations

mapped based on the information gathered from the Seremban City Council and SWCorp official website. The figure displays 14 locations that are identified as potential locations for recycling drop-off facilities based on their accessibility and spatiality, as well as the existing facility. On the same figure, the area of households was highlighted which comprises several neighboring sporadic demands. From this point onwards, we may use the terms "cluster area" or "demand area", which both denote locations of sporadic demand within the householders' territory. As illustrated in Figure 2, it can be observed that area 8 currently possesses a single KITARecycle facility. This location is excluded due to its proximity to the demand area and limited public accessibility.

Table 1 provides information on each cluster area location i that was gathered from the local municipality's official website. According to the table, the cluster area i = 10 has the most populations, and it is estimated total of approximately with an estimated 4000 households. This is because the cluster area contains several residential apartments. Conversely, area 2 has the fewest number of households with nearly 200 units due to its proximity to an industrial region (which the industrial area is excluded from this paper's scope).

Table 2 lists the potential location for the drop-off recycling facility, which is some of the potential locations for the drop-off recycling facility are selected from existing public facilities, such as mosques, public parks, and recreation areas. Some of the locations were selected based on spatiality and accessibility to the public, despite being privately owned facilities. Among these are MesaMall and Nilai 3 Wholesale

Table 2. The Potential Location for the Drop-off Recycling Facility

m	Location
1	Nilai 3 Wholesale Market (a)
2	Nilai 3 Wholesale Market (b)
3	Nilai Indoor Stadium
4	Taman Tasik Ujana Nilai Impian
5	Melati Hill
6	MesaMall
7	Park (near Al-Azim Mosque)
8	Batang Benar KTM Station
9	Lotus Nilai
10	Nilai Public Park
11	Parking Lot (near Al-Ikhlas Prayer Hall)
12	Nilai KTM Station
13	Seremban City Council (Nilai Branch), (MPS) (current existing facility)

Market. Both locations are easily accessible, well-known, and recognizable by the public. Additionally, at m = 13, i.e., the Seremban City Council (Nilai Branch), is the current drop-off recycling waste facility in the area of study. Meanwhile, Google Maps is used to determine the distance between the demand location and the potential location of the drop-off recycling facility. We scheduled Google Maps for the weekend at 10 a.m. with the exclusion of any public holidays in Malaysia, assuming that individuals will use some of their days off to conduct the separation at source activity.

2.4 Input Parameter Setting

For this paper, we set several values for parameters. These parameters are calibrated in order to obtain the optimal solution for two parties, namely the householders and the local municipalities. The householders would probably like to have nearest facility to them and with unlimited capacity, and unlike the local municipalities, the financial restriction is normally there, hence, there would be reasonable to have restriction on number of drop off facilities, and the allocation of containers at the drop off locations.

The number of K is set to be at most five containers at each operating facility of site j. The travel times from location i to j were based on Google Maps. Meanwhile, the maximum travel times, T, is set to be at 10, 15, and 20 minutes, where were chosen based on the highest travelling times of demand at location i to a site j. The container capacity (Q) value reflects the service capacity, and the value is set randomly, which at most 150 unit or 200 units for each container allocated at facility of site j. The maximum number of facility locations (δ) and maximum number of containers allocations (ε) are calibrated for each iteration by one step, with a maximum value of five. Note that the calibration procedure will be terminated if the demand coverage has reached more than 90% level. Finally, the service level, τ is set to be at 90% which means, only 10% of households are expected of not recycling at all. The summary of these parameters is shown in Table 3.

Please note that for our study, most of these values are chosen at random, but we keep the value as small as possible. This is because we want the proposed model to force the system mechanism to set facility locations and container allocations to be as minimum as possible. The model-solving procedure was executed simply via CPLEX 20.0 on a personal computer equipped with an Intel Core i5-7200 CPU (2.71 GHz) and 12 GB of RAM.

3. RESULTS AND DISCUSSION

The following section outlines the outcomes of the recycling facility location and container allocation model proposed for households in Nilai city. The study presents the outcomes of identifying the most suitable location for a recycling facility based on the utilization of calibrated parameter values.

3.1 Recycling Facility Locations and Containers Allocation

Tables 4 and 5 present the optimal facility location of Nilai city, its allocation of containers with varying capacities to the operating facility at site j, and the maximum travel times T. Based on the data presented in the tables, it can be inferred that in order to achieve a coverage of over 90% for the demand areas within Nilai city, a maximum of three units of the recycling facility and six container allocations are required at the minimum value of T (i.e., 10 minutes). Meanwhile, the maximum T value (i.e., 20 minutes) indicates that the operation of a single facility is sufficient. Both tables indicate that by locating a facility at site j = 4, it is sufficient to cover all demand areas within Nilai city. Conversely, the allocation of containers at the designated sites is reliant on the permissible capacity allowance, denoted as Q. According to Table 4, when the capacity allowance is set at 150 units, six containers are required. However, as shown in Table 5, when the allowance is increased to 200 units, the number of required containers decreases to five.

The tables also present the demand assignment and allocation of containers at each operating facility are also varies for both T and Q values. For example, as presented in Table 4, in order to provide coverage for all areas of demand, it is necessary for three sites (j = 3, 6, and 11) to be operational within a maximum travel time of 10 minutes. Four containers were allocated to j = 4, which covers seven demand areas. Additionally, one container was allocated to both j = 6 and 11. From the table, site j = 6 covers five demand locations, while j = 11 only covers two. Meanwhile, Table 5 demonstrates three facility locations are required, namely site j = 3, 10, and 12. For each respective operating facility, two containers have been suggested by the model so that 90 percent of demand areas are covered. Site j = 3 covers five demand areas, while j = 10 and j = 12 cover three and four demand locations, respectively. From this, the difference in assignment of demand locations, selection of facility locations, and container allocations would significantly impact T and Q values.

Table 3. Summary of Some Parameters for Numerical Experimentations

Containers Allocation at each j (K)	Maximum Travel Times (T)	Minimum Containers' Capacity (Q)	Minimum Service Level (τ)	Maximum Total of Facility Locations (δ)	Maximum Total of Containers Allocations (ε)
10	10, 15, 20 minutes	150, 200	90%	[1, 10]	[1, 10]

Table 4. The Assignment of Demand from Location i to the Recycling Facility Located at Site j, with a Container Capacity (Q) of 150 Units

	T = 10 mins		T = 15 mins		T = 20 mins	
m	Number of Containers Allocations	Demand Assignment	Number of Containers Allocations	Demand Assignment	Number of Containers Allocations	Demand Assignment
3	4	5, 6, 7, 8, 10, 11, 12	4	2, 4, 5, 6, 8, 9, 11, 12	-	-
4	-	-	-	-	6	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12
6	1	1, 2, 3, 4, 5	-	-		
11	1	6, 9	-	-	-	-
12	-	-	2	1, 3, 7, 10, 12	-	-

Table 5. The Assignment of Demand from Location i to the Recycling Facility Located at Site j, with a Container Capacity (Q) of 200 Units

	T = 10 mins		T = 15 mins		T = 20 mins	
m	Number of Containers Allocations	Demand Assignment	Number of Containers Allocations	Demand Assignment	Number of Containers Allocations	Demand Assignment
3	2	2, 3, 4, 5,11	3	1, 2, 3, 4, 5, 7, 9, 11, 12	-	-
4	-	-	-	-	5	1, 2, ,3, 4, 5, 6, 7, 8, 9, 10, 11, 12
10	2	1, 6, 12	-	-	-	-
12	2	7, 8, 9, 10	-	-	-	-
13	-	-	2	1, 2, 3, 6, 7, 8, 10	-	-

The location of the optimal recycling facility is shown in Figure 3. Based on the findings, it is recommended that the municipal government position the receptacle at location j = 4, specifically at Tmn Tasik Ujana Nilai Impian, with an allocation of either six or five containers. It is noteworthy that a single facility location is capable of covering 90% of the demand areas. Therefore, an increase in demand from households for recycling is anticipated to enhance the performance of the system.

3.2 Single Recycling Facility Locations vs. System Performance

Additional analyses were performed to anticipate the decision-making process in a scenario characterized by restricted financial resources. The proposed model's behavior was tested under the condition of a single operating facility. This was accomplished by calibrating the service level across a range of 10% to 90%. Figure 4 displays the findings.

The findings from Figure 4 indicate that augmenting the number of containers would continually enhance the performance of the system. The figure depicts the performance of the system with respect to the expected demand met by the utilization of two distinct capacity levels (Q), specifically 150 units

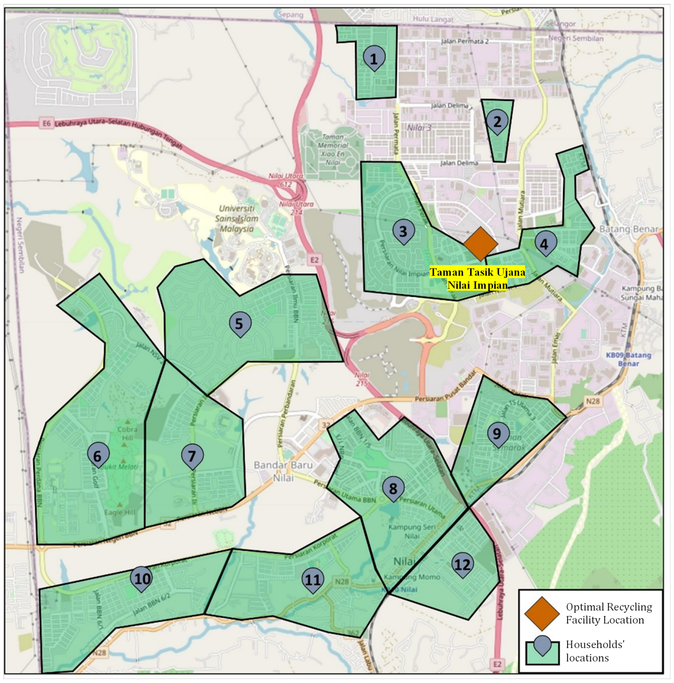

Figure 3. The Optimal Location for the Recycling Drop-off Containers

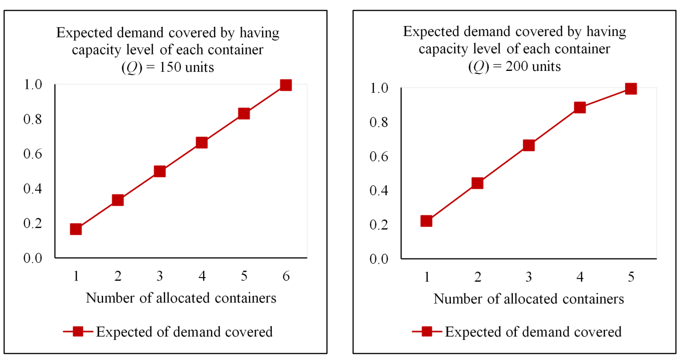

Figure 4. The Expected of Demand Covered when the Capacity is at 150 and 200 Units, with Different Values for Containers Allocation

and 200 units. The impact of container allocation on system performance is apparent as there is a positive correlation between capacity and the expected number of demands covered. Figure 4 is also valuable in depicting a scenario involving funding limitations for the allocation of containers. In cases where the funding for allocating recycling containers is limited or nonexistent, it is anticipated that the coverage of demand areas will decrease. A reduction in system performance will also follow. The information presented in the figure suggests that in order to promote higher rates of recycling among householders, it may be necessary for municipalities to allocate larger funding toward the provision of recycling containers. It is anticipated that by doing so, a greater volume of recyclable materials will be able to be accommodated, thereby contributing to an increase in recycling rates across the country. Clearly, the mathematical model that has been introduced effectively demonstrates the interconnectedness among system performance, container allocations, and operating facility locations.

4. CONCLUSION

This research paper introduced a mathematical model that was developed utilizing the "covering" concept to optimize the allocation of recyclable containers, recycling facility location, and demand assignments in order to achieve the maximum level of demand coverage. The city of Nilai, located in Malaysia, has been employed as a subject for the investigation of the proposed mathematical model. Presently, Seremban City Council (Nilai Branch) have established two KITARecycle facilities within the region. Our findings indicate that a single location suffices for the establishment of a recycling facility, albeit distinct from the existing ones. The Tmn Tasik Ujana Nilai Impian is the optimal location proposed by the model, as it can cover at least 90% of the residents of Nilai City who are located within a 20-minute travel time between the demand area and the facility location. Meanwhile, the allocation of containers is dependent on the permissible capacity, and it is found that a decrease in the required number of containers is observed with an increase in the capacity allowance.

Potential future modifications may be made to the current work where it is possible to execute extension works by implementing an optimal collection routing system at the established sites. The time-period component of the model could be integrated, which has the potential to discretize both the demand patterns and the timing of individuals' disposal of recyclable materials. Furthermore, the model's exclusion of outliers pertaining to periods of excess waste generation, such as those occurring during festivals, school holidays, or public holidays, suggests that incorporating these factors could yield intriguing results. A fuzzy component could be factored in that pertains to the preference of the demand for the travel distance between the facility's site and the demand's location.

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