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Collection and recycle bin location-allocation problem in solid waste management: A review

Purkayastha, D.[1*], Majumder, M.[2] and Chakrabarti, S.[3]

[1] M. Tech Scholar, Department of Civil Engineering, National Institute of Technology, Agartala P.O.: Former Tripura Engineering College Barjala, Jirania 799046, Tripura (W), India

[2] Assistant Professor, Department of Civil Engineering, National Institute of Technology, Agartala P.O.: Former Tripura Engineering College Barjala, Jirania 799046, Tripura (W), India

[3] Registrar (I/C), National Institute of Technology, Agartala P.O.: Former Tripura Engineering College Barjala, Jirania 799046, Tripura (W), India

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ABSTRACT: This comprehensive work explores the research performed in optimization of the collection bin and in recycle bin location-allocation issues in solid waste management. Although the collection phase of solid waste management accounts for a significant proportion of the municipal budget, it has attracted only limited attention of the researchers. Optimization of the collection bin and recycle bin location-allocation problems in solid waste management can be advantageous with respect to bin access to every individual person of municipality, reduction in the numbers of open dumping yards, considerable profit if the recycled products are properly processed, and as an effort toward sustainable and green world. Hence, the topic of interest should be pursued, especially in developing countries, to enable development of a cost-efficient and sustainable solid waste management system.

Keywords: collection bin, location-allocation problem, recycle bin, solid waste management.

INTRODUCTION

Municipal solid waste (MSW) has being produced since the establishment of mankind. Solid wastes are wastes generated due to human and animal activities and are unavoidable by products of human activities. The population growth, rapid economic development, and urbanization have led to an increase in the generation of solid waste. In some developing countries, the growth rate of the urban population is twice that of the world population, which has led to unplanned solid waste management (SWM) and disposal problems, further creating havoc to the environment (Gutberlet, 2003).

Location-allocation modelling is the method of optimizing the location of centers or facilities and allocating consumers or demands to the centers (Valeo et al., 1998). This modelling system has been widely used for facility location planning in both public and private sectors (Beaumont, 1987). Despite it being a significant factor in the successful achievement of SWM, the location-

* Corresponding Author E-mail: debasreep23@gmail.com

allocation problem of sitting storage depots have not been much studied. When determining the type and size of these bins during system planning and designing, the solid waste estimation and allocation are not adequately addressed. Most of the studies mainly investigated vehicular transportation of waste from bins to the disposal sites. Although this process requires heavy vehicles and machinery, its efficiency depends upon the number, location, type and size of bins, as well as the desired waste removal frequency (Vijay et al., 2005).

Parrot et al. (2009) noted that the spatial distribution of the garbage accumulation points (GAPs) inside towns often does not consider the needs of all local residents in terms of quantities of waste produced and the distance from their dwelling. They also reported that, when the average distance to the closest garbage bin (GB) is long, generally, fewer people (37.4%) dump their waste in a GB. This result may partially explain the accumulation of domestic waste in open areas. Similar concerns about the inconvenience of the location of the GAPs have been expressed by Zia and Devadas (2008).

Research Studies conducted in bin location-allocation problem

Only few studies have addressed the problem of collection bin (allowing disposal of all types of waste, i.e., mixed waste) location-allocation problem. Some studies that have addressed the said issue are discussed below. Table 1 shows the details of the optimization methodology adopted and the constraints, data, and objectives considered in formulating the optimization model.

Kao and Lin (2002) proposed a shortest service location (SSL) model for allocating collection points and compared the results obtained with those of two other models: Location set covering (LSC) and maximum covering location (MCL). They obtained the data of the study area from 1/5000 aerial photographs and geographical information system (GIS) data (ArcView 3.0) and used CPLEX 6.5 (optimization software) in their study. They reported that SSL model shortens the walking distance by 10% in comparison to LSC and MCL models.

Vijay et al. (2005) studied a GIS-based procedure for the precise estimation of solid waste generation. They computed the type and size of a bin for a 4km^2 area and estimated that 35 bins of type I (3.0, 4.0, and 4.5 m^3) and 11 bins of type II (1 m^3) should be placed within the study area as haul and stationary types, respectively. The removal frequency for 24 bins was alternate days and 22 bins were allocated for daily emptying, based on the waste quantity estimation and the size of bin selected.

Badran and El-Haggar (2006) proposed a mixed integer programming-based model for selecting the best location for collection station, considering cost minimization of the municipal SWM system as the main objective. They divided the total cost into two components: dependent on the facilities and dependent on the system operation. The former cost includes transportation, fixed, and variable costs of the facilities. The latter cost includes the cost of the operation system, which further includes the cost of the standard HDPE-wheeled bins 770 l, collection staff uniforms, and administration. They adopted this model for municipal SWM of Port Said, Egypt, and the model proposed 27 collection stations of 15 ton/day capacity and 2 collection stations of 10 ton/day capacity. They obtained a profit of 49,655.8 LE/day (equivalent to US$8418.23) by using this model.

Karadimas and Loumos (2008) proposed an innovative model that estimated the municipal solid waste (MSW) generation, identified the location and allocation of waste bins, and supported the routing of garbage trucks for waste collection. Three basic steps were followed for designing the model with ArcGIS (ESRI): Ground-based analysis, designing of the spatial geodata base in the GIS environment, data modelling, and analysis. During ground-based analysis, data were collected from every residential/commercial activities, such as street name, number of residences, parking slots, warehouses and offices, every non-commercial/residential activities, empty lands, and the current location of bins. A linear least square algorithm was used as a data modelling engine to evaluate the coefficients specifying the quantity of commercial activities into four groups. They basically evaluated the coefficients (specifying the quantity of commercial activities) to calculate the realistic estimate of the actual waste generated, from which the actual number of bins can be estimated. Application of this model enabled reduction in the number of bins to 112 from 162, which is almost 30% reduction. Thus, the authors concluded that the total surface area engaged in commercial activities is an important dynamic factor in the estimation of the actual number of bins required.

Erkut et al. (2008) adopted a mixed-integer multiple objective linear programming model to solve the location–allocation problem of municipal SWM facilities in the central Macedonia region of North Greece. They considered five objectives that are listed in Table 1. They formulated the multi-objective problem as a lexicographic minimax problem to obtain a fair non-dominated solution based on two instances: i) considering that each prefecture (in Greece, each region is divided into several prefectures) is self-sufficient and is provided with a waste facility and ii) considering regional planning, i.e., assuming a cooperation between prefectures to locate waste facilities to serve the entire region. After computing results of the central Macedonia region, they concluded that there is minimal gain in moving from the prefectural to regional level, although regional planning showed more promising results than prefectural planning.

Zamorano et al. (2009) asserted that optimization of MSW collection can reduce the management costs as well the negative impacts on the environment. They analysed the municipal waste collection in Churriana de la Vega (Granada, Spain) and described a method to improve waste collection services based on the information provided by the geographic information systems. This study revealed that the town had an excessive number of containers for organic matter and rest-waste fraction, reducing the efficiency of waste collection and raising the costs related to the purchase of containers, collection time, personnel costs, collection route length, and vehicle maintenance. With respect to recyclable fraction collection, waste collection could be improved by increasing the number of containers at optimized location.

Parrot et al. (2009) provided an overview of the state of MSW management in the capital city of Cameroon, Yaoundé, and suggested some possible solutions for its improvement. Their study revealed that remoteness and inefficient infrastructure have a major impact on waste collection. They mentioned GBs as the primary infrastructure needed in all quarters, irrespective of it being a high or low standard community. Furthermore, the construction of transfer stations and the installation of GBs were recommended as solutions to reduce the distances between households and GBs, thus improving the accessibility of waste collection vehicle. They suggested that transfer stations and GBs would enable the official waste-collection company to expand its range of services and significantly improve the waste-collection rates. They also emphasized on public awareness and recycling in Yaoundé in order to reduce the quantities of pure waste and to promote the ecological intensification in agriculture.

Table 1. Studies conducted on the collection-bin location-allocation issue

Author	Model Adopted	Objective of the Model	Assumptions of the Model	Data used in the Model
Kao and Lin (2002)	ArcView 3.0 and Shortest Service Location (CPLEX 6.5).	1. Minimum sum of distances between each demand point to the location serving it.	1. Each demand point is served by its nearest service point. 2. The selected location is nearest to all serviceable locations available for a particular demand point.	1. Population 2. Area 3. Aerial maps and GIS data 4. Waste generated
Vijay et al. (2005)	Triangulated irregular network (TIN) in a GIS environment.	-	1. Providing bins in shortest distance and descending slope for the ease of waste carrying by cart and tricycle pullers.	1. Boundary area of solid waste collection 2. Road network of the study area 3. Road elevation survey data of the road network 4. Road class information 5. Income group distribution 6. Population density distribution 7. Types and capacities of commercially available bins
Karadimas and Loumos (2008)	ArcGIS (ESRI) and linear least square algorithm	-	1. Ensure that bins are placed in roads accessible by trucks.	1. Road network of the study area 2. Population density 3. Present waste bin location 4. Waste generation pattern (Residential and commercial activities)
Tralhão et al. (2010)	Multi-objective mixed-Integer linear programming (MILP) + GIS	1. Minimize the total facility cost. 2. Minimizing the total distance from the dwelling to the allotedecoponto. 3. Minimizing the total number of people <10 m away from an ecoponto. 4. Minimizing the total number of dwellings located at >100 m from their respective ecoponto.	1. No dwelling is more than 200 m from an open candidate site (a site where ecoponto may be located by MILP). 2. Each sector is provided with only one open candidate location. 3. Capacity of the ecoponto is adequate to accommodate the waste generated. 4. Possibility of locating two or more ecopontos with different arrangements and/or different brands to be installed at the same open candidate site location.	1. Total number of inhabitants 2. Total number of dwellings 3. Capacity and brand of each type of ecoponto arrangement 4. Amount of each type of waste generated
Ghiani et al. (2012)	Integer programming model	1. Minimizing the total number of collection sites to be located.	1. Each collection site to be capacitated enough to fit the expected waste to be directed to that site. 2. Ensures that each citizen is served by the waste collection site closest to his/her home, rather than any site nearby.	1. Set of different type of bin available for location 2. Number, capacity, and dimension of bins available 3. Daily generation of waste 4. Total number of inhabitants

Table 1 (Continue). Studies conducted on the collection-bin location-allocation issue

Author	Model Adopted	Objective of the Model	Assumptions of the Model	Data used in the Model
Coutinho-Rodrigues et al. (2012)	Bi-objective mixed-integer linear programming (MILP).	1. Minimization of the total investment cost. 2. Minimization of the dissatisfaction.	1. No sector is >250 m away from an open candidate site (a site where ecoponto may be located by MILP). 2. Each sector is provided with only one open candidate location. 3. Capacity installed is adequate to accommodate the waste generated. 4. Possibility of locating two or more facilities with different arrangements to be installed at the same open candidate site location.	1. Road network of the study area (Specially slope, quality of footpath pavement) 2. Set of candidate site 3. Type of waste generated and its quantity 4. Set of different type of bin available for location 5. Number, capacity, and dimension of bins available. 6. Total number of inhabitants.
Nithya et al. (2012)	GIS solution	-	1. Public preferred walking distance to drop the MSW to the collection bin.	1. Municipal solid waste (MSW) generation in the ward 2. Population density 3. Existing bin locations 4. Road network
Ghiani et al. (2014)	Integer programming model.	1. Minimizing the total number of collection sites to be located.	1. Each collection site to be capacitated enough to fit the expected waste to be directed to that site. 2. Ensures that each citizen is served by the waste collection site closest to his/her home, rather than any nearby site. 3. Two bin types that cannot be served contemporary by the same vehicle are not placed in the same collection area. 4. Zoningto determine the collection districts to be served by each vehicle.	1. Set of different type of bin available for location 2. Number, capacity, and dimension of bins available 3. Daily generation of waste 4. Total number of inhabitants 5. Details of the vehicle types available for waste collection
Di Felice et al. (2014a)	Algorithm	-	1. The GAPs have to be placed on public roads. 2. Every house must have at a distance (measured along the public roads) not greater than a predetermined value of at least a GAP. 3. The number of bins of the different types of waste in each GAP must be sized according to the potential daily production of the household waste by the residents of the district.	1. The set of houses and public roads of the urban area 2. Type of waste to be stored in the garbage accumulation points (GAPs),the number of inhabitants in each house of the area to be served, and their per capita daily production of solid waste. 3. Capacity of the GBs and the frequency of emptying of the GBs of various types.

Tralhão et al. (2010) adopted a Multi objective Mixed-Integer Linear programming (MILP) approach to identify the locations and capacities of multi-compartment sorted waste containers. This approach incorporated optimization problem in a GIS-based interactive decision support system, which included four objectives as tabulated in Table 1. They believed that the large number of dwellings in Baixa was aggregated into linear sectors along the roads and dwellings and assumed that the residents in each sectors were located at the sector's mid-point. A combination of different arrangement and the brands of ecopontos were selected for placement, and approximately 300 constraints were adopted for the model, four of which are tabulated in Table 1. The solution provided by the model consists of sets of open-facility locations and the sectors (and corresponding people and waste production) assigned to each open site location. Results provided by the MILP suggested 10 solutions consisting of different combinations of containers for the disposal of four types of sorted wastes (viz., glass, plastic, paper, and other) in 12 candidate locations.

Ghiani et al. (2012) proposed an integer programming model aimed to help decision makers in selecting the sites to locate the unsorted collection bins in a residential town as well as the capacities of the bins to be located at each location site. They considered two constraints: i) making each collection site sufficiently capacitated to fit the expected waste that are to be directed to that site and ii) ensuring quality of service from the citizen's perspective. This quality of service requirement ensures that each citizen is served by the waste collection site closest to his/her home, rather than any random site. They also proposed a heuristic approach that provides good-solution quality in an extremely reduced computational time. They applied their proposed optimization model and the heuristic model to the city of Nardò, southeast Italy, in the Apulia region with 190.52 km^2 area. This area compromised of 560 collection sites. The results obtained by the heuristic model showed that approximately 227 optimal locations were needed with a threshold distance of 150 m and a per capita daily waste generation of 1.3 kg, i.e., an average reduction of approximately 73.5% in comparison to the present number of bins used. In the optimization model, Nardo was divided into two zones, A and B, area-wise. The model proposed 116 optimal locations for zone A, with an average reduction in bin numbers of 71.5% and 95 optimal locations for zone B, with an average reduction in bin numbers of 73.5%. These results demonstrate how much monetary profit as well as environmental benefit can be achieved by using the optimization techniques in location-allocation of the garbage collection bins.

Coutinho-Rodrigues et al. (2012) introduced a mixed integer, bi-objective programming approach to identify the locations and capacities of the collection bins. They considered two objectives, i) minimization of the total investment cost and ii) minimization of the dissatisfaction level, i.e., the number of individuals who do not want to live too close to collection sites, yet not be too far. They incorporated the pull and push characteristic of the decision problem, i.e., the second objective in the same function and employed more than 9300 constraints.

Nithya et al. (2012) designed a GIS-based model to investigate the adequate number and positions of collection bins in the Sidhapudur ward of Coimbatore, India. The fundamental objective of this approach was to develop a model on the basis of public-preferred walking distance to drop the MSW to the collection bin. They fabricated three models based on different proximity distances (50, 75, and 100 m) for the existing bins and the proposed bins. The 50- and 75-m buffer zone showed 32% and 38.6% coverage area, respectively, for the existing bin location model and 60% and 99%

coverage area, respectively, for the proposed bin location model. Hence, the proximity distance of 75 m was found to be optimum for the residents living in that ward area.

Ghiani et al. (2014) faced problems when attempting to implement the solutions obtained in their previous study (Ghiani et al., 2012) in the real world. In order to address the issues associated with the placement of two bin types that cannot be served contemporarily by the same vehicle, two different bin types were not placed in the same collection area with due consideration of zoning, i.e., to determine the collection districts to be served by each vehicle. They considered two constraints: i) forcing each collection site to be adequately capacitated to fit the expected waste to be directed to that site and ii) ensuring that each citizen is served by the waste collection site closest to his/her home, rather than any random site. Moreover, each bin type is characterized by the length, capacity, and the vehicle type (or a set of vehicle types) with the capability of unloading it. In fact, it was considered that a vehicle type can serve several (but not necessarily every) bin types and that a bin type can be served by several (but not necessarily every) vehicle types. The objective function aimed to minimize the total number of activated collection sites. They first proposed both an exact and a heuristic approach to locate the unsorted waste collection bins in a residential town and then decided the capacities and characteristics of the bins to be located at each collection site. They also proposed a fast and effective heuristic approach to identify the homogeneous zones that can be served by a single collection vehicle. They employed the computational results on a real-life instance and found reduction of one vehicle as well as 25% reduction in the average distance travelled by the vehicles for collection.

Di Felice et al. (2014a) computed the location of the GAPs as well as the number of bins by using two different algorithms for obtaining the location GAPs and the sizing of GAPs, respectively. They used spatial information (such as set of houses and public roads), and descriptive variables (such as type of waste to be stored in the GAPs, the capacity of the GBs, the frequency of emptying of the GBs of various types, the number of inhabitants in each house of the area to be served, and their per capita daily production of solid waste). Di Felice et al. (2014b) provided a pilot study of the above model in L’Aquila municipality (the capital city of Abruzzo, Italy). He applied the model to the Cansatessa district of L’Aquila municipality, which comprised of six GAPs and 30 GBs. The GBs were subdivided depending on the type of waste as for glass (n = 4), for paper (n = 4), for plastic (n = 4), for organic (n = 8), and for unsorted (n = 10). The model was run for 50, 100, 150, 200, 250, 300, and 500 m maximum distances between a GAP and each house. The author observed that the number of and the total number of GAPs decreased with the increase in the distance. For Cansatessa district, the best condition to address the situation was distance = 500 m with six GAPs and 82 GBs (13 for glass, 11 for paper, 15 for plastic, 28 for organic, and 15 for unsorted). Thus, according to the results of this study, the author concluded that the present situation of the Cansatessa district was much backward with only 30 GBs as 82 GBs are ideally required. He also clarified that adopting few GAPs may cause several drawbacks for the citizens.

Recycle bin location-allocation problem

The process of recycling began since 1995 in developed countries, although the developing countries are far behind in incorporating recycling as an essential and mandate process in their SWM strategies. The literature clearly depicts this unfortunate picture. Optimization of the recycling depots or bin locations has been performed by only few researchers. The literatures that have addressed this issue are detailed below. In addition, some papers that have studied the attributes or factors that emphasize the recycling practice have also been incorporated.

A consolidated table (Table 2) has been prepared detailing the optimization methodology adopted and the assumptions, data, and objectives considered in formulating the optimization model.

Chang and Wei (1999) proposed a strategic plan for allocating recycling drop-off stations of appropriate sizes and also designed the efficient collection route for the collection of the recycle bins for Taiwan. They used multi-objective non-linear mixed integer programming model in a GIS environment to solve the problem.

Flahaut et al. (2002) proposed a p-median model that incorporated transportation and externality costs in comparable units to compute the optimum locations for sitting recycle depots. They partly addressed the NIMBY syndrome (Not in My Back Yard) associated with the placement of recycling depots in the form of externality cost. Basically, the externality cost was measured in terms of noise, smell, visual, and traffic pollution. Their results revealed that high intensity of pollution have significant effect on the location-allocation model, leading to the selection of recycling depots located far away from the consumers. It was also concluded that small errors in quantifying the externality estimation have no significant impact on the final decision computed from the model.

Gonza´lez-Torre et al. (2003) studied the recycling process practiced in two specific areas: the Principality of Asturias (Northern Spain) and El Paso County (USA). Their observations are as detailed below:

- Lesser effort to disposal develops a habit of selective separation; hence, efforts should be made to increase and disperse the number of collection points and locate them close to population centers in order to reduce the time required to reach them.
- Smaller sizes of selective collection bins and collection centers in multiple locations are preferred over larger ones in strategic locations, provided that the collection frequency is good and that the containers do not overflow.
- Recycling rate can be increased by developing visually interesting containers and addressing the noise and smell effect associated with collection bins by improving the collection frequency.

Gautam and Kumar (2005) designed a multi-objective programming in a GIS environment to obtain the number, size, and location of recycle drop-off stations. They identified 18 recycling drop-off stations as per the conditions of maximization of the population served by the recycling drop-off stations and minimization of the total walking distance from a household to a recycling drop-off station. Both the objectives were fulfilled: no resident had to travel a distance of more than 250 m to reach a waste disposal bin (recycling drop-off stations) and the distance between two drop-off stations was not more than 500 m according to their proposed model.

Farhan and Murray (2006) reported that distance decay, coverage range, and partial regional service are of particular importance and needs to be addressed simultaneously while setting recycling facilities (undesirable) because the farther a recycling facility is from a residence and/or a business set up, more would be the associated negative impacts, for example, the cost of disposal would increase; thus, these facilities should not be too far away from the points of waste generation (residences and businesses). The authors developed a model, Maximal/Minimal Covering-Distance Decay Problem (MCDDP), which was based on distance decay, coverage range, and partial regional service as objectives and minimizing the coverage impact as the concern. Assuming the maximum impact distance as 1 mile (1.61 km), MCDDP took only 36 s and 569 iterations to process the result and the results obtained by them showed only 0.1% impact on the population (i.e., 922 of 1,068,978 people).

Martin et al. (2006) found that 80% of the householders of Burnley, England were willing to participate in recycling, but the local recycling services were too unreliable and inconvenient to allow them to do so comprehensively. Their findings also revealed that recycling takes time and therefore people with more free time (retired householders and elderly without children) were more likely to be full recyclers, while those with lesser free time (adults with children) showed lower rate of participation. They also suggested that by providing a variety of recycling containers to suit different waste-type circumstances, including extending the garden-waste service to the Asian–British population in order to collect kitchen waste may prove to be a good choice to encourage recycling.

Bautista and Pereira (2006) addressed the reverse logistic problem associated with the improper MSW collection system and thus initially established a relationship between the set-covering problem and the MAX-SAT (Maximum Satisfiability) problem and then developed four genetic algorithms (GA-1, GA-2, GA-3, GA-4) and a GRASP heuristic to solve each formulation. Their objectives are tabulated in Table 2. Both the models were assessed on a test-case related to a city in the Barcelona metropolitan area. The mean running time for each instance was 160, 158, 159, 158, and 225 seconds for GA-1, GA-2, GA-3, GA-4, and GRASP, respectively.

Table 2. Studies conducted on recycle-bin location-allocation problem

Author	Model Adopted	Objective of the Model	Assumptions considered in the Model	Data Used in the Model
Chang and Wei (1999)	Multi-objective non-linear mixed integer programming model in a GIS environment	1. Maximization of population served by the recycling drop-off stations.	1. Only a limited number of recycling drop-off stations can be sited in the network.	1. Population density.
		2. Minimization of the total walking distance from a household to a recycling drop-off station.	2. Avoiding possible overlap of service areas among individual recycling drop-off stations.	2. Waste generation rates.
			3. The recyclables collected at a candidate site should not exceed the storage capacity provided by those recycling tanks.	3. Spatially distributed sources of waste generation.
		3. Minimization of the total driving distance during vehicle routing.	4. Every node picked up as a recycling drop-off station must be visited once in a vehicle-routing process.	4. Road network of the study area.
			5. Service radius of each recycling drop-off station can be limited within a specified distance.	
Flahaut et al. (2002)	p-Median	1. Minimizing the sum of the transportation costs and the external costs characterizing the impact of afacility.	1. Transportation costs are proportional to distance, with a unitary transportation cost of 0.30 EUR/km.	1. Population.
			2. External costs of pollution produced in a demand point and measured in WTP (Willingness To Pay) to reduce nuisance, the maximum being equal to 1,980 EUR at a distance d = 0 from the source of pollution.	2. Number of recyclers visiting the recycling station.
				3. Quantity of waste produced.
			3. No demand point was considered across the boundary of the commune.	4. Road network of the study area.

Table 2 (Continue). Studies conducted on recycle-bin location-allocation problem

Author	Model Adopted	Objective of the Model	Assumptions considered in the Model	Data Used in the Model
Gautam and Kumar (2005)	Multi-objective programming in a GIS environment	1. Maximization of population serviced by recycling drop-off stations, i.e., to maximize the service ratio based on total residents in the service area. 2. Minimization of the total walking distance from each household to a recycling drop-off station.	1. No person should walk >250 m to dispose waste. 2. Every demand location is served. 3. Demand location can be assigned as a candidate facility location only if there is an open facility available.	1. Boundary area of solid-waste collection system. 2. Road network of the study area. 3. Income group distribution of the study area (HIG/MIG/LIG/Slums). 4. Population density distribution of the area. 5. Physical characterization of city refuse, which can be obtained by an actual field survey of the area under study.
Farhan and Murray (2006)	Maximal/Minimal Covering-Distance Decay Problem (MCDDP)	1. Minimizing the potential demand covered by the facility.	1. Distance decay. 2. Coverage range. 3. Partial regional service.	1. Land use data. 2. Census data.
Bautista and Pereira (2006)	Genetic algorithm and GRASP heuristic	1. Minimizing costs 2. Minimizing the number of collection areas given a maximum distance. 3. Minimizing the noise and visual impacts.	1. Maximum distance that any citizen is allowed to travel to reach the nearest collection point is fixed at 60 m.	1. Population density. 2. Road network and distribution of homes around the streets in the study area. 3. Waste generation pattern of the study area.
Lin and Chen (2009).	Computer integer programming.	-	1. The acceptable walking distance for a recycling participant was fixed at a particular value at various scenarios. 2. If two regions both lack suitable access to recycling collection points, the region containing more residents should be given a higher priority when determining the location of new recycling facilities. 3. Recycling participants who send material to the full-range recycling centers are more strongly motivated, either as a result of money or good intentions, than those using smaller recycling points.	1. Population density. 2. Present locations of recycling depots. 3. Quantities of recyclable materials being collected in each administrative tract.
Kao et al. (2010)	1. DO 2. DB 3. ND 4. EDO	1. Minimize the sum or average distances between each household to the closest recycling depot.	1. The maximum acceptable service distance between each household group and recycling depot was set to 2220 m for district M, N, and O and 820 m for other 13 districts. 2. Each district should have at least one recycling depot as the minimal requirement. 3. Each household is served by the nearest depot.	1. Number of households in the study area. 2. Total number of residents. 3. Predetermined candidate location data. 4. Street distances between each household group and each candidate recycling depot.

Table 2 (Continue). Studies conducted on recycle-bin location-allocation problem

Author	Model Adopted	Objective of the Model	Assumptions considered in the Model	Data Used in the Model
Kao et al.(2013)	1. MSD-DO 2. MSD-DB 3. District- MSD-DB 4. SR-ND 5. NOD-ND 6. Average Service Distance (ASD)-ND.	1. Minimizing the maximal service distance. 2. Maximizing the service ratio. 3. Minimizing the number of depots for district-based, district-open, and non-district scenarios.	1. The maximum acceptable service distance between each household group and the recycling depot is fixed to ensure spatial equity. 2. Each district should have at least one recycling depot as the minimal requirement. 3. Each household is served by the nearest depot.	1. The number of households in the study area. 2. Total number of residents. 3. Predetermined candidate location data. 4. Street distances between each household group and each candidate recycling depot

Suttibak and Nitivattananon (2008) studied the factors affecting the performance of solid waste recycling programs and showed that the common significant factors were perception of administrator awareness of SWM problems and source separation. The results of their study were as follows:

- In terms of school garbage banks, the provision of monetary incentive including interest and compensatory goods for recycling members, transportation cost, and low investment costs significantly affect the performance.
- Better performance for community garbage banks can be achieved by providing provision of loans, managing the programs as a cooperative organization, and provision of door-to-door service.
- In case of composting facilities, provision of free organic waste bins and cooperation with NGOs correlate with a higher rate of waste diversion.
- The performance of recycling systems can be enhanced via several measures including provision of monetary incentive, tax incentives, subsidizations, information dissemination, awareness campaigns, training, technical assistance, staff exchanges, and networking with voluntary organizations.

Lin and Chen (2009) proposed a computer integer programming to provide an optimization problem for locating supplementary recycle depots for Taiwan. They used three indicators spatial accessibility (SA), population loading (PL), and integration efficiency (IE) to evaluate whether a particular geographical area needs new recycling depots. They collected MSW and population statistics and then computed the three indicators and implemented the model to locate the recycling facilities and, finally, evaluated the optimal solutions for the study area. Their model helped identify regions that are in need of recycling facilities in contrary to concentrating on any optimal combination of locations. The model was successfully applied to the Taichung city, the third largest metropolis in Taiwan. The SA indicator analysis applied to Taichung for locating glass recycling points identified 35 regions without access to glass recycling depots. The PL indicator analysis applied to Taichung for locating glass recycling points identified 10 regions without access to glass recycling depots. The IE indicator analysis applied to Taichung for locating glass recycling points identified 10 regions without access to glass recycling depots. The major advantage of their model is flexibility provided by expeditious computational evaluation of competing design solutions.

Hage et al. (2009) studied the recycling behavior influenced by norms and economic motivations in Sweden and found that a convenient and improved collection infrastructure majorly influenced the process of recycling. Their results showed that property-close collection in multi-family dwelling houses leads to higher collection rates and that the strength of moral norms (maintaining a self-image as morally responsible and thus norm compliant) explains a large part of variation in recycling across households. However, the importance of such norms in driving recycling efforts partly diminishes when the improved collection infrastructure enables easy recycling for every household.

Troschinetz and Mihelcic (2009) conducted 23 case studies in developing countries and found the following 12 factors that influenced the MSW recycling in developing countries: government policy, government finances, waste characterization, waste collection and segregation, household education, household economics, MSWM (municipal SWM) administration, MSWM personnel education, MSWM plan, local recycled-material market, technological and human resources, and land availability. They found that the average MSW generation rate was 0.77 kg/person/day, with recovery rates of 5-40%. The waste streams of 19 of these case studies consisted of 0–70% of recyclable material and 17–80% of organic material.

Sidique et al. (2010) studied the effects of behavior and attitudes on drop-off recycling activities and found that the demographic factors (such as age, education, income, and household size), economic factors (such as travel distance, sorting time, income), and psychological factors (such as attitude and knowledge) drive the recycling behavior in the specific context to drop-off recycling. Their findings are listed below:

- The location of a drop-off recycling station influences its usage pattern; recyclers are likely to use a drop-off site more frequently when the travel distance from home to site is shorter.
- Locating drop-off recycling centers convenient to higher income, older neighborhoods is likely to lead to higher utilization.
- Recyclers tend to use the drop-off sites more when they believe el that recycling is a convenient activity and when they are familiar with the available recycling facilities. Hence, communication and educational efforts aimed at improving the awareness of recycling facilities and convenience can be effective in promoting visits to the recycling centers.
- Social norms are more appealing then environmental education in increasing the recycling activities.

Kao et al. (2010) considered the factors average service distance (the distance between the household and the closest recycling depot), LS ratio (ratio of local households receiving service), and service ratio (the ratio of residents receiving a service at an acceptable distance) for optimizing the recycling depot location-allocation problem. They addressed the problem by using four models: district-open (DO), district-based (DB), non-district (ND), and enhanced district open (EDO). The objective for all four models was minimizing the sum or average distance between each household to the closest recycling depot. The models were applied to one district in the northern and 15 districts in the eastern regions of the Hsinchu city, Taiwan with a total area of 21.28 km^2, 18,280 households, and 58,379 residents. In this study, the authors considered two scenarios: i) one depot per district and ii) three additional depots because of the sparse population in the three districts. They also found that the LS ratio is an important decision factor. The EDO model was suggested as the best model in this case.

Lee and Paik (2011) studied the recycling behavior of Korean household waste. They detailed that Korean government in 1995 implemented a volume-based waste fee system (unit pricing system) that required every household to purchase certified plastic bags for waste disposal, following the introduction of such stringent norms as MSW/person/day reduced from 2.3 kg/person/day in 1991 to 1.04 kg/person/day in 2008. Fig. 1 clearly depicts the change in MSW management in Korea.

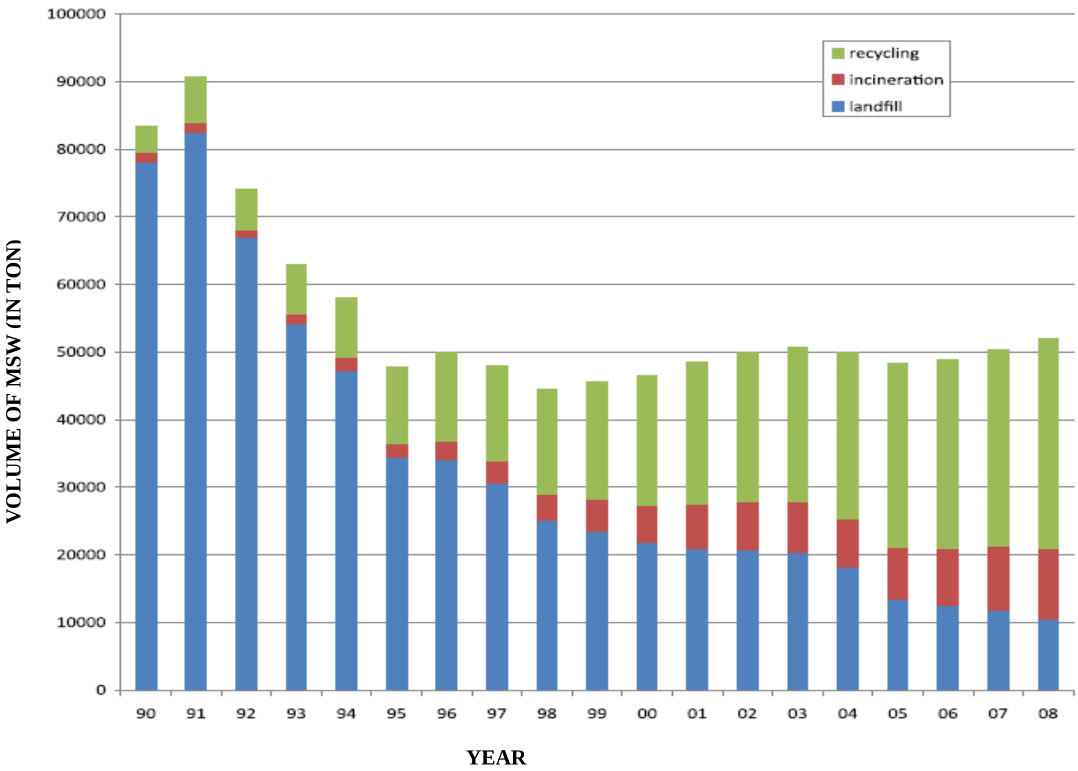

Fig. 1. Changes in the volumes of MSW from 1990 to 2008 (unit: ton). (Lee and Paik, 2011)

In addition to imposing stringent norms, the Korean government supports several other waste management methods to protect the environment, such as waste management planning for congregate housing site developments and new waste treatment facility construction, and energy cost for biofuel produced from incineration and landfill treatment. According to their analysis in SPSS 16 based on the data collected from a survey including 196 respondents, they concluded that the waste management attitude, age, and income significantly affected the recycling and waste management behaviours.

Miafodzyeva and Brandt (2013) studied 63 published empirical research articles to find different variables that influence and determine the recycling behaviour of householders using a meta-analysis. They roughly divided the variables in four theoretical groups: individual socio-demographic, technical-organizational, socio-psychological, and study-specific. They found that the most commonly used socio-demographic variables investigated in the literature include age, gender, income, education level, and dwelling. In the technical-organizational group of variables, they found the type of convenience (refers to the transparency of the collection scheme: ease of understanding and use), unit pricing, and access to kerbside (property close) collection. They observed that the socio-psychological variables were most frequently studied and therefore included seven variables of this group, including motivational factors such as general environmental concerns, moral norms, legal norms, and social norms and three situational factors such as information and knowledge, past behaviour, and personal effort. Study-specific variables included factors such as population density, political allegiance, religious identity and ethnicity, sense of community, new immigrants, and the amount of waste generated in a household. The group of study-specific variables was excluded from their study, as the number of results was statistically insignificant. The four strongest predictors obtained by the meta-analysis in their study included convenience, moral norms, and information and environmental concern, which are represented in the centre of the model, close to behaviour intention. They concluded that the variables such as kerbside, personal effort, social norms, and income are relatively less stronger in predicting the behavioural intention.

Rada et al. (2013) used web GIS solution to adopt an optimized selective collection (SC) system for four cities, including two Italian cities and two European cities. Their first case is one of the best examples of selective collection optimization in Italy. The obtained efficiency was very high; 80% of waste is source-separated for recycling purposes with a decrease in waste production per inhabitant of 18% in approximately 10 years, but the most important advantage was the decrease in residual MSW from 72% to 28% in 10 years and tripling of the increase in the recyclables. In their second reference case, the local administration faced optimization of waste collection through Web-GIS-oriented technologies for the first time. From 1955 to 2004, the collected waste was used as landfill. In 2004, the SC was introduced for the packaging waste (in a bag with a bar code) and others. In 2005, a selection plant was used to recycle and reuse a part of the collected packaging waste as well as to produce light fuel from the residues of the selection plant and from the waste as it is from specific companies. As per the results obtained with the implementation of the bar-coded bag, in 2011, an integrated solution of RFID for bins and LeO system for collection management was proposed by Rada et al. (2013). The last two case studies concerned pilot experiences in China and Malaysia.

Kao et al. (2013) reported that most of the location-allocation problem designed for recycling depots consider that “service distance to the recycling depot must be minimized”, but they investigated that the location selected based only on this factor lead to concentration of depots in only highly populated areas, while the rural areas remain deprived. Hence, to maintain spatial equity they suggested incorporating factors such as maximal service distance (MSD), service ratio (SR), trade-off between number of depot (NOD), and the total service distance can lead to an efficient optimum solution that addresses administrative issues. They formulated six models (tabulated in Table 2) based on three scenarios [district-open (DO), district-based (DB), and non-district (ND)] and applied the same to an urban area of 16 districts in the northern and eastern regions of Hsinchu, Taiwan with a total area of 21.28 km^2, 18,280 households, and 58,379 residents. The models were implemented using ILOG CPLEX 11.2; comparison of the models adopted in this paper with those in Kao et al. (2010) showed that the models in this paper with incorporation of MSD and SR were better than DB, DO, and ND models with same NOD. The results showed that SR-ND model (SR = 79%, NOD = 16, ASD = 241 m) and NOD-ND model (SR = 79%, NOD = 15, ASD = 250 m) showed the best SR, shortest-service distance, and good spatial equity. However, they recommended the NOD-ND model for their study area because the NOD required was less than that required by SR-ND model maintaining almost similar SR and ASD.

Teixeira et al. (2014) analyzed evaluation of the strength and weakness of a collection system and supported proactive decision-making and strategic planning using a core set of performance indicators (effective collection distance, effective collection time, and fuel consumption) for Oporto Municipality in Portugal. Their computation required data on the total amount of waste collected (MSWc), the distance travelled (De), the time spent (Te), and the fuel consumption (Fc) in each collection route from the first to the last container. The indicators: effective collection distance, effective collection time, and effective fuel consumption were computed from the normalization of the variables MSWc, De, Te, and Fc. The analysis provided collection circuit's operational assessment and supported effective short-term municipality collection strategies at the level of, for example, collection frequency, timetables, and the type of containers.

CONCLUSION

From the literature overview, it is clear that only few studies have been conducted to address the issue of collection bin and recycle bin location-allocation problem. Although the collection phase of SWM accounted for a significant amount of the budget, this topic has not been much explored by the researchers. Optimized and adequate location-allocation of bins can lead to various advantages such as access to bin to every individual in a municipality, reduction in the creation of uncountable open dumping yards, economic management, profit if the recycled products are properly processed, and switching to a sustainable and green world. Hence, this area of study should be encouraged, especially, in developing countries to ensure cost-efficient and sustainable SWM.

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