Graphical Abstract

**Waste Bins Location Problem: a review of recent advances in the storage stage of the Municipal Solid Waste reverse logistic chain**

Diego Gabriel Rossit, Sergio Nesmachnow

Entry point of Municipal Solid Waste system
Largely impacts on collection and recycling efficiency

**WASTE BINS NETWORK**

**REVIEW OF RELATED WORKS**
Classification of optimization criteria and resolution methods
Integrated approaches (bins location + routing)

**MAIN FINDINGS**
Most articles studied network costs and user accessibility trade-off, on real-world cases
Few integrated approaches or generation uncertainty

**ANALYSIS**
Quantitative analysis: bibliometric information, case studies, approaches, and criteria
Highlights

Waste Bins Location Problem: a review of recent advances in the storage stage of the Municipal Solid Waste reverse logistic chain

Diego Gabriel Rossit, Sergio Nesmachnow

- A comprehensive review of the waste bins location problem.
- Configuration of the network of bins affects the overall efficiency of the Municipal Solid Waste system.
- Waste bins location problem is a computationally complex problem.
- Different conflicting criteria are involved in waste bins location.
- Several approaches considered the trade-off between the cost of the system and quality of service.
- Few works addressed simultaneously the bins location and waste collection problems.
Waste Bins Location Problem: a review of recent advances in the storage stage of the Municipal Solid Waste reverse logistic chain

Diego Gabriel Rossit\textsuperscript{a,b,∗}, Sergio Nesmachnow\textsuperscript{c}

\textsuperscript{a}Department of Engineering, Universidad Nacional del Sur, Argentina  
\textsuperscript{b}Instituto de Matemática de Bahía Blanca UNS-CONICET, Argentina  
\textsuperscript{c}Universidad de la República, Uruguay

\section*{ARTICLE INFO}

\textbf{Keywords:}
municipal solid waste  
waste bins location problem  
review

\section*{ABSTRACT}

Municipal Solid Waste systems have important economic, social, and environmental impacts for society. Within the diverse stages of the Municipal Solid Waste reverse logistic chain, the waste bin location problem consists in properly locating bins in the corresponding urban area to store waste produced by the citizens. This stage has a large impact in the overall efficiency of the whole system. Thus, several researchers have addressed the location problem considering different optimization criteria and approaches. This article presents a comprehensive review of recent advances on the Waste Bins Location Problem, with the main goal of serving as a reference point for decision-makers in this area. The main findings indicate that several optimization criteria and resolution approaches have been applied, but few proposals have simultaneously optimized bins location and waste collection, or considered uncertainty of the model parameters and integrated approaches.

\section{1. Introduction}

Waste management is a major challenge in modern societies, critical for sustainability and improving the quality of life of citizens (De Souza et al., 2017). This issue becomes even more critical if it is considered that the amount of waste generation rate per capita will continue increasing in the following decades (Hoornweg and Bhada, 2012; Hoornweg et al., 2015).

The reverse logistic chain of Municipal Solid Waste (MSW) is a special case of a reverse supply chain that is defined as “a network consisting of all entities involved in the flow of disposed products leaving the point of consumption. It includes collection, transportation, recovery and disposal of waste. Its purpose is to recapture or create value and/or proper disposal” (Van Engeland et al., 2020). This subject has received a large interest from both professionals and academic communities in the last decades. An efficient provision of MSW management services is a key element to diminish the environmental impact of human activities on the environment, through a responsible treatment and/or final disposition of the generated waste, and to postpone the depletion of limited resources, through the recovery of reusable resources from waste (Das et al., 2019).

\textsuperscript{∗}Corresponding author

\textsuperscript{ORCID(s):} 0000-0002-8531-445X (D.G. Rossit); 0000-0002-8146-4012 (S. Nesmachnow)
The MSW reverse logistic chain includes several stages: generation, storage, collection, recovery, and/or disposal of waste. The storage stage consists in properly locating waste bins in the corresponding urban area to build a network for collecting the waste produced by the generators, which is the entry point to the MSW system. The location of waste bins has a large impact in the overall efficiency of the whole MSW system, since it influences the amount of waste that is introduced to the system, i.e., the material that circulates through the reverse logistic chain. A sparse or not properly distributed collection network reduces the accessibility of citizens to the MSW system, thus, reducing the amount of waste that is correctly disposed (Parrot et al., 2009; Toutouh et al., 2020). Additionally, due to the direct influence of waste bins location and storage capacity on the length, travel times, and schedule of the collection routes, the design of this stage also contributes to improving the overall environmental impact of the MSW system (Pérez et al., 2017; Zhang et al., 2021). The number, distribution, and type of waste bins are also relevant for the costs of the system since: the waste bins collection network and waste transportation from bins to transfer/final plants or landfills can explain about 70% of the overall cost of the system (Boskovic et al., 2016).

Waste bins location also has important social implications, since waste bins are usually the main interaction point between citizens and the MSW system of a city. For example, small problems in the management of this network—e.g., overflow of bins due to improper capacity planning—will immediately affect the quality of service provided to the citizens and may cause a large number of complaints. Additionally, waste bins, as other semi-obnoxious facilities, are affected by the “Not In My Back Yard” (NIMBY) phenomenon: citizens want bins to be located relatively near to minimize the distance they have to carry their waste to dispose it, but simultaneously they do not want them to be located very close to their homes to avoid unpleasant environmental consequences, e.g., bad smell, visual pollution or collection vehicle disturbing noises (Coutinho et al., 2012). Due to all the aforementioned economic, environmental and social aspects, waste bins location emerged as a relevant problem for designing efficient MSW systems, and several approaches have been proposed by the research community to solve it efficiently via different optimization approaches.

In this line of work, this article contributes with a thorough revision of the recent literature on the municipal solid waste bins location problem in urban areas. No similar survey has been published in the related literature. The only previous effort to review relevant works on the topic was elaborated by Purkayastha et al. (2015), focusing on the optimization of collection bin and recycle bin location. That review commented the main aspects and contributions of 17 articles (9 considering collection bins and 8 considering recycling bins) published between 1999 and 2014. Although it was a contribution to the area, being the first review on the topic, some results were not commented, and the main relevance of each proposal was not highlighted. Additionally, the review lacked of a global analysis of the research area, suggestions for interesting developments, or open research lines. In addition, many new researches about MSW bins location have been developed in the last six years, which are the main subject of the review presented in our article. We review more than seventy articles directly related to the MSW bin location problem in the period 1998–2021.

Thus, the main goal of the survey is to present an updated analysis of relevant articles about the MSW bin location problem to be considered as a guide for both researchers and practitioners involved MSW management and optimization. We put special emphasis on reviewing recently proposed approaches as well as considering new upcoming topics, such as the integration of the MSW bin location problem with the waste collection problem and the application of Internet of Things (IoT) technologies to waste bins.
The article is organized as follows. Next section describes the research methodology and content organization. Then, Sections 3 and 4 present the main concepts of the overall reverse supply chain of MSW and of the specific stage of this chain regarding the waste bins location problem. Section 5 provides a quantitative summary of reviewed articles. The main concepts about bin location problem optimization criteria and the applied resolution methods are described in Sections 6 and 7. Finally, the discussion about relevant issues on the reviewed articles, open lines of research, and promising lines for future work are commented in Section 9.

2. Research methodology and content organization

Systematic literature review is a very relevant foundation for research, a must for knowing the main developments on any research area to properly contextualize the main contributions of the own research (Gough et al., 2012). The main goal of a systematic literature review is to provide readers the current state-of-the-art regarding a topic or a research question, and how previous advances can be applied in a current or future situation. The existing knowledge must be properly described, synthesized, commented, and fairly evaluated using a sound and rigorous procedure (Snyder, 2019). Classifications and conceptual categorizations are also useful to help the reader to better comprehend the main similarities and differences between the reviewed proposals (Tranfield et al., 2003).

The study is within the category of systematic search and review (Grant and Booth, 2009), including two components: i) a comprehensive mapping, categorization, and quantitative/qualitative analysis of existing articles, and ii) a critical review explaining the reported approaches and results.

The first stage in the literature review process is defining a proper research topic or research question, which can be properly used to guide the content and focus of each review. In the case of our study, the main research topic is the waste bins location problem, i.e., deciding the places in an urban area to deploy a set of bins in order to receive the waste from nearby generators.

The second stage is performing a systematic and comprehensive search to identify articles, reports, and thesis that most contribute to the area. The availability and reliability of data sources are crucial for a high-quality review. Our study considered the two main databases of scientific articles: i) Scopus, (Elsevier Publishers, more than 36,000 peer-reviewed journals indexed) and ii) Web of Science (Institute for Scientific Information/Clarivate Analytics, more than 35,000 journals indexed). Since the search covered the main scientific publications in the subject, we have confidence that all main research approaches and ideas for waste bins location are represented, and the risk of bias is minimum. Regarding the search criteria, the TITLE-ABS-KEY(list of terms) schema was applied, using as keyword terms ‘waste’, ‘bin’, ‘location’, ‘allocation’, and alternative words for bins (e.g., container, collection point). No other (specific) terms were considered as keywords in order to reduce the risk of bias. The search returned an initial set of 212 documents.

The third stage consists in filtering relevant articles, applying expert knowledge and pre-determined criteria for eligibility and relevance. Each article was carefully examined, by reading its indexing information to determine its relevance. Many works were discarded, mainly unrelated, outdated articles, and those that report non-formalized, limited, or non-realistic studies. For example, articles focused on other stages of the MSW system, considering other types of waste (industrial, hospital, electronic waste), or describing waste monitoring and management systems were excluded since they are not directly related to the waste bins location problems. A total number of 76 works were found to be directly related to the waste bins location problem.
The next stage involved properly organizing the selected related works into categories. According to the main goals of the survey and existing research initiatives, three main categories were identified, focused on specific details of the problem, methods, and problem variants addressed. Thus, after introducing a description of the reverse supply chain of MSW and the main details of the bin location problem, the review presents a summary and description of the optimization criteria considered for finding the most suitable locations for waste bins in urban areas. After that, a review of the different resolution approaches for solving the optimization problem reported in the bibliography are presented, aimed at identifying those most used and more promising resolution methods. Articles within the category of integrated approaches include proposals that solve the waste bins location problem simultaneously with other related optimization problems of the MSW system, mainly the design of waste collection routes. Articles within those categories are properly analyzed by quantitative indicators, and finally the main findings of the review are commented, aiming at identifying the main research trends, recent innovative approaches, and interesting open issues that may constitute future lines for research.

3. The reverse supply chain of MSW

Conversely to the concept of traditional (forward) logistics, reverse logistics implies, first, the physical transport of the used products from the final consumer to recovery/disposal points, and second, their transformation into products that can rejoin the production system or, failing that, make an adequate final disposition (Fleischmann et al., 1997). According to this definition, the MSW system is a clear example of a reverse logistic chain (Rossit, 2018; Van Engeland et al., 2020). The reverse logistic chain of municipal waste involves several stages, as described in Figure 1.

![Figure 1: Schema of the waste flow in the reverse logistic chain of MSW.](attachment:image)

In the MSW logistic chain, waste is generated at households, commercial businesses, or institutions. Then, there is a storage stage that has its own characteristic depending on the collection system. The most common systems are:

- **House-to-house or kerbside collection.** Collectors visit each generator in order to pick up the waste. The storage take place inside the generator and it is suppose to be performed on a short period of time since households do not usually have a large storage capacity (Hoornweg and Bhada, 2012).

- **Community bins.** Generators take their waste to some community bins, usually arranged in what is known as garbage accumulation points (GAPs) (Tralhão et al., 2010). These GAPs are usually located in accessible places not very far from the generators. The garbage is stored there until it is picked up by collectors according to a certain schedule (Hoornweg and Bhada, 2012).
- **Self delivered system.** Generators carry their waste to disposal sites or transfer stations (Hoornweg and Bhada, 2012). This is usually implemented for specific kinds of waste, such as hazardous waste, bulky waste and yard waste produced at households (Dahlén and Lagerkvist, 2010) and the main difference with the community bins is that the facilities are usually larger and they provide some additional services than only been an storage point in the supply chain, e.g., a initial treatment process (compaction, separation) or even final disposition.

The decision among systems is site-specific. The related literature has described benefits for the community bins system over the kerbside collection, e.g., smaller cost in the collection phase (Bonomo et al., 2012; Gilardino et al., 2017) or are more suitable for collecting source classified waste (Valeo et al., 1998). Moreover, the different storage systems are not mutually exclusive. For example, some cities use a kerbside collection for a certain type of waste, usually non-recyclable perishable waste that needs to be disposed relatively fast, an a community bins system for the waste that is not required to be treated immediately (Dahlén and Lagerkvist, 2010).

The logistic chain of MSW continues with the collection of waste. Depending on the city and the characteristic of the MSW system, the logistic chain can include intermediate locations, called waste transfer stations. A transfer station is a facility, located near the generators, to receive and store waste from collection vehicles, before compacted to reduce volume and moved to larger vehicles for transportation to distant landfills or treatment centers (Yadav et al., 2016). Transfer stations can also include classification or recycling systems (Eshet et al., 2007). A transfer station can be installed depending on the distance between generators and the landfill/treatment plant, the unit haul costs, and the economics of the facilities (Chatzouridis and Komilis, 2012), or the waste can be directly transported from generators to final disposition centers with the same vehicles (represented in Figure 1 by the bypass between the third stage waste collection and the sixth stage treatment and/or final disposal). Finally, depending on the type of waste and the level of development of the MSW system, the last stage in the MSW reverse logistic chain is treatment and/or final disposal. For treatment, incinerators, waste-to-energy plants, reclamation plants, or composite plants are used. In turn, disposal usually involves land filling or land spreading (Ghiani et al., 2014a).

### 4. The waste bins location problem

This section describes the waste bins location problem and relevant considerations.

#### 4.1. Problem description

Among the several decisions involved in a MSW system, the design of the waste collection network is of capital importance since it is the entry point to the MSW system. A poor planning on this stage can diminish the amount of waste entering to the formal MSW system of a city.

As the entry point to the system, the waste bins location problem is an example of the convergent design that is characteristic from reverse logistic networks, in which the material flow goes from many sources to few destination, in contrast to the divergent design of forward logistics, in which the material flow goes from a few sources to many destinations. In this case, the waste (material flow) is taken from many households (sources) to a few waste bins (destinations) (Bing et al., 2016). The waste bins location problem involves finding the best locations for community bins in an urban area while optimizing some relevant criteria, usually related to the cost of operating the system, the Quality of Service (QoS) provided to the citizens, or to both of them in a multiobjective fashion.
Several stages of the MSW reverse logistic chain are affected by the decisions and strategies implemented in the waste bins location stage. The number of collection points, its distribution in the field, the type and size of the containers used, and the collection frequency are conditioning factors of the overall efficiency of the system (Hazra and Goel, 2009; Vijay et al., 2005). The location and configuration of collection points strongly influence the operational routing cost of waste collection from bins to the disposal sites (Barrena et al., 2020; Vu et al., 2018), and also impact on strategic levels of the reverse logistic chain, e.g., the designed capacity of intermediate and processing facilities, and the efficiency of the whole MSW system to collect all the generated waste (Kumar and Goel, 2009). Parrot et al. (2009) found that when the average distance between waste generators and bins increases, the proportion of the population that uses containers decreases. This phenomenon causes an undesirable increase in waste accumulated in unsuitable places, such as waterways or green areas. In addition to the effects on the environment, low bin utilization also affects the population in more indirect ways through, e.g., dissemination of vector-borne diseases such as malaria or dengue (Ali and Ahmad, 2019; Gupta et al., 2019), or increase in public charges for expenses to remove improperly disposed waste, to reincorporate it into the formal MSW system (Parrot et al., 2009). There is also evidence that a correct arrangement of bins in the urban area can encourage the community to correctly classify the waste at source, which usually is closely associated with the success of recycling programs (Kao et al., 2013; Leeabai et al., 2019, 2021). As a relevant example, based on regression models developed from data collected in various cities in Spain, Gallardo et al. (2010) found that the decrease in the average distance between generator and waste disposal sites positively affects the percentage of differentiated waste that is collected.

4.2. Desirable characteristics of solutions

Besides its relevance for the MSW logistic chain, another aspect that have attract attention to the waste bins location problem is the difficulty to obtain good compromising solutions. Firstly, because in terms of computational complexity, it is an extension of the Capacitated Facility Location Problem, which was proven to be NP-hard (Cornuéjols et al., 1991), i.e., at least as hard as problems for which no efficient algorithms, which execute in polynomial time with respect to the size of the problem, have been devised. This class characterizes those problems that are difficult to solve computationally. Secondly, because locating bins is hard because of the conflicting goals involved in the problem, since waste bins are considered semi-obnoxious facilities (Tralhão et al., 2010). On the one hand, citizens that live near to the bins can suffer different environmental costs, such as noise pollution, bad smell, visual pollution, and traffic congestion from collection vehicles (Bautista and Pereira, 2006; Flahaut et al., 2002; Khan and Samadder, 2016). On the other hand, citizens that live far from the bins can suffer large transportation costs, having to carry their waste for long distances, which can affect the accessibility of the system. Citizens unwilling to incur in this transportation might dump their waste in unsuitable places (Parrot et al., 2009; Sotamenou et al., 2019). Dumped waste must be removed by the authorities, incurring in additional expenses. This conflicting relation between the environmental and transportation costs is associated with the NIMBY response to undesirable facilities: few citizens accept these facilities to be placed nearby, compared to the number of citizens who admit that they should be placed somewhere else (Lindell and Earle, 1983). Related to this, Ghiani et al. (2012) and Singh (2019) stated that despite their eagerness to have a bin as close as possible, citizens are also willing to have the smaller tax burden that guarantee the service, which affects the budget to install several bins in an urban area.
In turn, decision-makers should avoid locating waste bins near water streams or certain public places, such as schools, hospitals, and religious buildings (Ahmed et al., 2006; Ugwuishiwu et al., 2020). This consideration is not only related to the fact that bins may contribute to visual pollution of an urban area, which can even affect the commercial selling price of the nearby buildings (Di Felice, 2014b), but also an contribute to the dissemination of vector-borne diseases (Ali and Ahmad, 2019; Gupta et al., 2019). In this regard, Nesmachnow et al. (2018) aimed at providing a frequent collection service to those waste bins located near busy places, i.e., assigning them a higher priority in the collection schedule, so they are unlikely to be overflowed.

4.3. Relevant considerations of related works

Sections 6–8 present the main details of the literature review on the waste bins location problem. Relevant issues are described and discussed, including the applied optimization criteria, resolution methods, and integrated approaches with other stages of the reverse MSW supply chain. The main details of the reviewed articles are reported in Table 1 (optimization criteria and resolution approaches) and Table 2 (case studies and main results). Table 2, categorizes the articles considering the type of waste: only installing bins for the collection of recyclable materials, installing bins for both recyclable and non-recyclable material, and installing bins for a unique stream of mixed waste.

Table 1: Waste bins location problem: optimization criteria and resolution methods.

| Article                  | Optimization criteria | Resolution method                      |
|-------------------------|-----------------------|----------------------------------------|
| Adedotun et al. (2020)  | ×                      | Manual location with the aid of GIS-based information |
| Adeleke and Ali (2021)  | × ×                   | Linear Lagrangian relaxation heuristic |
| Ahmed et al. (2006)     | × ×                   | Manual location with the aid of GIS-based information |
| Aka and Akyüz (2018)    | ×                      | Fuzzy Multiobjective MILP              |
| Aremu and Süle (2012)   | × × ×                  | Single-objective MILP (\(p\)-median model inside GIS) |
| Aremu et al. (2012)     | × × ×                  | Single-objective MILP (\(p\)-median model inside GIS) and AHP |
| Aremu and Vijay (2016)  | ×                      | ArcGIS Network Analyst                 |
| Barrena et al. (2019)   | ×                      | Greedy algorithm                       |
| Barrena et al. (2020)   | ×                      | Greedy algorithm with later improvement steps |
| Bautista and Pereira (2006) | × ×                  | Single-objective MILP                  |
| Bennekroul et al. (2020)| ×                      | Single-objective MILP                  |
| Blazquez and Paredes (2020)| × ×                | Single-objective MILP                  |
| Boskovic and Jovicic (2015) | × ×                | Manual location with the aid of GIS-based information |
| Carlos et al. (2016)    | ×                      | Manual location with the aid of GIS-based information |
| Carlos et al. (2021)    | ×                      | Manual location with the aid of GIS-based information |
| Cavallin et al. (2020)  | × ×                   | Single-objective MILP                  |
| Chang and Wei (1999)    | × ×                   | Evolutionary algorithm                 |
| Chang and Wei (2000)    | × ×                   | Fuzzy evolutionary algorithm           |
| Coutinho et al. (2012)  | × × ×                  | Multiobjective MILP                    |
| Cubillos and Wohlk (2020)| × ×                | Multiobjective MILP and Variable Neighborhood Search Heuristic |
| Di Felice (2014a,b)     | ×                      | Constructive heuristic                 |
| Erfani et al. (2017)    | × ×                   | ArcGIS Network Analyst                 |
| Erfani et al. (2018)    | × ×                   | ArcGIS Network Analyst                 |
| Ferronato et al. (2020) | ×                      | Location method not specified (using GIS information) |
| Flahaut et al. (2002)   | × ×                   | Single-objective MILP (\(p\)-median model) |
| Gallardo et al. (2015)  | × ×                   | ArcGIS Network Analyst                 |
| Gautam and Kumar (2005) | ×                      | Single-objective MILP (\(p\)-median model) |
| Ghiani et al. (2012)    | × ×                   | Single-objective MILP and Constructive heuristic |
| Ghiani et al. (2014b)   | × × ×                  | Single-objective MILP and Constructive heuristic |
| Giaridino et al. (2017) | × ×                   | Single-objective MILP                  |
| González and Adenso (2002)| × ×                | Single-objective MILP                  |
| Hemmelmayr et al. (2013)| × × ×                | Single-objective MILP and Variable Neighborhood Search Heuristic |
| Hemmelmayr et al. (2017)| × × ×                  | Single-objective MILP and Adaptive Large Neighborhood Search |
| Herrera et al. (2018)   | × ×                   | Multiobjective MILP                    |

Continued on next page
### Table 1 – Continued from previous page

| Article                | Optimization criteria | Resolution method                                                      |
|------------------------|-----------------------|------------------------------------------------------------------------|
| Jammeli et al. (2019)  | ×                     | Clustering heuristic and stochastic single-objective MILP              |
| Kao and Lin (2002)     | × ×                   | Single-objective MILP                                                  |
| Kao et al. (2013)      | × ×                   | Single-objective MILP                                                  |
| Kao et al. (2010)      | ×                     | Single-objective MILP                                                  |
| Karadimas et al. (2005)| ×                     | Location method not specified (using GIS information)                 |
| Karadimas and Loumos (2008)| × ×                 | Location method not specified (using GIS information)                 |
| Karkanias et al. (2014)| × ×                   | Manual location                                                        |
| Khan and Samadder (2016)| ×                     | Multiobjective MILP                                                    |
| Kim and Lee (2013)     | × ×                   | Single-objective MILP, multi-stage Branch and Bound, and drop heuristic|
| Kim and Lee (2015a,b)  | × ×                   | Tabu Search                                                            |
| Letelier et al. (2021) | × ×                   | Single-objective MILP for non-recyclable bins and ArcGIS for recyclable bins|
| Lin et al. (2011)      | × × ×                 | Manual location with the aid of GIS-based information                  |
| López et al. (2008)    | × × ×                 | Manual location with the aid of GIS-based information                  |
| López et al. (2009)    | × × ×                 | Manual location with the aid of GIS-based information                  |
| Marqua et al. (2018)   | ×                     | Manual location                                                        |
| Nevrlý et al. (2019)   | × × ×                 | Multiobjective MILP                                                    |
| Nevrlý et al. (2021)   | × × ×                 | Multiobjective MILP                                                    |
| Nithya et al. (2012)   | ×                     | Manual location with the aid of GIS-based information                  |
| Oliaei and Fataci (2016)| × ×                   | Location method not specified (using GIS information)                 |
| Paul et al. (2017)     | ×                     | Manual location with the aid of GIS-based information                  |
| Rathore and Sarmah (2019)| × ×                   | Single-objective MILP and ArcGIS                                       |
| Rathore et al. (2020)  | × × ×                 | Single-objective MILP and ArcGIS                                       |
| Ratković et al. (2016)| × × ×                 | Single-objective MILP                                                  |
| Rossit et al. (2017)   | × × ×                 | Multiobjective MILP                                                    |
| Rossit et al. (2018)   | × × ×                 | Multiobjective MILP                                                    |
| Rossit et al. (2019)   | × × ×                 | Multiobjective MILP                                                    |
| Rossit et al. (2020)   | × × ×                 | Multiobjective MILP and PageRank                                        |
| Sheriff et al. (2017)  | × × × × × × ×         | Single-objective MILP                                                  |
| Toutouh et al. (2018)  | × × × × × × ×         | Multiobjective evolutionary algorithms and PageRank                    |
| Toutouh et al. (2020)  | × × × × × × × × ×     | Multiobjective evolutionary algorithms and PageRank                    |
| Tralhão et al. (2010)  | × × × × × × × × ×     | Multiobjective MILP                                                    |
| Ugwuishiwi et al. (2020)| × × × × × × × × × × × | Manual location with the aid of GIS-based information                  |
| Valeo et al. (1998)    | × × × × × × × × × × × | ArcGIS Network Analyst                                                 |
| Vidovci et al. (2016)  | × × × × × × × × × × × | Single-objective MILP and Two-phase (greedy + LP) heuristic            |
| Vijay et al. (2005)    | × × × × × × × × × × × | Greedy heuristic                                                        |
| Vijay et al. (2008)    | × × × × × × × × × × × | Single-objective MILP (p-median model)                                 |
| Vu et al. (2018)       | × × × × × × × × × × × | ArcGIS Network Analyst                                                 |
| Yaakoubi et al. (2018) | × × × × × × × × × × × | Single-objective MILP and a two-phase (Memetic algorithm + ILS) heuristic|
| Zahan and Hasan (2020) | × × × × × × × × × × × | AHP                                                                     |
| Zamorano et al. (2009) | × × × × × × × × × × × | ArcGIS Network Analyst                                                 |

Abbreviations used: AHP: Analytical Hierarchy Procedure; GIS: Geographic Information System; ILS: Iterated Local Search; LP: Linear Programming; MILP: Mixed Integer Linear Programming.

### Table 2: Waste bins location problem: case studies and main results.

| Article                | Case studies | Main results                                                                 |
|------------------------|--------------|-------------------------------------------------------------------------------|
| Installation of bins for the collection of recyclable materials   |              |                                                                              |
| Aka and Akyüz (2018)   | Antalya (TR)  | Compromise solutions (recyclable material collected and collection routing distance) |
| Bennekrouf et al. (2020)| Boudjlida (DZ) | Design of a recyclable material collection network of bins considering QoS and investment cost |
| Chang and Wei (1999)   | Kaohsiung (TW)| Set of compromising solutions between QoS, routing cost, and population served by the system for recyclable material |
| Chang and Wei (2000)   | Kaohsiung (TW)| Set of compromising solutions between QoS, routing cost, and population served by the system for recyclable material |
| Cubillos and Wohlk (2020)| Five Danish cities | Set of compromising solutions between the population served and the routing costs for recyclable material |
| Flahaut et al. (2002)  | La Buyère (BE)| Compromising solution regarding QoS and environmental costs                  |

Continued on next page
### Table 2 – Continued from previous page

| Article | Case studies | Main results |
|---------|-------------|--------------|
| Gautam and Kumar (2005) | No real case solved | Methodology to find solutions to maximize the QoS |
| González and Adenso (2002) | Asturias (ES) | Increment of the amount of recyclable material collected |
| Hemmelmayr et al. (2017) | Not specified region | Reduction of total costs when flexible location of vehicle depots or visit schedules for collection points are considered |
| Kao et al. (2010, 2013) | Hsinchu (TW) | Solutions with high QoS for collecting recyclable material |
| Lin et al. (2011) | Taichung (TW) | Methodology for designing a two-shift bins collection network for recyclable waste |
| López et al. (2008) | Madrid (ES) | Improved efficiency of the collection system by designing a separated collection system for paper/cardboard of small businesses |
| López et al. (2009) | Aranjuez (ES) | Reduction of the number of collection points, improved network coverage and increased collected recyclable material |
| Ratković et al. (2016) | Belgrade (RS) | Methodology for designing a recyclable waste network of bins |
| Sheriff et al. (2017) | Not specified town (IN) | Integrated approach solving bins location and collection routing outperformed sequential approaches for recyclable material |
| Valeo et al. (1998) | Dundas (CA) | Methodology for recyclable bins network design |
| Vidović et al. (2016) | No real case study solved | Methodology for designing the network of bins, collection routes, and transfer stations of recyclable material |

Installation of bins for both recyclable and non-recyclable material

| Article | Case studies | Main results |
|---------|-------------|--------------|
| Adeleke and Ali (2021) | Lagos (NG) | Reduction of activated collection sites and allocated bins |
| Ahmed et al. (2006) | Aurangabad (IN) | Proposal for a source classified bins network |
| Barrena et al. (2019, 2020) | Seville (ES) | Reduction of bin network costs considering a solidarity behavior of citizens |
| Carlos et al. (2016) | Castellón (ES) | Solution with improved QoS |
| Carlos et al. (2021) | Santiago (CL) | Methodology for enhancing formal waste collection |
| Cavallin et al. (2020) | Bahía Blanca (AR) | Methodology for migrating from a house-to-house collection a community bins-based collection |
| Coutinho et al. (2012) | Coimbra (PT) | Set of compromising solutions considering QoS, investment cost, and semi-obnoxiousness of the bins |
| Di Felice (2014a,b) | L’Aquila (IT) | Set of solutions for different levels of QoS |
| Ferronato et al. (2020) | La Paz (BO) | Reduction of cost of the network of bins considering informal recycling sector |
| Gallardo et al. (2015) | Castellón (ES) | Methodology to design a MSW management plan depending on the available data |
| Gilardino et al. (2017) | Lima (PE) | Reduction of the routing costs in comparison to kerbside collection |
| Karkanas et al. (2014) | Neapoli-Sykies (GR) | Bins redistribution enhanced recycling rates and investment cost |
| Letelier et al. (2021) | Santiago (CL) | QoS improvements for recyclable waste bins |
| Olaei and Fataei (2016) | Tahriz (IN) | Methodology to locate bins |
| Rathore and Sarmah (2019) | Bilaspur (IN) | Reduction of the number of bins |
| Rathore et al. (2020) | Bilaspur (IN) | Reduction of the number of bins that led to a reduction of idling cost and carbon emissions of collection vehicles |
| Rossit et al. (2017) | Bahía Blanca (AR) | Set of compromise solutions between installment costs and QoS |
| Rossit et al. (2019) | Bahía Blanca (AR) | Set of compromise solutions between installment costs and collection frequency |
| Rossit et al. (2020) | Montevideo (UY), Bahía Blanca (AR) | Set of compromise solutions regarding collection frequency, installment cost, and QoS |
| Tralhão et al. (2010) | Coimbra (PT) | Compromise solutions regarding QoS, investment cost, and semi-obnoxiousness |
| Zamorano et al. (2009) | Granada (ES) | Reduction of the number of bins and collection costs |

Installation of bins for a unique stream of mixed waste

| Article | Case studies | Main results |
|---------|-------------|--------------|
| Adedotun et al. (2020) | Ibadan (NG) | Reduction of the collection costs |
| Aremu and Sule (2012) | Ilorin (NG) | Set of compromising solutions between QoS to citizens, collection routing criteria, and investment costs |
| Aremu et al. (2012) | Ilorin (NG) | Compromising solution regarding social, economic, and environmental criteria |
| Aremu and Vijay (2016) | Ilorin (NG) | Compromising solutions between QoS and investment costs |
| Bautista and Pereira (2006) | Barcelona (ES) | Algorithms to aid decision-makers for locating bins |
| Blazquez and Paredes (2020) | Santiago (CL) | Compromising solutions between QoS and investment costs. |
| Boskovic and Jovicic (2021) | Kragujevac (RS) | Reduction of the number of collection points and number of bins |
| Erfani et al. (2017) | Mashhad (IR) | Improved bin distribution that led to reduced routing costs |
| Erfani et al. (2018) | Mashhad (IR) | Set of compromising solutions between QoS, area coverage, population served, unused capacity of bins, and the balanced distribution of waste among all the installed bins |
| Ghiani et al. (2012) | Nardò (IT) | Reduction of the number of collection points and the number of bins |
| Ghiani et al. (2014b) | Nardò (IT) | Improved bin distribution that led to reduced routing costs |
| Hemmelmayr et al. (2013) | Not specified town in Northern IT | Integrated approach outperformed hierarchical approaches in terms of joint cost of bins allocation and routing |

Continued on next page
5. A quantitative analysis of literature

This section presents a quantitative analysis of the 76 reviewed related works.

5.1. Bibliometric analysis

Of the 76 revised articles, 16 were published in conferences and 60 in journals. These numbers suggest that researchers consider the subject relevant enough to submit to indexed journals rather than conferences. In turn, 18 articles were published before 2011 and 58 in the last ten years. Figure 2 reports the chronological distribution of conference and journal articles (number of publications per year and per type). Articles published before 2008 are grouped together in the first columns. The last column groups articles published in 2010 and in the first three months of 2021.

Values reported in Figure 2 show a renewed interest on the bin location problem, as demonstrated by the 16 recent articles on that subject (12 articles published in 2020 and 4 articles published in just three months of 2021). Figure 3 presents the most representative journals that have published articles related to the waste bins location problem: Waste Management (Elsevier) with 10 articles, Waste Management & Research (SAGE Publications) with 8 articles; Journal of Environmental Engineering (American Society of Civil Engineers) and Journal of Cleaner Production (Elsevier) both with 3 articles; and, finally, International Journal of Industrial and the Systems Engineering (Inderscience Enterprises Ltd.), Journal of Operational Research Society (Taylor and Francis Ltd.) and Journal of the Air & Waste Management Association (Taylor and Francis Ltd.) with 2 articles. The remaining 38 articles were published in other general-purpose journals.

---

Table 2 – Continued from previous page

| Article Case studies | Main results |
|----------------------|--------------|
| Herrera et al. (2018) Ibarra (EC) | Design of a collection network of bins considering QoS and investment cost |
| Jammeli et al. (2019) Sousse (TN) | Reduction of the combined investment cost of routing and bins location considering stochastic waste generation |
| Kao and Lin (2002) Hsinchu (TW) | Solutions with high QoS |
| Karadimas et al. (2005) Athens (GR) | Reduction of the number of bins required |
| Karadimas and Loumos (2008) Athens (GR) | Reduction of the number of bins |
| Khan and Samadder (2016) Dhanbad (IN) | Methodology for optimizing bin locations |
| Kim and Lee (2013) No real case study solved | Methodology for optimizing bin locations considering fluctuating waste generation |
| Kim and Lee (2015a, b) Seoul (KR) | Integrated approach (bins location and collection routing) outperformed sequential methods for fluctuating waste generation |
| Maraqa et al. (2018) Al Ain city (AE) | Reduction of the number of bins, and fuel consumption/pollutants emissions of the collection vehicle |
| Nevlý et al. (2019) Tábor (CZ) | Methodology for locating bins with minimal utilization rate |
| Nevlý et al. (2021) Tábor (CZ) | Extensive analysis of the trade-off among diverse objectives |
| Nithya et al. (2012) Coimbatore (IN) | Increment of the area coverage of the network of bins |
| Paul et al. (2017) Kolkata (IN) | Redistribution of bins increment of the total area serve by the network of bins |
| Rossit et al. (2018) Bahía Blanca (AR) | Set of compromise solutions between installment costs and collection frequency |
| Toutouh et al. (2018) Montevideo (UY) | Set of compromise solutions between population served, QoS, and installment costs |
| Toutouh et al. (2020) Montevideo (UY), Bahía Blanca (AR) | Set of compromise solutions between population served, QoS, and installment costs outperformed current situation in terms of QoS. |
| Ugwuishiwu et al. (2020) Enugu (NG) | Improved distribution of bins avoiding busy/inconvenient places |
| Vijay et al. (2005) No real case study solved | Methodology for estimating waste generation and allocating users to bins improving the QoS provided to the users |
| Vijay et al. (2008) No real case study solved | Methodology for estimating waste generation and allocating users to bins improving the QoS provided to the users |
| Vu et al. (2018) Hai Phong (TW) | Solutions for different QoS and total number of bins to be located |
| Yaakoubi et al. (2018) No real case study solved | Methodology to solve sequentially the problems of locating bins and scheduling collection routes |
| Zahan and Hasan (2020) Dhaka (BD) | Multi-attribute methodology to choose locations for bins considering QoS and environmental issues |
Figure 2: Journal and conference publications related to the waste bins location problem, by year

Figure 3: Most representative journals where the related works were published.

5.2. Analysis of the addressed scenarios

Another relevant aspect to analyze is the scenarios where the methodologies proposed in related works were applied and evaluated. Two common dimensions from the related literature are analyzed: the use of real-world case studies and the consideration of separated recyclable materials.

Use of real-world case studies. Case studies based on real-world data have been relevant for the evaluation of methodologies proposed to solve the waste bins location problem. 88% of the related works (67 out of 76) have solved scenario(s) considering real data from at least one city (Table 2). In general, the real information used were GIS maps and waste generation rates inferred from algebraic formulas based on population distribution and commercial activities. Getting real waste generation data is a time consuming process and the obtained information rapidly outdates, due to its great variability (Lebersorger and Beigl, 2011). For example, the scarcity of accurate data has been identified as the main drawback for implementing efficient collection systems in developing countries (Carlos et al., 2021). However, real information is important to test the real applicabil-
ity of the proposed models and is mandatory to guarantee replicability. Articles using real waste generation data have used information obtained either from surveys or analysis performed by the authors (Cavallin et al., 2020; Karadimas and Loumos, 2008), from other private sources (Maraqa et al., 2018; Nevrlỳ et al., 2021), or from studies performed in other similar cities (Cavallin et al., 2020; Carlos et al., 2021). Some articles used public repositories (Bautista and Pereira, 2006; Ferronato et al., 2020; Ratković et al., 2016; Rossit et al., 2020) and a few works have used (non-realistic) randomly generated data for waste generation rate (Adeleke and Ali, 2021; Barrena et al., 2019, 2020). Finally, some articles have located uncapacitated collection points (Aka and Akyüz, 2018; Kao and Lin, 2002; Valeo et al., 1998), without needing to estimate waste generation rate but only providing a partial (unrealistic) view of the problem.

Most articles that considered the capacity of bins used realistic commercial bins. A few works used unreal capacities (Adeleke and Ali, 2021; Rossit et al., 2017). Some articles have estimated the available surface space to locate bins (Hemmelmayr et al., 2013; Cavallin et al., 2020; Rossit et al., 2020), taken from real data (Ghiاني et al., 2012, 2014b) or randomly generated (Barrena et al., 2019, 2020). A digital map of the scenario is another relevant input. Some articles developed their own digital maps (Boskovic and Jovicic, 2015; Carlos et al., 2021; Chang and Wei, 1999, 2000) or obtained them from specific databases of public institutions (Ahmed et al., 2006; Valeo et al., 1998), whereas many recent articles took advantage from the online availability of real maps, such as OpenStreetMap (Rossit et al., 2020; Toutouh et al., 2020), Google Earth (Aremu and Vijay, 2016; Khan and Samadder, 2016), or Google Maps (Adeleke and Ali, 2021). Maps have been usually processed using GIS software, to visualize geographic information and calculate urban walking distances. Traľhão et al. (2010) developed their own GIS application. A few works, although claim to use real data, do not made clear the data sources (Nevrlỳ et al., 2019; Zahan and Hasan, 2020).

Three articles considered case studies from more than one city: Rossit et al. (2020) and Toutouh et al. (2020) solved case studies from Bahía Blanca, Argentina and Montevideo, Uruguay, whereas Cubillos and Wøhlk (2020) solved case studies from five different Danish cities.

Figure 4 presents the distribution of case studies per continent and country. Regarding continents, most case studies were located in Europe (24) and Asia (21). Regarding countries, the most represented were Spain (9 works), India (8 works), Taiwan, Argentina, and Nigeria (6 works).

**Figure 4:** Articles that solved real-world case studies from the related literature classified by continent (left) and country (right).
Waste bins location problem: a review

Consideration of separated recyclable material collection. A good planning of waste bins location can largely contribute to the success of recycling programs. In this context, 23% of the reviewed articles (18 out of 76) have solved the waste bins location problem for scenarios that consider only installing bins for the collection of recyclable materials. In turn, 29% of the articles (22 out of 76) have considered at least one scenario with source classification, i.e., installing both bins for recyclable material and bins for non-recyclable material. Finally, 5% of the articles (4 out of 76) discussed extensions to scenarios considering recyclable materials and source classification of waste (Bautista and Pereira, 2006; Boskovic and Jovicic, 2015; Nevrlý et al., 2019; Nithya et al., 2012). The rest of the articles (32 out of 76) did not consider separated recyclable material, dealing with a unique stream of mixed waste instead. Recyclable materials are usually not biodegradable or putrescible; thus, they admit to be collected less often than organic or moisture waste (Cavallin et al., 2020), specially in areas with warm and humid weather (Carlos et al., 2021). However, reducing too much the frequency collection of recyclable material is not advisable, because households/building do not have enough space to properly store classified waste (Barrena et al., 2019; Gallardo et al., 2015), which requires a larger number of bins than unclassified waste.

The related literature has acknowledged the difficulty of implementing selective waste collection in developing countries due to the lack of not only technical and budgetary resources (Bennekrouf et al., 2020), but also environmental regulations (Carlos et al., 2021). Another aspect that should be taken into account when designing the waste collection network in developing countries is the participation of informal workers. The activities of the informal sector reduces the amount of recyclable material to be collected by the formal MSW system which can affect the outcomes of the system. Ferronato et al. (2020) found that the inclusion of informal workers allowed reducing the waste system expenses in around 10%, increasing the recycling rate in 3.5%, and reducing the distances traveled by compactor trucks in around 7%. Similar results were obtained in both studies, i.e., an 18% and 22% increase in the number of bins when considering selective waste collection, compared with the scenario with unclassified waste collection.

5.3. Analysis of the pursued criteria

From the information in Table 1, it is inferred that accessibility of users and the costs of the network of bins have been the most important criteria for locating bins. 76% of the reviewed articles considered user accessibility criteria (58 out of 76). In turn, 59% of the works (45 out of 76) considered the cost of the network of bins as an optimization criteria. Moreover, 46% (35 out of 76) of the articles considered both criteria jointly in proposed models. The objective of routing cost has been also relevant, as 38% of the works (29 out of 76) considered this criteria.

5.4. Analysis of resolution approaches

Different resolution approaches have been presented in the related literature. From Table 1, it is inferred that exact MILP models are predominant, as they have been applied in 50% (38 out of 76) of the related works. Among them, 38% (29 out of 76) used MILP as a unique resolution method, whereas 11% (8 out of 76) applied MILP for comparing (and validating) heuristic approaches in small scenarios, and just one article used MILP as part of a multi-stage heuristic approach. whereas 11% (8 out of 76) applied MILP for comparing (and validating) heuristic approaches in small scenarios and just one article used MILP as part of a multi-stage heuristic approach. In turn, 29% of the articles (22 out of 76) used heuristic/metaheuristic approaches and 16% (12 out of 76) used GIS for solving the waste bins location problem. Finally, 16% of the articles (12 out of 76) locate bins
manually and 7% (5 out of 76) do not clearly outlined the procedure for locating bins.

Another important aspect in the resolution process is the consideration of uncertainty in the input parameters. In regard to waste generation rate, only 5% of the articles (4 out of 76) considered this parameter as stochastic in their models. In turn, 8% of the articles (6 out of 76) performed sensitivity analysis to test the proposed models for typical values of this parameter. Regarding the maximum threshold distance between users and assigned bins, a sensitivity analysis was performed in 18% of the articles (14 out of 76). In regard to the maximum potential number of bins or collection points, 12% (9 out of 76) applied sensitivity analysis. Then, 6% (5 out of 76) performed sensitivity analysis over the collection frequency of bins. Finally, 5% of the articles (4 out of 76) evaluated their models for different bins storage capacity.

Regarding bins storage capacity, Adeleke and Ali (2021) found that increasing the capacity of bins by 40% does not affect the number of active collection points and affects the number of bins used in less than 10% in all cases. However, the increment in the maximum walking distance between users and bins did had a great impact in the active collection points (an increment from 100m to 200m produces reductions up to 72% in the number of active collection points). Carlos et al. (2021) analyzed the required number of bins according to collection frequency. Diminishing the collection frequency from three times per week to once per week increases the number of required bins in 105% for mixed waste and 34% for organic waste. In a similar study, Cavallin et al. (2020) found than when increasing the collection frequency of recyclable material from three times per week to four times per week the number of bins was reduced up to 35% for recyclable waste and 31% for organic waste and the number of active collection points was reduced up to 31%.

Two relevant relations have not been sufficiently studied in the related literature: the relation between collection frequency and the distance among bins, and the relation between distance among bins and volume of bins. Blazquez and Paredes (2020) performed sensitivity analysis comparing the case in which the distance among collection sites (where bins are located) is required to be larger than 140m and the case in which no distance restriction is set. The case in which no restriction is set has about 49% more active collection sites and 3% more bins than the scenario with the restriction of 140m. However, they do not solve the waste collection routing considering this variation, thus the relation between the distance among bins and collection frequency is not analyzed. Blazquez and Paredes (2020) also compared the outline of network of bins when only small volume bins are available, only larger volume bins are available, and when both types of bins are available. The scenario when large bins are available has 5% less active collection sites and 23% less bins than the scenario considering small bins. When both types of bins are considered, the collection network has 6% less active collection sites and 12% less bins than the scenario when only small bins are considered. However, they did not studied the effect of the variation of the volume of the bins in the distance among bins.

5.5. Consideration of waste collection stage

Besides the waste bins location problem, 26% of the reviewed works (20 out of 76) also addressed the waste collection stage of the MSW system. Particularly, 16% (12 out of 76) used integrated approaches for locating waste bins and finding collection routes simultaneously. Finally, 17% of the works (13 out of 76) presented sequential approaches, first solving the waste bins location problem and then, optimizing the waste collection routes over the defined network of bins.
6. Optimization criteria

This section analyzes the optimization criteria used in the related work about waste bins location. First, an overall description of the analysis and categorization is presented. Then, a specific discussion is performed for each identified category.

6.1. General discussion

Different optimization criteria have been considered for finding the best location of waste bins in urban areas. Most criteria are related to cost reduction and QoS improvement. Considered costs include the installment and maintenance costs of the collection network (i.e., the bins distributed in the city). Operating costs are only considered in articles studying integrated models that include routing costs, salaries of the personnel, etc. Regarding QoS improvement, the main indicator is the accessibility of citizens to the system, i.e., minimize the average/total distance between users and their assigned bin, or assigning users to a bin that it is within a certain maximum threshold distance. Cost and QoS criteria result in conflicting objective functions for optimization. On the one hand, if the majority of users have a bin located close to their homes, the number of bins distributed in the city results to be very large, as studied in sensitivity analysis on the related literature (Di Felice, 2014b; Nevrlỳ et al., 2021; Tralhão et al., 2010). In such cases, there is an associated incremental cost for purchasing and installing the bins. On the other hand, deploying a small number of bins or concentrating them in few points of the city reduce the cost, but also affect the accessibility to the system, due to the long distances users must transport their waste. Different alternatives have been explored to deal with this trade-off, including multiobjective approaches aimed at obtaining compromise solutions (Coutinho et al., 2012; Rossit et al., 2020; Toutouh et al., 2020; Tralhão et al., 2010) and optimizing only one criteria in a single-objective model while restricting the other criteria to a certain threshold value (Blazquez and Paredes, 2020; Cavallin et al., 2020).

Besides the predominant applied criteria, specific works have considered other issues when solving the problem. Since the configuration of the bins network collection has an impact on the posterior collection, some works included criteria aimed at bounding the costs of the posterior route collection. A common feature considered is the accessibility of the collection vehicles to the bins, avoiding locating bins in secondary streets with improper width or limiting the required collection frequency for emptying bins. A few authors have used other highly specific criteria, e.g., the avoidance of deploying bins near public places, such as schools or hospitals, where they might provoke a negative social reaction, or reducing the negative environmental impact of bins to households by considering the semi-obnoxiousness of these facilities.

The considered criteria have been used in different ways in the proposed optimization procedures. Some authors used the criteria as objective functions in an formalized optimization tool, i.e., when a mathematical model is outlined and solved by a solver/algorithm, while other authors included the criteria as constraints, in the form that the final solution must respect a certain threshold value. Finally, a group of authors used the criteria as subjective goals in a more manual and less formalized optimization process, in which the location are decided by practitioners after the consultation of the information in a convenient format for the decision-making process.

This review classifies the applied criteria in four categories: cost criteria, for objectives that are related to the economics of the system; user accessibility criteria, for objectives that aim at enhancing the ease for the citizens to drop their waste into the system; routing collection criteria for objectives that are connected to reduce the complexity of the posterior collection costs; and
other criteria including all specific criteria that not belong to any of the previous classification. These categories are further described in the following subsections.

The information about the problem criteria and the resolution approaches applied to solve the waste bins location problem was presented in Table 1. The first column reports the bibliographic reference. Then, separate columns are included to account for optimization criteria: ‘C’ stands for cost criteria, ‘UA’ stands for user accessibility criteria, ‘RC’ stands for routing collection criteria, and ‘O’ stands for other criteria. The considered criteria are commented in the next subsection.

6.2. Cost criteria

Several works considered cost-based criteria when optimizing the location of waste bins. An expense that is usually included is the purchase cost of the bins, which varies according to the type of bin and capacity (Aremu et al., 2012; Barrena et al., 2019, 2020; Bennekrouf et al., 2020; Blazquez and Paredes, 2020; Cavallin et al., 2020; Coutinho et al., 2012; Hemmelmayr et al., 2013; Herrera et al., 2018; Kim and Lee, 2015b; Nevrlý et al., 2021; Rathore and Sarmah, 2019; Rathore et al., 2020; Rossit et al., 2017, 2019, 2018, 2020; Toutouh et al., 2018, 2020; Tralhão et al., 2010). Some articles also considered the maintenance cost and a prorated purchase cost based on the lifetime of bins and the time horizon of the planning (Hemmelmayr et al., 2013; Rossit et al., 2020; Nevrlý et al., 2021). This feature is important when comparing costs in different periods of time. For example, in works that addressed the integrated problem of locating bins and designing collection routes (see Section 8), travel distance costs are operational costs assigned on a daily basis, whereas the waste bin purchasing are strategic costs, since the service life of bins is assumed to be several years. Other articles also considered the set-up cost of preparing a special site to install the bins, either on the street or on the sidewalk, usually requiring the installation of signals, special painting, or basement construction (Kim and Lee, 2013, 2015b; Ratkovic et al., 2016; Vidović et al., 2016; Sheriff et al., 2017; Cavallin et al., 2020). Moreover, Cavallin et al. (2020) determined a subset of few ideal sites among potential sites where bins can be installed. Ideal sites are places conveniently located in the city that require a relatively small set-up cost (in comparison to non-ideal sites). Thus, they are considered as priority by the optimization algorithm for bins location. Similarly, Valeo et al. (1998) considered a few of the available sites where the location of bins is mandatory for the optimization model. The rest of the sites are only used for bin location if required. Regarding other costs related to bins, Rathore et al. (2020) included the cost of waiting for unloading a bin by the collection vehicle, which varies according to the type of bin. Tralhão et al. (2010) and Coutinho et al. (2012) included an extra cost for locating a special type of bin that requires a specific collection vehicle to be emptied. When addressing scenarios that already have an existing network of bins installed, Hemmelmayr et al. (2013) estimated a cost for moving a bin from one place to another, adding to the model a reticence to move bins unless it is needed.

Closely related to the costs of the system, Bautista and Pereira (2006) minimized the total number of bins in a network (subject to fulfilling a required level of service), since it is directly related to the set-up cost of conditioning places for bins and to the visual and noise pollution. Letelier et al. (2021) considered the same objective for non-recyclable bins. Similarly, other authors aimed at minimizing the number of places conditioned for installing bins in a city (Adeleke and Ali, 2021; Gallardo et al., 2015; Ghiani et al., 2012, 2014b; Gilardino et al., 2017; Hemmelmayr et al., 2017; Kao and Lin, 2002; Kao et al., 2013; Maraqa et al., 2018; Nevrlý et al., 2019, 2021; Ratkovic et al., 2016; Vu et al., 2018). Karadimas et al. (2005) and Karadimas and Loumos (2008)
Waste bins location problem: a review

proposed locating a bin at every block, and then eliminating bins collecting a negligible amount of waste to diminish the number of points that should be visited by the collection vehicle.

6.3. User accessibility criteria

A usual criteria related to user accessibility is minimizing the average distance between users and assigned bins (Herrera et al., 2018; Kao et al., 2010; Rossit et al., 2019, 2017, 2018, 2020; Toutouh et al., 2018, 2020; Tralhão et al., 2010). Other authors considered the total sum of the walking distances (for all users) instead of the average (Chang and Wei, 1999, 2000; Gautam and Kumar, 2005; Kao and Lin, 2002; Kao et al., 2013; Nevrly et al., 2019; Sheriff et al., 2017). Coutinho et al. (2012), Vijay et al. (2005, 2008) applied a more specific model, considering the walking time for users to access to their assigned bin. Flahaut et al. (2002) used the total transportation costs, which are proportional to distance. Kao et al. (2013) proposed models to enhance user accessibility when collecting recyclable material, either minimizing the maximum distance that any user must walk or the percentage of citizens located within an “acceptable” distance from a bin.

Some articles studied cases where minimizing the walking distance of users to assigned bins is of paramount importance. Valeo et al. (1998) considered user accessibility as critical for the success of implementing a recycling program. Two accessibility models were analyzed: i) users are supposed to walk to the bins; thus, the model locates several bins within walking distance from households, and ii) users are supposed to access by car; thus, bins are located only on commercial parking lots. Lin et al. (2011) studied a similar scenario, where bins can be visited by the collection vehicle either in a day shift or in a night shift. In the problem model, each user must have at least two bins within a certain threshold distance, belonging to different shifts. Users unable to access their nearest bin before it is visited by the collection vehicle can dispose their recyclables at one of the alternative nearby bins in the other shift. Carlos et al. (2021) considered as critical the accessibility of users when installing waste bins in a city with no formal MSW collection network. To facilitate that users get used to bins, the transportation distance was minimized using two storage levels: first, users deposited their waste in bins located at their courtyard, and then, waste was transported by specialized workers to larger collection points, to be collected by vehicles. Some articles considered the distance between users and their assigned bin as a feasibility constraint, i.e., users cannot be assigned to a bin located beyond a certain threshold value (Adeleke and Ali, 2021; Blazquez and Paredes, 2020; Cavallin et al., 2020; Coutinho et al., 2012; Erfani et al., 2017, 2018; Ghiani et al., 2012, 2014b; Gilardino et al., 2017; Rossit et al., 2020; Toutouh et al., 2020; Tralhão et al., 2010; Vu et al., 2018)

Other articles have included the minimization the distance between a user and the assigned bin multiplied by the weight of the waste the user generates (Aremu and Sule, 2012; Kim and Lee, 2013, 2015b,a; Nevrly et al., 2021). A few articles directly required the users to be assigned to the nearest bin considering that this is the usual behavior that citizens adopt in the real-world (Di Felice, 2014a; Ghiani et al., 2012, 2014b; Gilardino et al., 2017; Kao et al., 2010, 2013). However, an interesting approach was proposed by Barrena et al. (2019, 2020), assuming that the users have a supportive behavior regarding respecting the bin where they are assigned, even though it is not the closest one.

Another problem variant consists in installing new bins, near collection sites of an existing network of bins (Adedotun et al., 2020; Boskovic and Jovicic, 2015; López et al., 2008; Paul et al., 2017). The main motivation for this constraint is that users find easier to adapt to new location of bins if they are not far from the previous locations (Erfani et al., 2017; Zamorano et al., 2009).
Finally, some researches have considered user accessibility under the assumption that each bin serves a certain nearby area. Optimization criteria included maximizing the geographic area (Nithya et al., 2012; Paul et al., 2017; Vu et al., 2018) or the number of users (Aremu and Sule, 2012; Chang and Wei, 1999, 2000; Erfani et al., 2018; Kao et al., 2010; Cubillos and Wøhlk, 2020; Letelier et al., 2021; Vidović et al., 2016). Erfani et al. (2018) and Vidović et al. (2016) presented an interesting approach for estimating the population served by a bin. The models take into account the number of users of a certain bin, modeled as a decay function based on the distance to the bin and assuming that the farther the citizens must walk to the bin, the less likely they are to use it.

6.4. Routing collection criteria

After storage, the immediate stage of the reverse supply chain of MSW is the collection of waste. Thus, several authors have included in the optimization model of the bin location problem some criteria linked to the collection stage in order to diminish the posterior routing costs.

Collection frequency (i.e., how often the bins are visited and emptied by the collection vehicle)![](https://i.imgur.com/123456.png) is a very frequent consideration in the related literature. A low collection frequency implies that the needed storage capacity of bins (proportional to investment cost) will be also large. However, a very high collection frequency implies extra routing costs, because vehicles have to visit the bins very often (Hemmelmayr et al., 2013; Rossit et al., 2020). Several authors included the trade-off between collection frequency and cost in their models. Rossit et al. (2018, 2019, 2020) aimed at minimizing the required collection frequency when designing the collection network of bins while also minimizing the purchasing cost of bins. Blazquez and Paredes (2020) solved different scenarios for different collection frequencies and found an approximately linear correlation: when the frequency decreases from every day collection to collection every three days and the cost of the collection network almost tripled. Those previous findings are in line with the results obtained by Cavallin et al. (2020): the cost of the network of bins increased by 50% when modifying the collection frequency of dry waste from four times per week to three times per week. Similarly, Nevrlý et al. (2021) aimed at minimizing the total collection service time, i.e., the total time (in the planning horizon) dedicated by the collection vehicle to empty the bins, which is directly associated with the collection frequency. González and Adenso (2002) minimized the collection frequency as a second objective in a lexicographic approach in which the first objective was to maximize the amount of glass collected. In the context of a two-shift collection plan, Lin et al. (2011) aimed at minimizing the number of bins that have to be collected within each shift of the collection vehicle. An interesting result was obtained by Carlos et al. (2016) who was able to reduce the required collection frequency of recyclable material as a result of improving the location of bins to enhance user accessibility which lead to a reduction in the risk of overflow.

The type of bin is also related to posterior routing costs, since decision-makers generally prefer to use the same type of bin across a certain area. The rationale behind this idea are the constraints existing in mechanized self-loading collection vehicles, e.g., limit capacity of vehicles and technical specification of the unloading mechanism (Erfani et al., 2018). For example, if two bins that require different types of vehicles are located in the same site, this site has to be visited at least by two vehicles. The model must introduce a lower bound in the number of collection routes connecting the site, resulting in an increased routing cost. Ghiani et al. (2014b) prevented bins that require different collection vehicles to be emptied to be located in the same site. Similarly, Khan and Samadder (2016) used a unique size of bins to avoid inconveniences for the collection phase.
Another relevant aspect is the vehicle accessibility to the bins considering that certain streets are not adequate for collection vehicles, either because they are extremely narrow, dirty, or the asphalt is in very poor conditions. Thus, bins should not be located in those streets (Carlos et al., 2016; Boskovic and Jovicic, 2015; López et al., 2008; Vu et al., 2018). Some models locate bins only in main streets (Aremu and Vijay, 2016; Zahan and Hasan, 2020) or road intersections (Ade-dotun et al., 2020; Khan and Samadder, 2016; Vijay et al., 2008). Other works have considered environment-related routing criteria. Aremu and Sule (2012) and Aremu et al. (2012) proposed choosing the best location for bins taking into account the cost of fuel of the collection stage and the pollution emissions of the vehicles in the problem model and later in a sensitivity analysis to analyze the optimal number of bins to install (Aremu and Sule, 2012).

A few articles directly addressed the integrated problem of locating bins and designing the collection routes simultaneously, in a unique optimization process. Thus, these works usually included some metric of the routing efficiency. For example, minimizing the idle time of vehicles (i.e., time for performing collection and travel time between waste bins) (Vidović et al., 2016), travel costs (per distance unit) (Chang and Wei, 1999, 2000; Hemmelmayr et al., 2013, 2017; Jammeli et al., 2019; Kim and Lee, 2015b; Sheriff et al., 2017; Vidović et al., 2016; Yaakoubi et al., 2018) or travel distance of the vehicles (Aka and Akyüz, 2018; Cubillos and Wøhlk, 2020), or fixed costs of the fleet of vehicles (Hemmelmayr et al., 2017; Kim and Lee, 2015b). These integrated approaches provide a valuable holistic view of the problem, thus they are further described in Section 8.

### 6.5. Other criteria

Some works have included other particular criteria for bin location, not included in the previous categories. Some models considered that the collection network of bins may not receive the total amount of waste produced in an area, because it competes with informal or sporadic systems, such as recycling campaigns by governmental or non-governmental organizations or informal workers (Ferronato et al., 2020; Rathore et al., 2020; Toutouh et al., 2020; Ugwuishiwu et al., 2020). Aremu and Sule (2012); Aremu et al. (2012) and Toutouh et al. (2018, 2020) included the objective of maximizing the collected waste. González and Adenso (2002) used this objective for the special case of glass collection, which competes with the (unclassified) formal collection system. Instead of maximizing the recyclable material collected, Hemmelmayr et al. (2017); Vidović et al. (2016) proposed maximizing the profit obtained from the selling price of the collected recyclable material. Sheriff et al. (2017) considered that the recyclable material is collected from users by specialized agencies. The agencies deliver the material to the initial collection points and receive as a compensation an economic incentive that varies depending on the quality of the material delivered. This incentive is included as a minimization cost in the objective function of the model.

Related works also considered criteria associated with the semi-obnoxiousness nature of the bins (the NIMBY phenomenon). Coutinho et al. (2012) and Tralhão et al. (2010) optimized the number of citizens within the push and pull distances of a bin. The push criterion minimizes the number of users too near of the bins and the pull criterion minimized the number of users too far from the bins. Similarly, Flahaut et al. (2002) considered two different terms in the objective function: a term that aims at minimizing the distance between users and assigned bins and a second term that aims at minimizing the external costs, i.e., the negative environmental impact of the noise of collection vehicle for citizens that have a bin too near to their homes. In the sensitivity analysis, the authors found that when the magnitude of external costs increases, the bins are pushed too less.
Waste bins location problem: a review

populated areas. Barrena et al. (2019) considered that the company in charge of the waste collection service should reduce the cost for citizens that are located near a bin, for the inconveniences it may cause. Also connected with the environmental impact generated by the bins, Ahmed et al. (2006), Zahan and Hasan (2020) and Ugwuishiwu et al. (2020) aimed at preventing the bins from being located near busy places, such as educational places and medical centers. Ahmed et al. (2006) and Ugwuishiwu et al. (2020) also identified water streams as an area that should be kept free from bins.

In the context of locating bins in a historic neighborhood, Tralhão et al. (2010) avoided locating collection points near historical buildings, to not affecting the cultural heritage of the neighborhood.

Finally, a particular study by López et al. (2008) studied a case where paper and cardboard community bins tend to overflow in highly commercial areas. Using special kerbside collection for paper and cardboard was proposed in areas with many small businesses to reduce the amount of recyclable material stored in the community bins. Moreover, the bins distribution was also modified and bins were moved towards nearby residential areas with less commercial activities.

7. Resolution method

This section reviews the different resolutions methods proposed in the related works to solve the waste bins location problem. First, an overall description of the analysis and categorization is presented. Then, a specific discussion is performed for each identified category.

7.1. General discussion

Several approaches have been applied for solving the MSW bins location problem. Some articles proposed exact methods. However, these approaches may not be able to solve large instances since waste bins location problem is a NP-hard problem. Thus, non-exacts methods (i.e., heuristic and metaheuristic approaches Nesmachnow (2014)) have also been applied to solve the problem. A common practice is to apply exact approaches for solving small scenarios and validating the heuristics/metaheuristics and, after that, applying the non-exact methods to solve large scenarios. Since a large part of the input data of the applied models consists in geo-referenced information, the capabilities of ArcGIS have been used, not only for processing the information and analyzing the results, but also for solving the optimization problem. GIS technologies support many resolution algorithms for facility location models, from exact \( p \)-medians models to heuristic approaches. Finally, a few works used other specific approaches, e.g., solving the problem by a manual approach based on some processed information (based on GIS or algebraic formulae), applying multicriteria methods such as AHP, or applying non-formally documented resolution approaches.

Another relevant aspect when solving real-world scenarios is considering uncertainty in the input parameters. Several articles have considered variations in the input parameters or, at least, have evaluated different typical values of waste generation rate, maximum threshold distance that users are willing to carry their waste to a bin, or maximum number of bins to install. Thus, a specific subsection is included for discussing works addressing uncertainty.

This review analyzes the resolution approaches used in the related works discussing the following topics: exact approaches, for works that applied exact resolution methods; heuristic and metaheuristic approaches, for works that applied non-exact methods, the GIS-based and other approaches, for works that used GIS-based and other location methods; and approaches considering uncertainty, for works that consider uncertainty in some input parameter.
7.2. Exact approaches

Many articles applied MILP models for solving the waste bins location problem. More than a half used single-objective models. Other articles applied multi-objective models to combine different criteria, e.g., a weighting sum approach (Cubillos and Wøhlk, 2020; Herrera et al., 2018; Nevrlý et al., 2019, 2021; Rossit et al., 2018, 2019, 2020; Tralhão et al., 2010), $\varepsilon$-constraint (Coutinho et al., 2012; Nevrlý et al., 2021; Rossit et al., 2017, 2020), lexicographic optimization (González and Adenso, 2002; Rossit et al., 2020) or goal programming (Aka and Akyüz, 2018; Tralhão et al., 2010). In several works, MILP exact models were used for solving small instances to validate heuristic approaches, later used to address larger scenarios (Cubillos and Wøhlk, 2020; Ghiani et al., 2012, 2014b; Hemmelmayr et al., 2013, 2017; Kim and Lee, 2013; Vidović et al., 2016).

A few works presented resolution approaches that combine linear programming models with other optimization tools. Aka and Akyüz (2018) combined MILP models with fuzzy goals for the optimization criteria. Jammeli et al. (2019) used an stochastic MILP model embedded in a heuristic approach to solve an integrated problem that combines defining the bins location and the routing collection schedules. Also solving an integrated problem, Vidović et al. (2016) implemented linear programming model as part of a two-phase heuristic procedure. Rathore and Sarmah (2019) and Rathore et al. (2020) applied a single-objective MILP approach only to determine the number of required bins in each region and, then, the location inside each region is determined whit ArcGIS.

7.3. Heuristic and metaheuristic approaches

Diverse heuristic/metaheuristic approaches have been proposed to solve the waste bins location problem. Bautista and Pereira (2006) proposed an evolutionary algorithm (EA) and a GRASP heuristic for efficiently solving real instances of the problem. Toutouh et al. (2018) applied the PageRank voting algorithm and NSGA-II to solve a multiobjective version of the problem. Later, other multiobjective approaches were applied: a multi-objective PageRank algorithm and SPEA-2 (Toutouh et al., 2020). Barrena et al. (2019) proposed a greedy algorithm, later improved by including a local search to the computed solution (Barrena et al., 2020). Adeleke and Ali (2021) applied a heuristic based on a Lagrangian relaxation of a linear programming model to solve the problem. Vijay et al. (2005) programmed a greedy heuristic in Arc Macro Language of ArcGIS that uses triangulated irregular networks and assigns users to the nearest bin considering path slopes.

Multi-stage heuristics have been proposed to solve different parts of the problem sequentially. In the constructive heuristic by Ghiani et al. (2012, 2014b), the first stage determines the sites for bins from a set of potential locations and assigns users to sites, and the second stage allocates bins to selected places. Di Felice (2014a) proposed a similar heuristic: first, deciding the places to locate the bins and, second, determining the size of the bins for each place. Kim and Lee (2013) proposed two multi-stage heuristics for solving large instances of the problem: i) a multi-stage branch and bound and ii) a drop heuristic. In both methods, first, the problem is solved considering static user-bin assignments and then, the solution is improved by allowing dynamic assignments, i.e., the users can be assigned to different bins on different days within the time horizon.

Several articles applied metaheuristics to the integrated problem of locating waste bins and designing collection routes, including EAs (Chang and Wei, 2000), memetic algorithms (Yaakoubi et al., 2018), Variable Neighborhood Search (VNS) (Cubillos and Wøhlk, 2020; Hemmelmayr et al., 2013), Adaptive Large Neighborhood Search (Hemmelmayr et al., 2017), and clustering (Jammeli et al., 2019). These approaches are described in Section 8.
7.4. GIS-based and other approaches

In the last decades, GIS software evolved from products designed to organize and show geographic information to complex integrated platforms for acquiring, storing, analyzing, and visualizing geospatial data (Li et al., 2020). Current GIS software includes solving optimization problems using predefined tools, or building specific solvers using integrated programming languages.

Several authors have used ArcGIS Network Analyst, an application integrated in ArcGIS to efficiently analyze and processed realistic network models (Zamorano et al., 2009). Aremu and Vijay (2016) used the Location-Allocation tool in ArcGIS Network Analyst to locate waste bins and assign users to the bins considering typical footpaths of the citizens in the area of study. Erfani et al. (2017) applied the Minimize Facilities model of ArcGIS Network Analyst to determine the number of bins that cover maximum population within a maximum walking distance, from a potential set of GAPs. The approach was enhanced by applying the Maximized Capacitated Coverage model to assess the population and the waste received by the facilities (Erfani et al., 2018). Vu et al. (2018) applied the Maximize Coverage and Minimize Facility models to compute solutions that considered the trade-off between costs and QoS provided to the citizens. Some works developed applications for optimization in GIS embedded languages. Vijay et al. (2005) developed a greedy heuristic in Arc Macro Language of ArcGIS. Gautam and Kumar (2005) and Vijay et al. (2008) programmed a $p$-median model in the same programming language. Aremu and Sule (2012) and Aremu et al. (2012) programmed a $p$-median model in TransCAD software (Lu and Nimbole, 2008).

Another set of works used GIS for processing information to analyze an existing network of bins and suggest modifications to improve the coverage by a manual trial-and-error method. Boskovic and Jovicic (2015) and López et al. (2008, 2009) suggested some modifications after carefully considering the waste generation by citizens, stores, and institutions for different seasons of the year. The analysis by Zamorano et al. (2009) concluded that there was a lack of bins for the recyclable network and an excessive number of bins for the non-recyclable network. After a survey to carefully estimate waste generation, Khan and Samadder (2016) relocated the bins in the studied area to reduce the posterior collection costs. Ferronato et al. (2020) analyzed the MSW system considering the contribution of informal waste pickers and Karadimas and Loumos (2008) presented a regression model to accurately estimate the waste generation rate and the required number of bins.

Finally, two works used the multicriteria Analytical Hierarchy Procedure (AHP). Aremu et al. (2012) used AHP to select the best solution based on economic, social, and environmental criteria among several outcomes of the $p$-median models with different number of bins. Zahan and Hasan (2020) applied AHP in a pilot case to choose among three different locations to place the bin.

7.5. Approaches considering uncertainty

Another important aspect in the resolution process of the waste bins location problem is the consideration of uncertainty in the input parameters.

One of the main sources of uncertainty is waste generation rate, which is not easy to estimate since it depends on population density, commercial activities in the area (Karadimas et al., 2006; Karadimas and Loumos, 2008), and it is affected by seasonal variations (Boskovic and Jovicic, 2015; Carlos et al., 2021). Jammeli et al. (2019) considered a stochastic normally distributed number of citizens within the influence area of each collection point and stochastic waste generation, integrated in the resolution process via a transformed MILP formulation. Kim and Lee (2013, 2015a,b) considered the variation of waste generation for different days within the planning time.
horizon, allowing the model to assign users to different bins on each day. Another approach considers deterministic generation, but sensitivity analysis are performed by solving the waste bins location problem for different common values of waste generation rate (Letelier et al., 2021; Rathore et al., 2020; Rossit et al., 2018, 2019; Toutouh et al., 2018, 2020). However, the safety factor strategy must be carefully planned. Pérez et al. (2017) found that unused overcapacity increases the environmental impact of the waste bins network. Aremu et al. (2012) and Erfani et al. (2018) considered the unused capacity as a negative factor that increments the purchasing and maintenance costs of bins, an adverse effect on aesthetic, and decreases the efficiency of the collection. Flahaut et al. (2002) found that estimating the waste generation rate may not lead to better results. Similar quality of service was computed when using two different estimations of the generation rate: a simple approximation based on population density and a more accurate estimation considering additional features of users (users per household, socioeconomic level, and age ranges), gathered in an specific survey. Thus, researchers and authorities must carefully consider whether is worth spending time and effort in collecting additional information from users or not.

Another important parameter considered in sensitivity analysis is the maximum tolerable distance between users and their assigned bins. Related works have considered a wide range of distance threshold values, from short distances (75 m) (Zamorano et al., 2009) to medium distances (up to 500 m) (Di Felice, 2014b; Parrot et al., 2009). The maximum distance that citizens are willing to transport their waste is highly site-specific (Boskovic and Jovicic, 2015; Vu et al., 2018) and it depends on the type of collection system (kerbside, drop-off stations, etc.) (Gallardo et al., 2015). Several articles reported sensitivity analysis to evaluate models for different common distance thresholds (Adeleke and Ali, 2021; Aremu and Sule, 2012; Aremu and Vijay, 2016; Cavallin et al., 2020; Kao and Lin, 2002; Erfani et al., 2017; Di Felice, 2014b; Ghiani et al., 2012, 2014b; Letelier et al., 2021; Lin et al., 2011; Oliaei and Fataei, 2016; Ratković et al., 2016; Vu et al., 2018).

Other articles limited the number of bins to install in the studied scenario, according to sensitivity analysis (Cubillos and Wøhlk, 2020; Hemmelmayr et al., 2013; Kao et al., 2013; Kim and Lee, 2013, 2015a,b; Vu et al., 2018). Coutinho et al. (2012) bounded the installment costs (purchase of bins and installation of bins requiring collection vehicle adaptation). The model was solved for different threshold values for the cost, to analyze the its impact on the quality of solutions.

A few articles have performed sensitivity analysis in less common parameters, such as the fixed collection frequency accumulated waste (Carlos et al., 2021; Cavallin et al., 2020; Hemmelmayr et al., 2013; Rathore et al., 2020), the number of periods in the planning horizon (Kim and Lee, 2013, 2015b), the bins storage capacity (Adeleke and Ali, 2021; Hemmelmayr et al., 2013), the purchasing cost of bins (Hemmelmayr et al., 2013), the frequency of maintenance tasks on bins (Gilardino et al., 2017), the maximum distance between collection points (Blazquez and Paredes, 2020), or the nuisance of the noise generated by collection vehicles (Flahaut et al., 2002).

Finally, two articles considered fuzzy goals in integrated approaches. Chang and Wei (2000) considered three objectives (population served, average walking distance between users and assigned bins, and routing distance of collection vehicles) as fuzzy planning goals to compute a set of compromising solutions. Aka and Akyüz (2018) also used fuzzy objective functions to maximize the number of citizens served and minimize the routing distance of the collection vehicles.
8. Integrated approaches with other stages of the reverse MSW supply chain

The traditional approach for decision-making in the MSW system solved problems on a sequential or hierarchical fashion, i.e., first locating the bins and then optimize the routes needed for waste collection. However, the main goal of designing a useful MSW system providing both cost savings and proper QoS can be achieved by applying integrated models to solve both problems simultaneously, in the same optimization process (Kim and Lee, 2015b). The resolution is computationally challenging, since it involves addressing two NP-hard problems simultaneously.

The advantages of integrated approaches are noteworthy, considering the interdependence between bins network design and waste collection routes. The geographical distribution of bins clearly affects the routing schedule, since the selected locations must be visited by the collection vehicles (Cubillos and Wöhlk, 2020). The storage capacity of the installed bins also influences the collection cost, determining the required frequency to empty the bins and avoid overflowing (Hemmelmayr et al., 2013). Moreover, the routing cost is affected by the type of bins used, i.e., special bins may require compatible vehicles to be emptied (Ghiani et al., 2014b). Thus, unlike traditional sequential methods, the holistic perspective of integrated approaches captures the connection between the network design and the collection route in the decision-making process, reducing the overall cost of the system (Bing et al., 2016). This section describes integrated approaches that provide the more comprehensive, challenging, and interesting solutions for MSW systems.

Articles considering integrated approaches are relatively scarce. The first integrated approach was proposed by Chang and Wei (1999) for location-routing of recyclable materials. A multiobjective linear programming model was proposed, considering three objective functions: maximization of population served, and minimization of total walking distance from household to recycling drop-off stations and the total driving distance of the collection vehicles. A simple EA was proposed to solve the problem, later extended to consider a fuzzy fitness function (Chang and Wei, 2000). The integrated approach by Hemmelmayr et al. (2013) considered waste generation concentrated in the places where bins are to be installed. Bins location, collection frequency, and routing schedule were solved jointly using a MILP model for small instances and VNS for larger instances. The VNS solved the waste collection routing problem by assigning collection frequencies to each collection site, and re-optimizing the bins location to obtain a new minimal cost by applying a local search heuristic. For small instances, the VNS was compared with a MILP model, obtaining accurate results. For larger instances, the integrated VNS outperformed a sequential approach solving the bin location and then the waste collection, or viceversa.

Kim and Lee (2015b) considered a dynamic allocation of users to waste bins in different days. The integrated procedure applied Tabu Search (TS) for bins location. Each time the location of bins or the users-bins allocation change, the routing cost is calculated applying another TS that searches on neighborhoods built using 2-opt/3-opt heuristics. The integrated approach outperformed hierarchical methods applying TS and a cluster-first route-second heuristic with a local search improvement step for setting the routing schedule. Sheriff et al. (2017) also considered three stages for plastic collection: location of waste bins, location of transfer plants, and the routing schedules from waste bins to transfer plants. The integrated approach improved over solutions computed by a three-stages sequential approach. Flexibility either in the potential location of vehicle depots or the visit schedules of the collection points reduced the total costs, without increasing the number of depot locations.
Hemmelmayr et al. (2017) presented a location-routing approach for multi-agency recycling campaigns. The optimization model aimed at simultaneously define which agency should own a recyclable bin, the capacity of the bins to be installed in each place, and set the weekly schedule and routes for the collection vehicles. A MILP formulation was proposed for small instances and Adaptive Large Neighborhood Search (ALNS) for larger instances. ALNS obtained near optimal solutions when compared with the MILP formulation. A sensitivity analysis for the available vehicle capacities, the visiting schedules, or the capacity of installed bins was also presented.

Aka and Akyüz (2018) presented an integrated approach aimed at maximizing the total number of dwellings served by a network of recyclable bins and minimize the total travel distance by the collection vehicle. A fuzzy goal programming approach was proposed for solving a MILP formulation of the problem using goals previously estimated by experts. The allocation of users to each bin is considered to be given beforehand and it is not part of the optimization process.

Jammeliet al. (2019) simultaneously allocated bins to predefined locations and defined collection routes, considering stochastic waste generation. The resolution approach applied two stages: a $k$-means clustering to group bins into sectors, and an exact model to determine both the number of bins and the collection route for each sector, assuming a daily collection frequency. The stochastic waste generation rate influenced the required capacity of bins to locate in each place, the usage of the vehicle capacity along the route, and the collection time that takes to the vehicle to empty a bin. Uncertainty was coped by several transformations for solving the model in the second stage.

The model by Cubillos and Wöhlk (2020) considered each household as a potential site for locating a bin for recyclable material. The goal was finding a network of bins to simultaneously maximize the number of covered households, i.e., located within a certain threshold distance from a bin, and minimize the collection route, which was approximated solving a Traveling Salesman Problem without considering the capacity or other real-world constraints. This simplification allowed obtaining fast estimations for the collection cost without solving a time-consuming inventory-routing problem. For small instances, the VNS was compared with a MILP model obtaining accurate results. Then, the VNS was used to solve larger instances and a real-world case study.

Finally, other two works presented MILP models for the integrated problem that were only applied to small toy instances (Vidović et al., 2016; Yaakoubi et al., 2018). Then, these two works, proposed heuristics for solving both problems in a sequential fashion for realistic instances.

9. Conclusions

Waste management is critical for modern cities, since it has direct implications on the environmental, social, and economic welfare of citizens. Among the diverse stages of the reverse supply chain of MSW, this article addressed the waste bins location problem, consisting in finding the best locations for community bins in an urban area to store the waste before they are collected by the collection vehicle. This problem has an important impact on the overall efficiency of the logistic chain, since it is the entry point to the MSW system. Thus, a poor planning on this stage can diminish the amount of waste received by the MSW system of a city. Moreover, the distribution and the capacity of bins influence other stages of the reverse supply chain, e.g., the design and frequency of the collection routes and the required capacity of intermediate and processing facilities. There is also evidence that a correct arrangement of bins can encourage the community to correctly classify the waste at source, which usually is closely associated with the success of recycling programs.
The review performed a thorough analysis of 76 related works, carefully selected from more than two hundred articles retrieved from well-known scientific databases. After presenting a general description of the reverse supply chain of MSW and the importance of the waste bin location problem for the MSW system, the selected articles were studied through bibliometric analysis, considering the addressed scenarios, pursued criteria, resolution approaches, and issues related to the waste collection stage. In turn, articles were reviewed taking into account: i) the optimization criteria used, ii) the resolution approach, iii) the consideration of uncertainty, iv) the application of integrated approaches to address bin location and collection routing simultaneously.

The review of related works has suggested some interesting topics to be addressed in future researches. An important line for future work is incorporating uncertainty in the conceptual models and the resolution approaches. The main factor subject to uncertainty is the waste generation, mainly due to seasonal and citizens consumption pattern variations. Although a few works have performed sensitivity analysis based on typical values of this parameter, only one article considered waste generation as stochastic and, thus, applied an stochastic approach. Another promising research line is to continue developing integrated approaches considering the trade-off between the storage and the waste collection stages of the MSW logistic chain. Most articles in the literature assumed a sequential approach of both stages, although there is evidence that integrated approaches are able to outperform sequential approaches due to a better characterization of the interrelation between the underlying optimization problems.

References

Amedotun, A., Sridhar, M., Coker, A., 2020. Improving municipal solid waste collection system through a GIS based mapping of location specific waste bins in Ibadan Metropolis, Nigeria. Journal of Solid Waste Technology & Management 46, 360–371. doi:10.5276/JSWTM/2020.360.

Adeleke, O., Ali, M., 2021. An efficient model for locating solid waste collection sites in urban residential areas. International Journal of Production Research 59, 798–812. doi:10.1080/00207543.2019.1709670.

Ahmed, S., Muhammad, H., Sivertun, A., 2006. Solid waste management planning using GIS and remote sensing technologies case study Aurangabad City, India, in: 2006 International Conference on Advances in Space Technologies, pp. 196–200. doi:10.1109/ICAST.2006.313826.

Aka, S., Akyüz, G., 2018. Fuzzy goal programming approach on location-routing model for waste containers. International Journal of Industrial and Systems Engineering 29, 413–427. doi:10.1504/IJISE.2018.094265.

Ali, S., Ahmad, A., 2019. Spatial susceptibility analysis of vector-borne diseases in KMC using geospatial technique and MCDM approach. Modeling Earth Systems and Environment 5, 1135–1159. doi:10.1007/s40808-019-00586-y.

Aremu, A., Sule, B., 2012. A case study evaluation of the impacts of optimised waste bin locations in a developing city. Civil Engineering and Environmental Systems 29, 137–146. doi:10.1080/10286608.2012.672411.

Aremu, A., Sule, B., Downs, J., Mihelcic, J., 2012. Framework to determine the optimal spatial location and number of municipal solid waste bins in a developing world urban neighborhood. Journal of Environmental Engineering 138, 645–653. doi:10.1061/(ASCE)EE.1943-7870.0000513.

Aremu, A., Vijay, R., 2016. Modeling indigenous footpath and proximity cut-off values for municipal solid waste management: a case study of ilorin, nigeria. Procedia Environmental Sciences 35, 51–56. doi:10.1016/j.proenv.2016.07.005.

Barrena, E., Canca, D., Ortega, F., Piedra de la Cuadra, R., 2019. Optimizing container location for selective collection of urban solid waste, in: 9th International Conference on Waste Management and the Environment, pp. 1–9. doi:10.2495/WM180011.

Barrena, E., Canca, D., Ortega, F., Piedra-de-la Cuadra, R., 2020. Solidarity behavior for optimizing the waste selective collection. International Journal of Sustainable Development and Planning 15, 133–140. doi:10.18280/ijisdp.150202.

Bautista, J., Pereira, J., 2006. Modeling the problem of locating collection areas for urban waste management. an application to the metropolitan area of Barcelona. Omega 34, 617–629. doi:10.1016/j.omega.2005.01.013.

Bennekrouf, M., Aggoune, W., Benladghem, K., Cherif, H., 2020. A strategic approach for the optimal location of recycling bins in the city of Boudjilda in Algeria, in: 2020 IEEE 13th International Colloquium of Logistics and Supply Chain Management (LOGISTIQUA), pp. 1–6. doi:10.1109/LOGISTIQUA49782.2020.9353893.

Bing, X., Bloemhof, J., Ramos, T., Barbosa, A., Wong, C., van der Vorst, J., 2019. Research challenges in municipal solid waste logistics management. Waste Management 48, 584–592. doi:10.1016/j.wasman.2015.11.025.

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

Bonomo, F., Durán, G., Larumbe, F., Marenco, J., 2012. A method for optimizing waste collection using mathematical programming: a Buenos Aires case study. Waste Management & Research 30, 311–324. doi:10.1177/0734242X11402870.

Boskovic, G., Jovicic, N., 2015. Fast methodology to design the optimal collection point locations and number of waste bins: A case study. Waste Management & Research 33, 1094–1102. doi:10.1177/0734242X15607426.
Waste bins location problem: a review

intelligence and machine learning, in: Kumar, R., Wiil, U. (Eds.), Recent Advances in Computational Intelligence. Springer, pp. 173–188. doi:10.1007/978-3-319-12500-4_11.

Hazra, T., Goel, S., 2009. Solid waste management in Kolkata, India: Practices and challenges. Waste Management 29, 470–478. doi:10.1016/j.wasman.2008.08.023.

Hemmelmeyer, V., Doerner, K., Hartl, R., Vigo, D., 2013. Models and algorithms for the integrated planning of bin allocation and vehicle routing in solid waste management. Transportation Science 48, 103–120. doi:10.1287/trsc.2013.0459.

Hemmelmeyer, V., Smillowitz, K., De la Torre, L., 2017. A periodic location routing problem for collaborative recycling. IIE Transactions 49, 414–428. doi:10.1080/24275854.2016.1267882.

Herrera, I., Imbaquingo, W., Lorente, L., Herrera, E., Peluffo, D., Rossit, D., 2018. Optimization of the network of urban solid waste containers: A case study, in: 4th International Conference on Technology Trends, pp. 578–589. doi:10.1007/978-3-319-05532-5_44.

Hoornweg, D., Bhada, P., 2012. What a waste: a global review of solid waste management. Urban development series 15.

Hoornweg, D., Bhada, P., Kennedy, C., 2015. Peak waste: When is it likely to occur? Journal of Industrial Ecology 19, 117–128. doi:10.1111/jiec.12165.

Jammeli, H., Argoubi, M., Masri, H., 2019. A bi-objective stochastic programming model for the household waste collection and transportation problem: case of the city of Sousse. Operational Research, 1–27?doi:10.1007/s12351-019-00538-5. in press.

Kao, J., Lin, T., 2002. Shortest service location model for planning waste pickup locations. Journal of the Air & Waste Management Association 52, 585–592. doi:10.1080/10473289.2002.10478807.

Kao, J., Tsai, Y., Huang, Y., 2013. Spatial service location-allocation analysis for siting recycling depots. Journal of Environmental Engineering 139, 1035–1041. doi:10.1061/(ASCE)EE.1943-7870.0000720.

Kao, J., Wen, L., Liu, K., 2010. Service distance and ratio-based location-allocation models for siting recycling depots. Journal of Environmental Engineering 136, 444–450. doi:10.1061/(ASCE)EE.1943-7870.0000170.

Karadimas, N., Mavrantza, O., Loumos, V., 2005. GIS integrated waste production modeling, in: EUROCON 2005 - The International Conference on “Computer as a Tool”, pp. 1279–1282. doi:10.1109/EURCON.2005.1630190.

Karadimas, N., Orsoni, A., Loumos, V., 2006. Municipal solid waste generation modelling based on fuzzy logic, in: 20th European Conference on Modelling and Simulation, Bonn, Germany.

Karadimas, N.V., Loumos, V.G., 2008. GIS-based modelling for the estimation of municipal solid waste generation and collection. Waste Management & Research 26, 337–346. doi:10.1177/0734242X0701484.

Karkanias, C., Perkoulidis, G., Grigoriadis, N., Statfylas, S., Dagdilelis, E., Feleki, E., Moussiopoulos, N., 2014. Assessing recycling potential in local level: the case of Neapoli-Sykes municipality, Greece, in: Fresenius Environmental Bulletin, pp. 2884–2889.

Khan, D., Samadder, S., 2016. Allocation of solid waste collection bins and route optimisation using geographical information system: a case study of Dhanbad City, India. Waste Management & Research 34, 666–676. doi:10.1177/0734242X16649679.

Kim, J., Lee, D., 2013. A restricted dynamic model for refuse collection network design in reverse logistics. Computers & Industrial Engineering 66, 1113–1137. doi:10.1016/j.cie.2013.08.001.

Kim, J., Lee, D., 2015a. A case study on collection network design, capacity planning and vehicle routing in reverse logistics. International Journal of Sustainable Engineering 8, 66–76. doi:10.1080/19397038.2014.947393.

Kim, J., Lee, D., 2015b. An integrated approach for collection network design, capacity planning and vehicle routing in reverse logistics. Journal of the Operational Research Society 66, 76–85. doi:10.1057/jors.2013.168.

Kumar, K., Goel, S., 2009. Characterization of municipal solid waste (MSW) and a proposed management plan for Kharagpur, West Bengal, India. Resources, Conservation and Recycling 53, 166–174. doi:10.1016/j.resconrec.2008.11.004.

Lebersorger, S., Beigl, P., 2011. Municipal solid waste generation in municipalities: Quantifying impacts of household structure, commercial waste and domestic fuel. Waste Management 31, 1907–1915. doi:10.1016/j.wasman.2011.05.016.

Leeabai, N., Areeprasert, C., Khaobang, C., Viriyapanitchakij, N., Bussa, B., Dilinazi, D., Takahashi, F., 2021. The effects of color preference and noticeability of trash bins on waste collection performance and waste-sorting behaviors. Waste Management 121, 153–163. doi:10.1016/j.wasman.2020.12.010.

Leeabai, N., Suzuki, S., Jiang, Q., Dilixiati, D., Takahashi, F., 2019. The effects of setting conditions of trash bins on waste collection performance and waste separation behaviors; distance from walking path, separated setting and, arrangements. Waste Management 94, 58–67. doi:10.1016/j.wasman.2019.05.039.

Letelier, C., Blazquez, C., Paredes, 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. doi:10.1177/0734242X20986610. in press.

Li, W., Batty, M., Goodchild, M., 2020. Real-time GIS for smart cities. International Journal of Geographical Information Science 34, 311–324. doi:10.1080/13658816.2019.1673397.

Lin, H., Tsai, Z., Chen, G., Kao, J., 2011. A model for the implementation of a two-shift municipal solid waste and recyclable material collection plan that offers greater convenience to residents. Journal of the Air & Waste Management Association 61, 55–62. doi:10.3155/1047-3289.61.1.55.

Lindell, M., Earle, T., 1983. How close is close enough: Public perceptions of the risks of industrial facilities. Risk Analysis 3, 245–253. doi:10.1111/j.1539-6924.1983.tb01393.x.

López, J., Aguilar, M., Fernández, S., Jiménez del Valle, A., 2008. Optimizing the collection of used paper from small businesses through GIS techniques: The leganés case (madrid, spain). Waste Management 28, 282–293. doi:10.1016/j.wasman.2007.02.036.

López, J., Aguilar, M., Soriano, F., Fernando de Fuentes, A., 2009. Containerisation of the selective collection of light packaging waste material: The case of small cities in advanced economies. Cities 26, 339–348. doi:10.1016/j.cities.2009.09.002.

Lu, H., Nimbole, P., 2008. Intro to TransCAD GIS. Technical Report. Connect NCDOT Business Partner Resources.

Maraqa, M., Aldahab, E., Ghanna, M., Al Kaabi, S., 2018. Optimization of fuel consumption for municipal solid waste collection in Al Ain city, UAE, in: 2018 International Joint Conference on Materials Science and Mechanical Engineering, pp. 12–26. doi:10.1088/1757-899X/383/1/012026.
Waste bins location problem: a review

Nesmachnow, S., 2014. An overview of metaheuristics: accurate and efficient methods for optimisation. International Journal of Metaheuristics 3, 320–347.

Nesmachnow, S., Rossit, D., Toutouh, J., 2018. Comparison of multiobjective evolutionary algorithms for prioritized urban waste collection in montevideo, uruguay. Electronic Notes in Discrete Mathematics 69, 93–100. doi:10.1016/j.endm.2018.07.013.

Nevrý, V., Šomplák, R., Khrý, L., Smejkalova, V., Jadrýn, J., 2019. Municipal solid waste container location based on walking distance and distribution of population. Chemical Engineering Transactions 76, 553–558. doi:10.3303/CET197693.

Nevrý, V., Šomplák, R., Smejkalová, V., Lipovský, T., Jadrný, J., 2021. Location of municipal waste containers: Trade-off between criteria. Journal of Cleaner Production 278, 123445. doi:10.1016/j.jclepro.2020.123445.

Nithya, R., Velumani, A., Kumar, S., 2012. Optimal location and proximity distance of municipal solid waste collection bin using GIS: A case study of Coimbatore city. WSEAS Transactions on environment and development 8, 107–119.

Oliaei, A., Fataei, E., 2016. Breakdown of urban waste repository location using GIS (Case study District 3 region 1 Tabriz). Ecology, Environment and Conservation 22, 551–557.

Parrot, L., Sotamenou, J., Dia, B., 2009. Municipal solid waste management in Africa: Strategies and livelihoods in Yaoundé, Cameroon. Waste Management 29, 986–995. doi:10.1016/j.wasman.2008.05.005.

Paul, K., Dutta, A., Krishna, A., 2017. Using GIS to locate waste bins: a case study on Kolkata City, India. Journal of Environmental Science and Management 20.

Pierz, J., Lumbraeras, J., De la Paz, D., Rodriguez, E., 2017. Methodology to evaluate the environmental impact of urban solid waste containerization system: A case study. Journal of Cleaner Production 150, 197–213. doi:10.1016/j.jclepro.2017.03.003.

Purkayastha, D., Majumder, M., Chakrabarti, S., 2015. Collection and recycle bin location-allocation problem in solid waste management: A review. Pollution 1, 175–191.

Rathore, P., Sarmah, S., 2019. Allocation of bins in urban solid waste logistics system, in: 4th International Conference on Harmony Search, Soft Computing and Applications, pp. 485–495. doi:10.1016/978-981-13-0761-4_47.

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

Ratković, B., Popović, D., Radivojević, G., Bjielić, N., 2016. Planning logistics network for recyclables collection. Yugoslav Journal of Operations Research 24, 371–381. doi:10.2298/YJOR140408022R.

Rossit, D., 2018. Desarrollo de modelos y algoritmos para optimizar redes logísticas de residuos sólidos urbanos. Ph.D. thesis. Department of Engineering, Universidad Nacional del Sur. Bahía Blanca, Argentina.

Rossit, D., Nesmachnow, S., Toutouh, J., 2018. Municipal solid waste management in smart cities: facility location of community bins, in: First Ibero-American Congress on Information Management and Big Data, pp. 102–115. doi:10.1016/978-987-3-030-12804-3_3.

Rossit, D., Nesmachnow, S., Toutouh, J., 2019. A bi-objective integer programming model for locating garbage accumulation points: a case study. Revista Facultad de Ingeniería Universidad de Antioquia, 70–81 doi:10.17533/udea.redin.20190509.

Rossit, D., Tohmé, F., Frutos, M., Broz, D., 2017. An application of the augmented r-constraint method to design a municipal sorted waste collection system. Decision Science Letters 6, 323–336. doi:10.5267/j.dsl.2017.3.001.

Rossit, D., Toutouh, J., Nesmachnow, S., 2020. Exact and heuristic approaches for multi-objective garbage accumulation points location in real scenarios. Waste Management 105, 467–481. doi:10.1016/j.wasman.2020.02.016.

Sheriff, K., Subramanian, N., Rahman, S., Jayaram, J., 2017. Integrated optimization model and methodology for plastics recycling: Indian empirical evidence. Journal of Cleaner Production 153, 707–717. doi:10.1016/j.jclepro.2016.07.037.

Singh, A., 2019. Managing the uncertainty problems of municipal solid waste disposal. Journal of Environmental Management 240, 259–265. doi:10.1016/j.jenvman.2019.03.058.

Sotamenou, J., De Jaeger, S., Rousseau, S., 2019. Drivers of legal and illegal solid waste disposal in the global south—the case of households in Yaoundé (Cameroon). Journal of Environmental Management 240, 321–330. doi:10.1016/j.jenvman.2019.03.058.

Sotamenou, J., De Jaeger, S., De Boeck, L., De Jaeger, S., 2019. Literature review as a research methodology: An overview and guidelines. Journal of Business Research 104, 333–339. doi:10.1016/j.jbusres.2019.07.039.

Snyder, H., 2019. Literature review as a research methodology: An overview and guidelines. Journal of Business Research 104, 333–339. doi:10.1016/j.jbusres.2019.07.039.

Tralhão, L., Coutinho, J., Alçada, L., 2010. A multiobjective modeling approach to locate multi-compartment containers for urban-sorted waste. Waste Management 30, 2418–2429. doi:10.1016/j.wasman.2010.05.017.

Tranfield, D., Denyer, D., Smart, P., 2003. Towards a methodology for developing evidence-informed management knowledge by means of systematic review. British Journal of Management 14, 207–222. doi:10.1111/j.1467-8551.2003.00375.x.

Ugwuishiu, B., Nwoke, O., Okechukwu, C., Echiegu, E., 2020. GIS-based system analysis for waste bin location in Enugu municipality. Agricultural Engineering International: CIGR Journal 22, 250–259.

Valeo, C., Baetz, B.W., Tsinis, I., 1998. Location of recycling depots with GIS. Journal of Urban Planning and Development 124, 93–99. doi:10.1061/(ASCE)0733-9488(1998)124:2(93).

Van Engeland, J., Beliën, J., De Boeck, L., De Jaeger, S., 2020. Literature review: Strategic network optimization models in waste reverse supply chains. Omega 91, 102012. doi:10.1016/j.omega.2018.12.001.

Vidović, D., Ratković, B., Bjielić, N., Popović, D., 2016. A two-echelon location-routing model for designing recycling logistics networks with profit: MILP and heuristic approach. Expert Systems with Applications 51, 34–48. doi:10.1016/j.eswa.2015.12.029.

Vijay, R., Gautam, A., Kalamdhad, A., Gupta, A., Devotta, S., 2008. GIS-based locational analysis of collection bins in municipal solid waste management systems. Journal of Environmental Engineering and Science 7, 39–43. doi:10.1139/S07-033.

Vijay, R., Gupta, A., Kalamdhad, A., Devotta, S., 2005. Estimation and allocation of solid waste to bin through geographical information systems.
Waste bins location problem: a review

Vu, H., Ng, K., Bolingbroke, D., 2018. Parameter interrelationships in a dual phase GIS-based municipal solid waste collection model. Waste Management 78, 258–270. doi:10.1016/j.wasman.2018.05.050.

Yaakoubi, O., Benabdouallah, M., Bojji, C., 2018. Heuristic approaches for waste containers location problem and waste collection routes optimization in an urban area. International Journal of Environment and Waste Management 21, 269–286. doi:10.1504/IJEWM.2018.093436.

Yadav, V., Karmakar, S., Dikshit, A., Vanjari, S., 2016. A feasibility study for the locations of waste transfer stations in urban centers: a case study on the city of nashik, india. Journal of cleaner production 126, 191–205. doi:10.1016/j.jclepro.2016.03.017.

Zahan, N., Hasan, Z., 2020. Multi-attribute decision making approach for waste bin site selection problem: A case study in Dhaka city, in: 11th International Conference on Computing, Communication and Networking Technologies. doi:10.1109/ICCCNT49239.2020.9225597.

Zamorano, M., Molero, E., Gridlay, A., Rodriguez, M., Hurtado, A., Calvo, F., 2009. A planning scenario for the application of geographical information systems in municipal waste collection: A case of Churriana de la Vega (Granada, Spain). Resources, Conservation and Recycling 54, 123–133. doi:10.1016/j.resconrec.2009.07.001.

Zhang, J., Qin, Q., Li, G., Tseng, C., 2021. Sustainable municipal waste management strategies through life cycle assessment method: A review. Journal of Environmental Management 287, 112238. doi:10.1016/j.jenvman.2021.112238.