Chapter 3
Technology Status of Waste Collection Systems

Abstract The increasing rate of waste production per capita, the technological advances in packaging products, and the new waste policy and the legal provisions adopted in developed countries created a constant change in the set of parameters that determine the design of solutions for integrated waste management, where waste collection plays a fundamental role. A vast spectrum of technologies for source-separated waste collection and devices was developed, making the evaluation and selection of the one to be applied a difficult task. The purpose of this chapter is to reduce the complexity of identifying, selecting, and benchmarking waste collection systems, presenting a taxonomic classification for the different technical solutions, related to the relevant parts of collection activities and critical equipment characteristics.

Keywords Containers · Vehicles · Classification · Underground · Surface · Lift · Crane · Compaction · Manual · Assisted

3.1 Waste Collection

3.1.1 Waste Collection Role

Collecting waste is one of the most critical phases of the cycle of waste generation-transformation-elimination (Bautista and Pereira 2006), playing a central but often underestimated role in the waste management system (Bilitewski et al. 2010). Waste collection is a highly visible municipal service that involves large expenditures and operational problems; plus it is expensive to operate regarding investment and operational and environmental costs (Faccio et al. 2011). In fact, due to the massive fuel consumption and labor involved, municipal solid waste (MSW) collection is usually the most polluting and costly component of MSW management (MSWM), representing 50–75% of the total costs (Bilitewski et al. 2010; Tchobanoglous et al. 1993). Waste collection is the contact point between waste generators (citizens) and waste management system and can be associated with different kinds of problems such as littering, overfull containers, low recovery rates, and contamination. A lot of

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these problems can be solved by the proper implementation of a system when it is new and by increasing facilitators through adequate information and feedback to the public and a good, well-planned collection system (Petersen and Berg 2004).

Although MSW collection has the primary role of providing public health to citizens, several waste streams are source separated to obtain quality waste materials that can be recovered and recycled. Nowadays, other roles have been given to MSW collection, making it more sustainable:

- Technical role: the way how waste is collected can influence its properties and, consequently, the waste treatment technologies. If waste is collected commingled and compacted, its destination can be in landfill, mechanical-biological treatment, or incineration units; however, if specific waste streams are source separated, they have a better quality to be recycled than mixed waste.
- Environmental role: besides recycling, MSW collection has been conducted to reduce fuel consumption or even replace fossil fuels by non-fossil fuels like biogas, with the intention to reduce emissions of greenhouse gases. Also, due to the low average speed of collection vehicles, and numerous stops during collection, the effect they have on congestion, air pollution, and noise is higher than that of other types of freight transportation in cities (Johansson 2006).
- Social role: MSW collection is the WMS identity or municipality identity. Without an appropriate communication, all the effort in promoting waste source separation can fail. The recovery rate depends on the participation activity and separation efficiency of the waste producers (Tanskanen and Melanen 1999). Also, collection operation can create problems of the occupation of public space, noise, odors, and traffic and industrial accidents (Poulsen et al. 1995) that, if not minimized, contribute to a negative image of the entire WMS. It should also highlight the job creation promoted by MSW collection, being the ISWM component in which more jobs are created.
- Economic role: MSW collection is an expensive component of ISWM, regarding investment costs (i.e., vehicles fleet) and operational costs (i.e., fuel, maintenances) (Faccio et al. 2011). It should be regarded that MSW collection is a public good, due to the public health driver, so it has to be available to everyone. When waste streams belong to an extended producer responsibility management system, collection costs should be ensured by the fee paid. However, this is not adequately addressed in practice. The residual fraction collection has to be optimized, to not cumbersome citizens.
- Legal role: in order to fulfill policy and legal provisions adopted in the European Union on waste, a broad spectrum of measures and technical solutions for different types of problems and wastes was developed during the last decades (Bilitewski et al. 2010), promoting a wide range of separate collection systems and giving rise to a number of studies assessing and comparing management strategies (Gallardo et al. 2012; Iriarte et al. 2009).

This evolution of the applied roles has been possible due to technological development, especially in the last decades. MSW collection has evolved from trash cans to robust high-tech material and attractive container design and, at the same time, from dedicated and straightforward collection vehicles to trucks with a global positioning system and radio-frequency identification sensors to identify containers and optimization models to increase efficiency.

Being capable of considering all these roles and taking sustainable decisions in choosing and managing an MSW collection system is not an easy task. It is even more difficult when national legislation implements collection targets to be reached because it will influence MSW collection activities (Pieber 2004; Kogler 2007). At a micro- or local scale, any improvement in MSW collection organization – type, size, and receptacle combination – and the collection frequency will influence the composition of MSW as well as the quality and quantity of the separately collected recyclables and thus demands and costs for the subsequent treatment (Bilitewski et al. 1997; Tchobanoglous et al. 1993). At a macroscale, recovery rate targets are in demand and increase the complexity and total costs of MSW management – dividing the total waste mass into separate waste streams results in an increased number of waste flow paths, functional elements, and interdependence in the waste management systems, increasing the number of containers and the amount of collection work (Kogler 2007; Pieber 2004; Tanskanen and Melanen 1999).

3.1.2 Waste Collection Systems

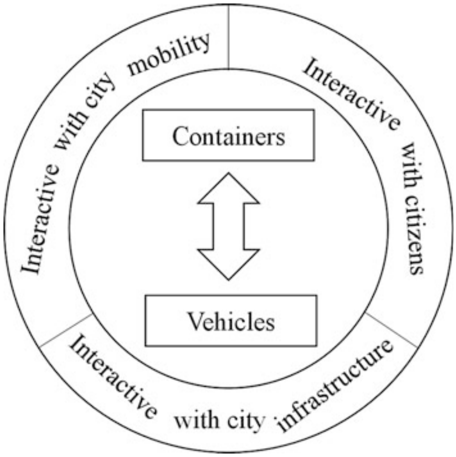
The process of the waste collection begins when the generated waste is thrown into appropriate receptacles and ends when these receptacles are picked up and emptied by collection vehicles. However, the functional element, referred to as "collection," includes not only the removal of waste but also the transport to the place where the collection vehicle is emptied, including this last operation (Tchobanoglous et al. 1993). Collection and transport must include (Bilitewski et al. 1997):

- Recovery and collection of all household, industrial, and commercial waste, including separate collection of recyclables, removing them from the place where they are produced
- Transport of the collected waste into the processing and disposal facilities

Local governments are usually charged with the responsibility for waste collection and transportation to the disposal facilities, but they may choose to hire private contractors. The functional elements that MSWM involves are waste generation, separation and storage at source, collection, sorting, processing and transformation, and disposal (Tchobanoglous et al. 1993). According to Tchobanoglous et al. (1993), the collection can be decomposed into three operations:

- Deposition, which consists of the set of operations after waste generation, involving waste storage and placement in containers to be removed
- The transfer operation carried out by appropriate personnel and equipment for this purpose, by transferring the waste to the collection vehicles
- The transport, which corresponds to the distance that the collection vehicle makes between the last point of collection and the place of its destination

Fig. 3.1 Waste collection system diagram



Upstream of the collection is the waste generation and separation at the source and downstream is transfer and transport, treatment or deposition. The selective collection is not independent of the method of treatment. In fact, in MSW management process, the collection of recyclable materials is of critical importance as the way in which the materials are collected determines the possible options for their recovery and the need for more or less investment in the sorting processes.

Based on the system perspective, a waste collection system (WCS) is composed of the component containers and vehicles, which are interdependent and where interactions occur, forming a relative complex whole. The way how elements interact with each other and with the background system, composed of the waste producers (citizens) and city's infrastructure, will dictate its efficiency and the interaction with city mobility. A WCS has to be attractive, available, near, and safe for citizens to use it. Because WCS involves traffic movement, their schedule needs to be planned to promote its rapid collection and avoid periods of high traffic. Also, the place where to locate containers is influenced by the existing city infrastructure and sidewalk and street inclination, just to name a few. The diagram presented in Fig. 3.1 intends to highlight the complexity.

3.2 Waste Collection System Classification

During the last decades, a broad spectrum of suitable measures and different types of technical solutions for different types of problems and wastes could be developed and realized in technically leading countries (Bilitewski et al. 2010). The need to ensure mandatory recycling and recovery levels for different waste fractions introduced much pressure on waste municipalities systems, forcing them to optimize technical solutions for collection. High recovery rate targets have been set for MSW that municipalities aim to reach mainly by source separation, but the extent to which policies are based on scientific knowledge has been questioned (Dahlén and Lagerkvist 2010).

WCS is a relevant component of a waste management system, being implemented all over the world, but has been classified in a disorganized and dissimilar way. Container and vehicle diversity is quite vast, almost tailor-made for all situations and requirements, so keeping track on their development has become hard. The complexity of equipment, devices, and vehicles increased the difficulty in making a decision on which MSW collection should be implemented to be technically competent, economically affordable, and socially accepted, at the same time, complying with all legal targets and environmental challenges.

The evaluation of collection systems depends on the system boundaries and will always, to some degree, be site-specific. It may not even be desirable to control the factors that cannot be controlled using waste management, but these factors should still be understood as they may offer explanations of variations. One of the factors that can be controlled using waste management is the equipment and technical solutions adopted, but the complexity is high and needs to be reduced to critical factors when searching for causes and effects.

3.2.1 State of the Art

WCS classification has been promoted since the 1990s. Several aspects which could characterize the complex system depend on its components (container and vehicles), how both are interrelated (the collection method), how waste is to be treated and recovered (waste streams), and how WCS is located in the city (i.e., the type of service). According to Bilitewski et al. (2010), a WCS can be defined as a combination of technology and human activities and characterized by (i) the receptacles used for collection, (ii) the applied method of setting them out and picking them up, and (iii) the collection vehicles. The main approaches on WCS classification are going to be presented in this section, divided into container type, vehicle type, collection method, waste streams, and type of service.

(a) Container Type

Container type is referent to the receptacle where waste is disposed temporarily. The variety of containers is quite huge. However, existing classifications found in the literature are characterized mainly by the type (bags, containers, barrels, wheeled, underground), material (plastic, metal), and size (small, medium, large). An instinctive relation exists between container type and its size, being bags and containers without wheels the small-sized containers and wheeled and underground containers the ones with larger dimension. For example, EN840 and EN 12574 family of norms (CEN 2014) classifies containers as two-wheeled with capacity up to 400 L, four-wheeled with a capacity up to 1300 L with flat or dome lid(s), and four-wheeled with a capacity up to 1700 L.

(b) Vehicle Type

The vehicle has the function to discharge the waste container into the vehicle where waste will be transported (Diaz et al. 2005). It can be characterized by the type, which considers collection method, compaction, loading mechanization container lifting device, and by the loading site. Possible vehicle types by collection method are hauled and stationary. By compaction a vehicle can be classified as a compactor (compartmented or not) when waste is compressed, or non-compactor (open or closed truck), and by lifting device vehicles can be classified has hoist truck or lift-off, tilt frame or roll-off, hook lift, crane trucks, trucks with loader up/over, or side loader. Loading site identifies vehicles as front/top, side, and rear.

(c) Collection Method

The collection method is related to the process of emptying the container and its mechanization. Concerning the emptying process, the collection can have different designations. The recipient can be emptied in the same place, being named simple emptying or stationary, can be exchanged by another emptied container, being named as exchange, or can be hauled into the destination, being named hauled or one-way. Only the case of the stationary collection is possible to consider a manual loading system; all the rest is mechanized. Concerning mechanization designations, manual, mechanized, semiautomatic, or automatic special collection systems are all used in literature.

(d) Waste Source and Source Separation

This criterion is related to the source of waste (the place where it is produced) and the source separation considered in the area. Waste source is divided into residential/household, commercial/household-like commercial, and institutional and industrial, being residential divided into dwellings and apartments, mostly. When source separation exists, WCS can be defined by the waste collected, as commingled, residual waste, dry recyclables, and recyclables, just to name a few.

(e) Type of Service: Drop-Off or Pickup Systems

Concerning the service type, different designations exist which are related to the type of waste collected (commingled or separate waste streams) and how the citizen interacts with the WCS. For mixed/commingled waste, the service can be classified as curbside, backyard, alley, setout, and setback and for waste stream designations as a drop-off/bring centers, buyback centers, pickup systems, neighborhood containers, zone containers, green points, and multi-container and special collection (Table 3.1).

Although there is diversity of designations, two main approaches can be adopted:

(i) Pickup system or curbside collection, where the receptacles are installed/set up for collection close to the houses of the waste generators.
(ii) Drop-off or bring systems, where accumulated waste amounts are taken by the waste generator to a central location, being dropped into containers specially set up for this purpose. Contrary to the pickup arrangement, the collection vehicles must go to central sites only and not pick up the waste from the curbside in front of each house (Fig. 3.2).

Table 3.1 WCS service type categories and definitions

Service type	Definition
Door-to-door, full-service collection, curbside, alley pickup, or household containers	Containers like bins, racks, sacks, and bags are allocated to individual families, very near to the source of waste generation, where the homeowner is responsible for placing the containers to be emptied at the curb on collection day and for returning the empty containers to their storage location (Dahlén and Lagerkvist 2010; Gonzalez-Torre et al. 2003; Tchobanoglous et al. 1993)
Setout-setback	Containers are set out on the homeowner's property and set back after being emptied by additional crews working in conjunction with the collection crew responsible for loading the collection vehicle (Tchobanoglous et al. 1993)
Backyard carry	The collection crews enter the property to collect refuse. Containers may be transported to the truck, emptied, and returned to their original storage location or emptied into a tub or cart and transported to the vehicle so that only one trip is required (O'Leary 1999)
"Just-in-time" collection	Residents bring out their wastes at the time the collection vehicle reaches a particular spot and rings a bell, a system that works in middle- and upper-class housing of many developing countries (Uriarte 2008)
Drop-off systems or bring systems	It provides containers of different sizes and shapes, and residents are required to deliver recyclables (Dahlén and Lagerkvist 2010; Rhyner et al. 1995)
Multi-container	Citizens dispose each fraction in specific containers located in two areas of the street: organic and residual fraction containers are located on the curb at a maximum distance of 50 m from the dwellings; containers for glass, paper, and packaging are located in areas with groups of containers located at a maximum distance of 300 m from the dwellings (Iriarte et al. 2009)
Neighborhood containers	Individual families are responsible for delivering their waste to a typical container or neighborhood garbage bin near the source of waste generation (Gonzalez-Torre et al. 2003)
Zone containers	Large bins for different waste types are located in central areas that serve one or multiple neighborhoods (Gonzalez-Torre et al. 2003)
Green points	Specifically designed to collect not only separated items from the particular catchment areas and curbside bins but also to selectively collect materials not covered by the other systems, such as hazardous waste, household electrical appliances, and clothes (Gonzalez-Torre et al. 2003)
Buyback centers	Establishments where participants can deliver materials in return for cash payment, such as for recyclable collection (Rhyner et al. 1995)

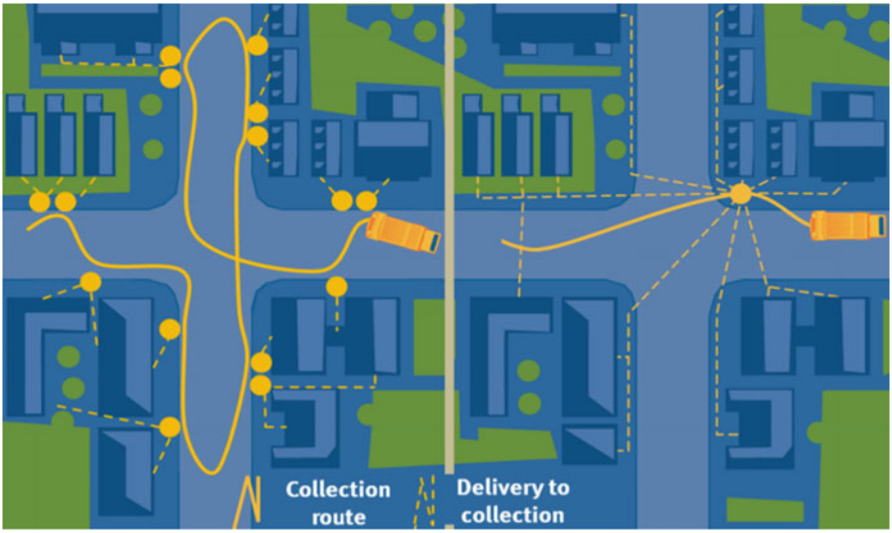


Fig. 3.2 Schematic drawing of pickup and drop-off arrangement for waste collection. (Source: Bilitewski et al. (2018))

Excluding the container and vehicle type, these classifications have a quite low contribution to distinguishing the several WCS, being unable to promote a robust classification. Taxonomy to classify WCS should show the similarities and differences between WCS and its components, and users should be able to systematically fill and recall information efficiently and effectively to facilitate the use of the taxonomy by diverse scientific and research fields.

The technical details (the features) have implications for planning and operating WCS. Once known and adequately addressed, the features can mitigate WCS costs and environmental impacts. In modeling WCS, parameters such as time per stop (Groot et al. 2014; Sonesson 2000), unload time of a bin (Faccio et al. 2011), and the number of workers (Groot et al. 2014) are all needed.

A taxonomic classification based on the technological features relevant to classify WCS is proposed in the next section. The features highlighted in the taxonomy, such as the container's vehicle coupling, mobility, emplacement, container access for container and body mechanization, lifting mechanization, and loading location for vehicles, influence those variables present in WCS models.

3.2.2 *Waste Collection System Types*

This taxonomy is divided into three components, container, vehicle, and collection method, and classes and subclasses, which are capable of characterizing the container-vehicle system presented in Fig. 3.3. Trees are used to describe the classes and subclasses of each component. Identification of a feature can reach up to five levels,

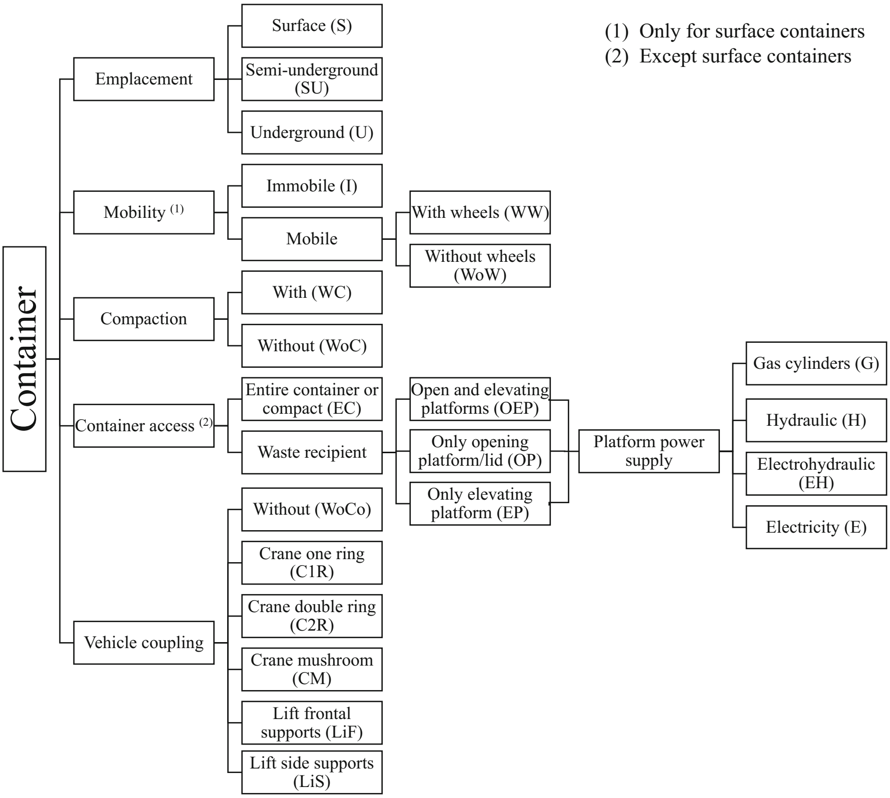


Fig. 3.3 Container classification diagram. (Source: Rodrigues et al. (2016))

and key components will be described to support the taxonomy. The three components result in a nomenclature, to be applied to characterize WCS.

Container Component

Class 1 is the container, and the first-level branch of its classification tree (Fig. 3.4) is divided into relevant technical aspects used to identify container component, identified by subclasses: emplacement (1.1), mobility (1.2), compaction (1.3), container access (1.4), and vehicle coupling (1.5). Container emplacement refers to location related to ground level. Containers can be positioned at the surface (100% of the recipient's capacity is at ground level), entirely underground, or semiunderground. A specific property of surface containers is mobility. Underground and semiunderground are static and must be accessed by the vehicle for waste collection, whereas surface containers can be located and replaced on the street without specific construction work and are easily carried to the collection vehicle. Mobility can be a)

b)

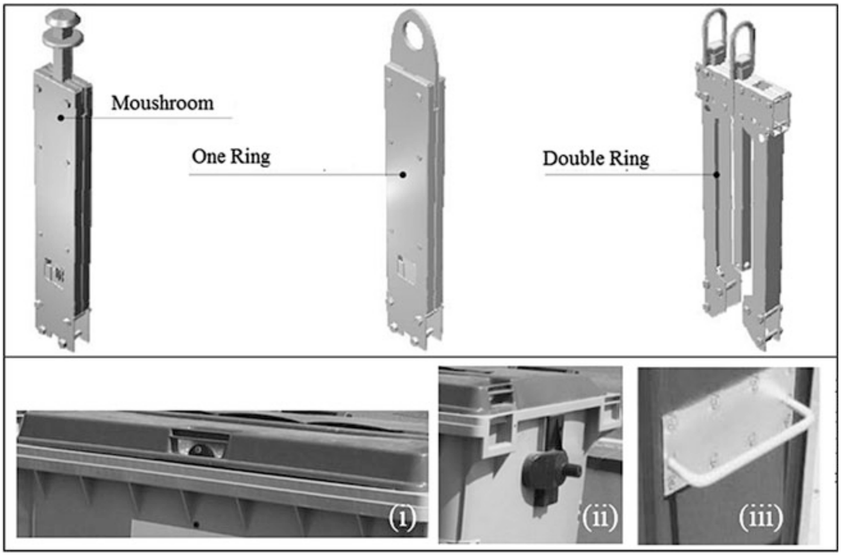


Fig. 3.4 Coupling systems' schematic illustrations. (**a**) Crane coupling systems (OVO Solutions 2012a) and (**b**) lift coupling systems in (i) frontal comb, (ii) HDPE lifting trunnions, and (iii) metallic wings. (Source: Rodrigues et al. (2016))

divided into immobile and mobile containers, with or without wheels. Containers can also be designed to compact waste.

Semiunderground and underground containers must be accessible to the waste collection vehicle. It is not mandatory that all container elements such as platforms, deposition columns, and waste recipients are removed as a unit to dispose waste into the vehicle (compact container). Sometimes only the waste recipient element is removed to be discharged, and vehicle access can be through an open platform, elevated platform, or both. An open platform corresponds to the opening of the surface pull-down lid to access the container; the vehicle pulls the container from its underground location, and the elevating platform raises the container to surface level. When there is no elevating platform, the vehicle itself pulls the container from the underground receptacle. An additional feature characterizing existing platforms is the platform power supply, which can be gas cylinders, hydraulic, or electrohydraulic.

Vehicle coupling defines how the container interacts with the vehicle to promote container discharging. The existing options are absence of coupling system or by the type of coupling system: crane rings, crane mushroom, and crane supports. Rings and mushroom refer to a crane option in the vehicle, and supports are related to the lift option in the vehicle. Crane coupling can be one ring, double ring, or mushroom (Contenur 2014; OVO Solutions 2012b) (Fig. 3.4a). One ring coupling is suitable for truck cranes with a simple forklift, known as simple hook, where the ring is secured on the frame support and detaches the lower lid, which is automatically opened when the pedal (also named *palpeur* system) touches the

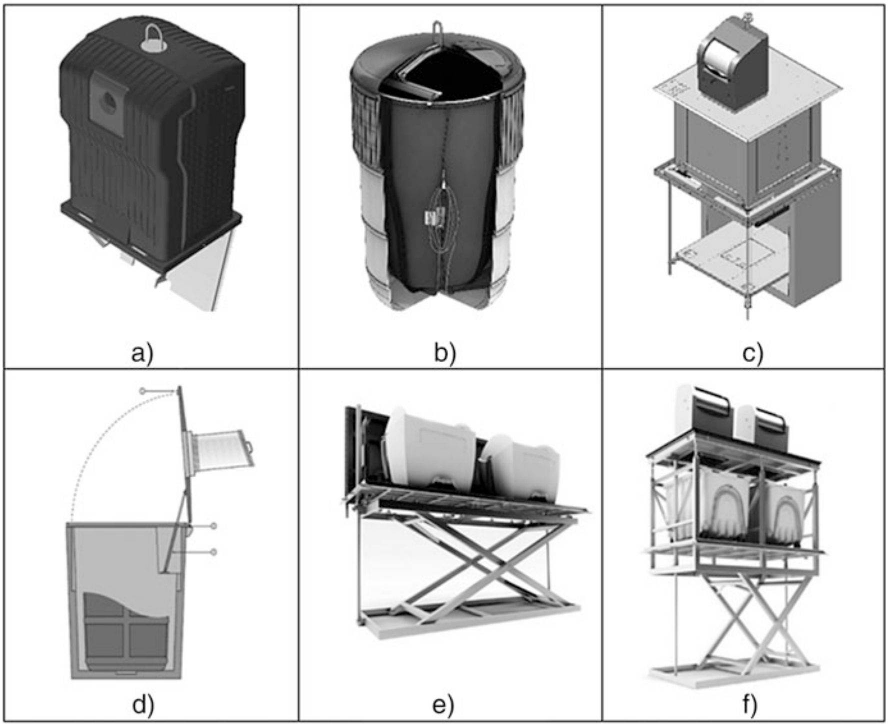


Fig. 3.5 Container schematic illustrations. (**a**) Case 4 (OVO Solutions 2012b), (**b**) case 5 (Sopsa 2012), (**c**) case 6 (OVO Solutions 2012a), (**d**) case 7 (Sotkon 2007), (**e**) case 8 (TNL 2014b), and (**f**) case 9 (TNL 2014c). (Source: Rodrigues et al. (2016))

bottom of the loading truck (OVO Solutions 2012b). The double-ring operation is secured by two sliding rods, and the lifting arm has a double command; one raises the container and opens the lower lid, and the other one keeps the container at the desired height (OVO Solutions 2012b). Mushroom containers, also known as double disc and by the trademark *Kinshofer*, consist of a half sphere or "disc" on the top; the hoisting cable is also equipped with a double command similar to double ring, and the operation is ensured by two tubes sliding one inside the other. This system requires that collection vehicles are equipped with controlled and high-precision positioning and coupling devices, eliminating the need for manual engagement (Kinshofer 2014).

The containers for lift coupling supports have handles or handgrips built into the container body (according to EN 840 (CEN 2014)) with different designations, depending on the lift side (Fig. 3.4b). For frontal handles, a ventral system consists of a frontal comb integrated with the upper body of the container. For side supports, lifting trunnions or points are secured to the upper sides of the container body by two high-density polyethylene (HDPE) lateral pivots and *Ochsner* handles composed of two metal lateral wings (Sulo 2014; Weber 2006). Crane-compatible containers are bottom discharge containers with a trapdoor(s) or cable opening bags; liftcompatible containers have superior discharge capabilities by lid opening and overturning.

Based on the developed classification, ten possible key container component cases describe how the taxonomy works and exemplifies the components of the container to be analyzed (Fig. 3.5):

Case 1. Surface, without wheels, without compaction, vehicle coupling
Case 2. Surface, with wheels, without compaction, lift vehicle coupling
Case 3. Surface, immobile, without compaction, lift vehicle coupling
Case 4. Surface, immobile, without compaction, crane vehicle coupling
Case 5. Semiunderground, without compaction, compact, crane vehicle coupling
Case 6. Underground, without compaction, compact, crane vehicle coupling
Case 7. Underground, without compaction, with opening platform, crane vehicle coupling
Case 8. Underground, without compaction, with open and elevating platform container access, lift vehicle coupling
Case 9. Underground, without compaction, with elevating platform container access, lift vehicle coupling
Case 10. Underground, with compaction, with the open and elevating platform, hook lift vehicle coupling

Case 1 containers are characterized by semitransparent plastic or paper bags or non-wheeled bins, usually with two handles, a cover, and no vehicle lifting handles and with a wide range of capacities, from 0.035 up to 0.11 m^3 (Bilitewski et al. 1997; ISWAWGCTT 2004). Ordinary grocery bags or biodegradable bags for organic waste collection can also be used. Because they have no coupling system with the collection vehicle, all the effort in lifting and disposing is by manual workers.

Case 2 containers include mobile garbage containers with two or four wheels. The generic capacity of these containers goes from 0.12 to 1.1 m^3 (Bilitewski et al. 1997; Kogler 2007) although two-wheeled can start at 0.06 and go up to 0.36 and four-wheeled between 0.66 and 1.1 m^3 (Sulo 2014; Weber 2006). Lift vehicle coupling containers have side and frontal handles and a flat or tilt-curved lid and may have a lid opening system with a pedal or deposition opening adapted to the waste stream (Contenur 2014; Sulo 2014; Weber 2006).

Case 3 steel or HDPE containers were developed for side-loading automated lifts, with a vertical alignment crosshair and four Teflon roller supports at the base of the body instead of wheels. They have an opening lid, or deposition opening adapted to the waste stream. Capacities range between 1.8 and 3.2 m^3 (Contenur 2014; Ros Roca 2014).

Case 4 containers were designed for source-separated collection with a crane and had two main designs: igloo and prismatic (Contenur 2014). Container openings are located on the top, with specific designs for packaging waste type. A container frame attaches the securing system directly to the metal base and to the lower lid using support arms, rods, or clevis fasteners (OVO Solutions 2012b). Capacities range between 2.5 and 3.2 m^3 (Contenur 2014; OVO Solutions 2012b).

Case 5 refers to semiunderground, compact, one-ring crane coupling containers composed of two parts: (1) the outer shell in HDPE and (2) an interior polypropylene bag where the waste is placed, fixed at the top of the container using a metal ring, and opened by the action of a cable to discharge. Other possible options are a rigid plastic container instead of the flexible bag (Molok 2009; Sopsa 2012) or a concrete monobloc wheel in place of the HPDE outer shell (Sopsa 2012). These cylindrical-shaped containers have a capacity range from 0.3 to 5 m^3, being 3 and 5 m^3 as the most common for municipal waste (Molok 2009).

Case 6 refers to the underground, entire/compact containers for crane vehicle coupling, installed inside an underground watertight concrete bunker with a fixed pedestrian platform in galvanized steel (Contenur 2014; OVO Solutions 2012b). At surface level, only the inlet structure (column) and pedestrian platform are visible. These containers are called compact containers because the column, container, and pedestrian platform are a unit removed together. The stainless steel container is emptied by one or more opening flaps underneath, designed to collect liquid. Capacity ranges from 1 to 5 m^3 (OVO Solutions 2012b).

Case 7 consists of underground containers with opening platform access, with one ring crane vehicle coupling. Case 7 containers are distinguished from case 6 by container access because the only element hoisted is the waste recipient, not the compact container. Access to the waste recipient is ensured by the pedestrian platform, which opens (in contrast to case 6) and has a manual hook engagement to the ring container (Resolur 2013; Sotkon 2007). The platform power supply can be hydraulic, electrohydraulic, or gas cylinders (Sotkon 2007; TNL 2014a). Containers' capacity ranges from 1 to 5 m^3 (Resolur 2013; Sotkon 2007; TNL 2014a), which can be bottom discharged using a trapdoor located at the base or by overturning using both vehicle coupling options, crane and adapted rear lift.

Case 8 consists of underground containers with open and elevating platforms for container access and lift vehicle coupling, which stands on the platform and is elevated to the surface level rather than discharged by automated lifting and side-loading vehicles. Both platforms are powered by an electrohydraulic unit, activated inside the vehicle cabin using a remote control (Contenur 2014; Equinord 2009; TNL 2014b). Containers' capacity ranges from 3.2 to 4 m^3 (Contenur 2014; TNL 2014b).

Case 9 differs from case 8 in container access, in which case 9 is by an elevating platform only. With a capacity range from 0.8 to 1 m^3, the container is emptied by semiautomated lifting rear-end loading vehicles (Contenur 2014; TNL 2014c). The elevating platform is operated either by remote control console or independent central electrohydraulic or collection vehicle (Contenur 2014; Equinord 2009; TNL 2014c).

Case 10 consists of underground compaction containers with a top-loading chamber, with openings and elevating platforms and hook lift vehicle coupling. The elevating platform lifts the compacting container box up to the street level, and the opening platform rotates on the back axle to facilitate container access (TNL 2014d). Both platforms are powered by an electrohydraulic power station (TNL 2014d). A system on the compaction plate controls the container's filling rate, with capacities between 12 and 25 m^3 (Equinord 2009; Villiguer 2014).

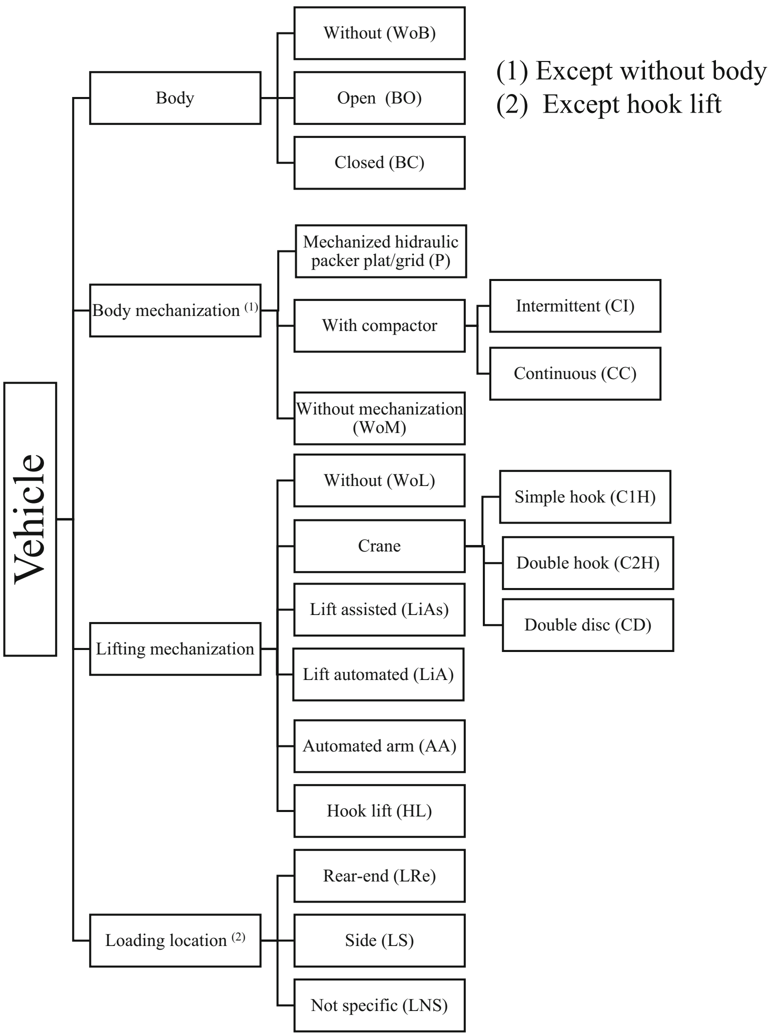


Fig. 3.6 Vehicle classification diagram. (Source: Rodrigues et al. (2016))

Vehicle Component

Vehicle class 2, presented in Fig. 3.6, is divided into subclass body (2.1), body mechanization (2.2), lifting mechanization (2.3), and loading location (2.4). The location waste determines if the body is discharged, which can be open, closed, or nonexistent, in which case the whole container is put into the vehicle, as occurs in the hauled collection. The open and closed body can be non-compartmented or compartmented to separately collect two or more types of waste at the same time (e.g., vertically split body, dual compartment), classified as multi-compartment or single compartment body, respectively. The body can be mechanized with different structures (body mechanization), such as a sweep plate, grid, or a compactor, which work continuously or intermittently. Also, lifting can be variously mechanized (lifting mechanization) with hooks, lifts (forks, bars, or both), hook lifts, and automated arms. Different lifting devices can be used in the same vehicle, classified using the corresponding taxonomic characteristics. All crane-based lifting devices can be interchangeable because they are non-fixed elements; using all in the same vehicle is possible. Available options for loading location include rear-end, side, and even nonspecific, as in the case of manual loading where the body is opened to dispose waste bags. The proposed taxonomy is presented in Fig. 3.6.

The literature analysis found ten key vehicle components representing all possible taxonomic components:

1. Body open, non-mechanized, crane lifting, not specific loading site
2. Body closed, mechanized packer plate/grid, lift assisted, rear-end loading site
3. Body closed, with intermittent compaction, lift assisted, rear-end loading site
4. Body closed, with intermittent compaction, crane lifting (and lift assisted), rear-end loading site
5. Without body, hook lift
6. Body closed, with intermittent compaction, crane lifting, not specific loading site
7. Body closed, with intermittent compaction, lift assisted, side-loading site
8. Body closed, with continuous compaction, lift assisted, rear-end loading site
9. Body closed, with intermittent compaction, lift automated, side-loading site
10. Body closed, with intermittent compaction, arm automated, side-loading site

Case 1 vehicles (Fig. 3.7a) are composed of an open box body and a hydraulic crane, which can be manually operated from the crane footboard, on the floor, or remotely. Different coupling systems can be installed on the crane, depending on compatibility with different container crane vehicle coupling types.

Case 2 vehicles, also called as satellite units, are composed of a rear-loading forklift mechanism and a simple hydraulic sweep plate or grid that clears the rear of the hopper to provide load security and distribution inside the load box but provides no compaction or semi-compaction (Heil Farid 2014; Ros Roca 2014).

Case 3 vehicles are composed of a hydraulically powered compression/ejection plate, a load box, an articulated sweep plate, and a rear tailgate with a large hopper capacity and a lifting mechanism (Ecofar 2013). Front or lateral support coupling containers are raised by a loading fork that hooks onto the front of the container or by retractable lift bars (Bilitewski et al. 1997), respectively. A moving plate scoops the waste out from the loading hopper and compresses it against a moving wall (intermittent compaction), with a leachate tank at the bottom of the body. With the body full of waste, the compaction wall moves and ejects waste through an open tailgate.

Case 4 vehicles (Fig. 3.7b) are similar to case 3 but have a telescopic crane, an enlarged loading hopper, and a tailgate with a higher load volume to receive big underground waste containers (Ros Roca 2014; Soma 2014) or discharge from

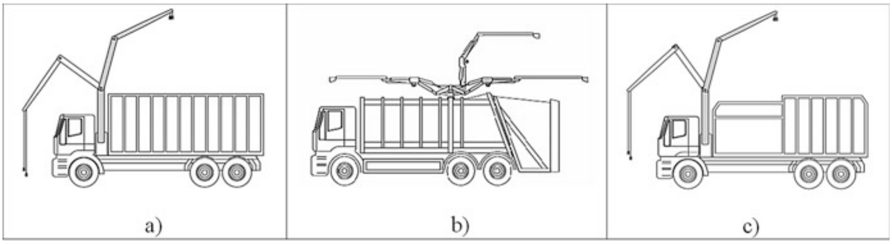


Fig. 3.7 Vehicle schematic illustrations. (**a**) Case 1 (Sotkon 2007), (**b**) case 4 (Sotkon 2007), and (**c**) case 6 (Sotkon 2007). (Source: Rodrigues et al. (2016))

satellite vehicles. Containers are collected with the crane or with both crane and adapted rear lift (Soma 2014).

Case 5 vehicles are designated as hook lift or container vehicles, mostly used to collect high-volume containers. Underground compactor containers (container case 10) are lifted over the collection vehicle chassis with a hook lift system. These demountable body handling technology vehicles are known by trademarks such as "Ampliroll" and "Multilift."

Case 6 vehicles (Fig. 3.7c) are composed of a self-contained waste compaction mobile unit with a top-loading compacting chamber, where waste is unloaded and compacted. The container body is fed by a longitudinal sliding drawer in the compacting chamber through bottom tabs and unloaded by the tailgate, hydraulic, or gravity-opened doors (Mofil 2014). A hydraulic crane collects containers.

Case 7 vehicles are side-loading vehicles with ejection plates, also called satellite vehicles because a transfer system transfers the payload to a full-size rear loader (Ecofar 2013; Heil 2014). These vehicles are a one-piece body construction in which the waste processing and unloading are carried out by the hydraulic ejection panel (Ecofar 2013). These vehicles may have single- or dual-side hopper doors for manual loading operation or a side lift with a loading fork (Ecofar 2013; Heil 2014).

Case 8 vehicles are for continuous compaction, differentiated from case 3 by the compaction system, which consists of a fixed compacting screw system in the rear and a spiral screw conveyor inside the cylindrical body drum that continuously mixes and compacts the entire load during collection (FAUN 2014).

In cases 9 and 10, the vehicles are automatic side lift or arm grabber, operated by the driver inside the vehicle, using a joystick and a video system (Heil 2014; Heil Farid 2014). The vehicle stops alongside the container, and the arm (single or double) grabs the container, empties it, and replaces it automatically (Kogler 2007). A continuously reciprocating metal pusher plate at the loading hopper forces the waste through an aperture into the main body, compacting against the material already loaded.

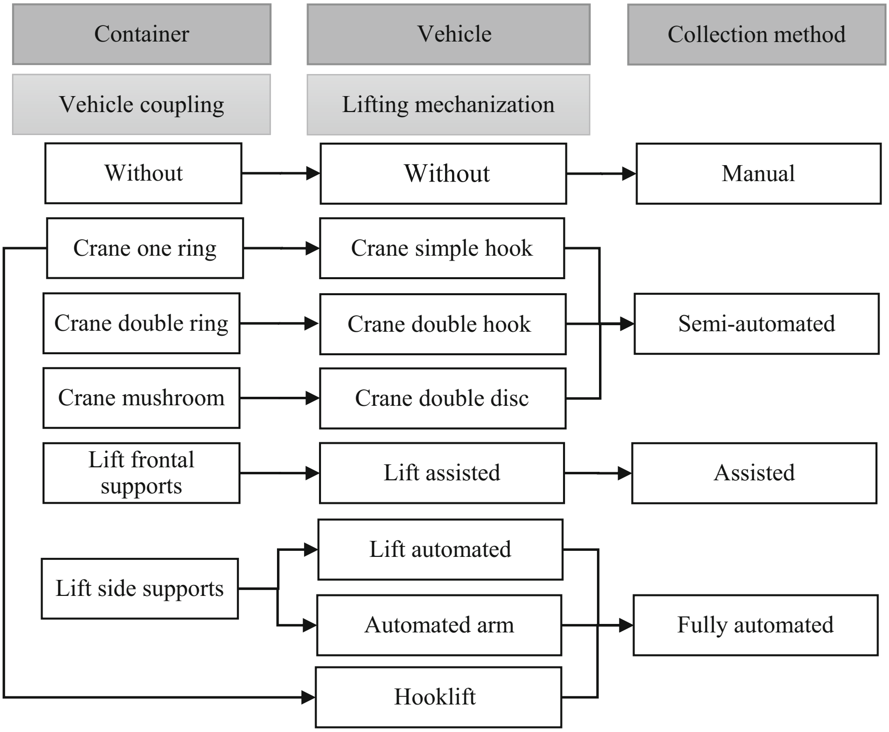


Fig. 3.8 Collection method classification diagram. (Source: Rodrigues et al. (2016))

Collection Method Component

Collection method categories describe how the container interacts with the vehicle and workforce. The collection method can be manual, assisted, semiautomated, and fully automated. Manual collection occurs when the worker carries, lifts, and unloads waste bins or bags into the vehicle. Assisted collection is a mix of manual and mechanical processes in which the container displacement near the vehicle is manual and mechanization occurs only in the lifting and emptying by the vehicle. Semiautomated collection is a mechanized process of all steps involved in collection procedure, but the worker must be outside the vehicle to control the coupling and provide manual assistance on vehicle-container coupling and uncoupling. Fully automated collection involves no direct intervention of workers, and the container-vehicle interaction is controlled by a single operator inside the vehicle cabin.

A relation between container and vehicle components is needed to classify WCS by collection methods. Because collection methods are related to mechanization and provide a link between container and vehicle, the features to be addressed are container-vehicle coupling and vehicle lifting mechanization (Fig. 3.8).

Key Collection Methods

The key container and vehicle components can characterize the four key collection methods. Manual collection occurs for containers classified as surface, without wheels, and without vehicle coupling (e.g., bags and bins without wheels) and collected by vehicles classified as open body, non-mechanized body, without lifting or specific loading tools, or closed body, with intermittent compaction and lifting mechanization, which is not used.

In the assisted collection method, wheeled mobile surface containers with lift vehicle coupling frontal or lateral supports are rolled by the workers to the collection vehicle, which can have an intermittent or continuous compactor, semiautomated lifting, and a rear, frontal, or side-loading location. Three or more workers are usually needed for assisted and manual collection.

Semiautomated collection methods can use underground containers with platform access and crane vehicle coupling, collected by vehicles with the closed or open body or an intermittent compactor or non-mechanized body with a hook lifting or double-disc rear loading or nonspecific location. Two workers (driver and crane operator) are usually sufficient, although a single operator can control the double-disc system.

Fully automated collection methods have no direct intervention of workers because the driver inside the vehicle operates all collection processes. An example is a surface container without wheels, with side supports, collected by a closed-body vehicle with intermittent compaction and automated lifting and side loading. Fully or semiautomated collection methods are also characterized by a relatively higher container capacity than assisted or manual collection methods, which are workforce dependent.

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