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Digital Transformation of Solid Waste Management

Waste Collection Innovation, Business Intelligence, and Digital Technologies to Transition Waste Management Towards Circularity in Latin America and the Caribbean

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Inter-American Development Bank

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SOURCE OF INNOVATION

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Abbreviations and Acronyms

AI	Artificial Intelligence
BC	Body Controller
BI	Business Intelligence
DTC	Diagnostic Trouble Codes
EV	Electric Vehicle
USEPA	United States Environmental Protection Agency
ERP	Enterprise Resource Planning
EC	European Commission
GIS	Geographic Information System
GPS	Global Positioning Systems
GHG	Green House Gas
IGIS	Integrated Geographic Information Systems
IDB	Inter-American Development Bank
IoT	Internet of things
KPI	Key Performance Indicator
LAC	Latin America and the Caribbean
MIS	Management Information Systems
MRFs	Material Recovery Facilities
MSW	Municipal Solid Waste
NG	Natural Gas
NSWMA	National Solid Waste Management Authority
OLAP	Online Analytical Processing
RFID	Radio-frequency Identification
SWT	Smart Waste Technologies
SaaS	Software as a Service
SWM	Solid Waste Management

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Prologue

The circular economy is very much related to the Fourth Industrial Revolution, also known as Industry 4.0 or smart technology, and has a significant impact on the way we analyze and measure waste management. Nowadays, talking about recycling is just the "tip of the iceberg" of understanding the different cycles and flows of waste materials. Given that Latin America and the Caribbean (LAC) and many other regions are transitioning towards a circular economy, we must contemplate the reinsertion and flow of materials within the biological cycle for renewable resources, the technical cycle for finite materials, and the circulation of materials for reuse, repair, remanufacturing, and recycling.

The circular economy is a triple impact economic model that addresses sustainable economic growth, employment generation, and climate change. There is a positive correlation between this model and GDP growth (Chen y Pao, 2022), where an increase of between 5% and 10% is estimated in countries that adopt circular economy models (Elkins et al., 2019). In LAC, the shift towards circularity will generate an estimated 4. 8 million jobs by 2030 (UNEP, 2023). Waste is the third largest anthropogenic source of methane, and improved waste management policies, such as separation, recycling, and composting, have the potential to slash total waste sector emissions by 84%.[1] Nevertheless, the transition towards circularity brings greater challenges for solid waste management systems in LAC, especially related to generating reliable and real-time data and the traceability of material flows. These aspects have become drivers for creating new policies and monitoring circular economy goals set at the local and national levels. Hence, the significant growth in the importance of the sector's digitalization.

As populations and economies expand, the global production of goods and services increases, which in turn leads the demand for renewable and finite materials to grow, and thus, increases solid waste outputs. In fact, the increased amount of waste production and its mismanagement is related to what's known as "the triple planetary crisis", one the three main interlinked issues that humanity must face: climate change, pollution, and biodiversity loss, as outlined by the United Nations.

According to the IDB's Solid Waste and Circular Economy Hub, the LAC region generated approximately 230.47 million tons of municipal solid waste (MSW) in 2021, an average of 361 kg per person per year. In LAC, 46.06% of MSW ends up in sanitary landfills, 25.57% ends up in unauthorized final disposal sites, 15.25% of MSW is not collected, 8.72% has an unknown destination, and a mere 4.39% enter recovery systems (Alarcón et al., 2023b). The LAC region struggles with several challenges in terms of MSW collection, treatment, recovery/valorization, and final disposal, aside from a growing vulnerability due to the continuingly increasing trend of waste generation, due not only to its growing population, but also its rapid urbanization and imminent industrialization. The region must have adequate waste management services with reliable data collection and analytical systems that can encourage better decision-making and policy design for a more efficient and timely transition to a circular economy.

In recent years, several technological tools have been developed and put into operation to improve the efficiency of solid waste management worldwide, such as the Internet of Things (IoT), Artificial Intelligence (AI), and cloud computing. These mechanisms are now key for generating and analyzing data for better decision-making and improved service provision in solid waste management (SWM).

[1] See https://www.no-burn.org/zerowaste-zero-emissions

The transition to a circular economy goes hand in hand with the generation, use, and dissemination of reliable statistics on production, consumption, waste management, and resource use. Thus, there is a growing need for comprehensive, reliable, and up-to-date data on material flows in the LAC region. Along these lines, the IDB has been working on developing tools that allow reliable data to be generated through the Solid Waste and Circular Economy Hub, and promoting technological and digital innovation to improve the provision of waste management services, data collection and analysis through the *Source of Innovation*[2] alliance.

Early digitization and innovation in the sector are a priority for the solid waste management agenda, specifically within the framework of the IDB's water, sanitation and waste guidelines. Therefore, this technical document identifies key trends in technological and digital innovation in municipal SWM, and thus contributes to the dissemination of information for better decision-making in the transition toward digitization and circularity within the LAC region.

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Chief of the Water and Sanitation Division
Inter-American Development Bank

[2] Source of Innovation is an alliance of the IDB Group with external partners to promote the development and adoption of innovative solutions in the water, sanitation, and solid waste sectors to achieve smart, inclusive, and sustainable services, with a focus on service providers in Latin America and the Caribbean. Source of Innovation is funded by the Government of Switzerland, through its Secretariat of State for Economic Affairs (SECO), the FEMSA Foundation, the Republic of Korea, through its Ministry of the Environment, The Coca-Cola Foundation, the Government of Spain, through its Ministry of Economy, Trade and Business (MINECO), and the Government of Israel, through its Ministry of Finance. The alliance is also complemented by direct contributions from IDB Lab and the Water and Sanitation Division of the IDB, and coordinates directly with the Aquafund, the fund created with IDB capital and to which a wide range of public and private sector partners contribute.

Executive Summary

This publication discusses the digital transformation of solid waste management (SWM), with a focus on the use of technological tools to improve efficiency and cost-effectiveness. It covers various tools, such as Business Intelligence (BI), Enterprise Resource Planning (ERP), Customer Management Systems, and Fleet Management Software, and their applications in SWM, and highlights the benefits of digital transformation, including improved data collection and analysis, better decision-making, and increased operational efficiency. The document also provides examples and case studies involving implementation of these tools in different countries, including Argentina, Colombia, Ecuador, and Barbados. The publication emphasizes the use of digital technologies within waste management service providers, analyzing their impacts on service efficiency, institutional digital maturity, and enabling tools for a sustainable transition towards digitalization and its impact in a circular economy model. Information is presented in the following chapters.

Smart waste technologies: Key concepts

Digital technologies used in the solid waste sector are commonly referred to as Smart Waste Technologies (SWT). This chapter aims to describe the main concepts and technological innovations within SWT in different stages of Municipal Solid Waste (MSW) management and their potential contribution toward digitalization of the sector and approach towards a circular economy model. The basic concepts about SWT are presented and how these technological tools have impacted the SWM chain, especially related to the use of AI, IoT, cloud computing, data analysis, robotics, and computer technologies. Examples of SWT are given in each of the stages of the waste management chain.

Table 1. Main digital technologies used in waste management

Digital Technology	Brief description of its use in waste management
Communication Technologies	Facilitate communication processes between relevant stakeholders as service providers, auditing entities, final customers of waste management services, among others. Examples: Web pages, mobile applications, social networks, etc.
Internet of Things (IoT)	Tendency that more and more devices connect to the internet or other networks even though the primary purpose of these devices is not to connect (Berg et al., 2020) Examples: Sensors for intelligent containers, weight measurement systems, temperature sensors, geo-referencing of equipment and machinery, QR codes, NFC tags, GPS, RFID, etc.
Data analytics	The task of processing and analyzing data to identify patterns, trends, model calibration, among others (Berg et al., 2020). Examples: Data analysis for the recycling industry (trend detection, model calibration, control in energy recovery plants, etc.).
Cloud computing	Model that allows access to the network on- demand, anytime, anywhere to a shared pool of configurable computing resources, storage systems, applications and services, servers, or networks (Berg et al., 2020). Examples: Container management, real-time operations management, collection route planning, collection vehicle lifespan, etc.
Artificial Intelligence	Intelligent system that solves problems independently and efficiently. A highly used approach in waste management is machine learning using neural networks, based on the use of data or examples to solve problems without explicit programming (Berg et.al., 2020). Examples: Image recognition, forecasts of waste generation patterns, optimization of waste collection routes, predictions of bin level status/ biogas generation/ leachate formation, autonomous vehicles, identification of illegal dumps, among others.
Robotics	Machines that have different options for action in an autonomous way. Examples: Robots with the ability to identify and sort waste, robots that operate collection trucks, mechanical sweepers that operate autonomously.

Source: Authors' elaboration (2023).

Business Intelligence Tools

Business intelligence (BI) tools are types of application software that collect and process large amounts of unstructured data from internal and external systems, analyze that data, and report the findings in simple and understandable dashboards and data visualizations. This chapter offers a brief description of BI tools available for waste management, as well as data types and sources for BI tools than can provide useful data analysis for waste management actors. Specific examples are provided on how BI tools can be used by service providers and regulatory agencies for better decision-making in the waste management sector.

Digital Technology Tools

This chapter provides a brief overview of the different types of software used for waste management, and describes how they help digitize, analyze, and make better decisions for waste management service stakeholders. Examples of software use in data collection and analysis for better management of services are included. Moreover, the chapter describes hardware trends among waste management service providers and how such trends improve service efficiency.

Tools and Innovative Practices for Solid Waste Collection

This chapter details some examples of new technologies and innovative practices for efficiency improvement, traceability, and service digitalization, describing digital technologies related to design of "smart routes," telematics for fleet maintenance, and personal safety. It also explores best practices in waste collection systems as guidance for service providers.

Case Studies

This chapter provides specific case studies in the use of digital technologies in waste management systems. The studies provide examples of "in house" digital tools designed by service providers, as well as SWT and BI tools in use in the LAC region. Practical examples are provided with the aim to empower waste management service providers on the road to digitalization of the sector.

Finally, this publication presents recommendations for the implementation of smart waste technologies in LAC.

1. Introduction

This publication aims to provide a review of innovative technologies and practices in MSW management, with a special focus on BI tools and digital technologies in solid waste collection services. Industry 4.0 has transformed the way we handle and manage waste and become essential in the transition toward the digitalization and circularity of the sector. Therefore, it is important to understand its potential contributions within waste management services worldwide, and especially in the LAC region.

In the journey toward circular economy, data collection and analysis is crucial, not only to establish the baseline and subsequent compliance goals to achieve circularity, but also for the design and implementation of public policies that suit the specific realities of each territory. Within this transition, digitalization of the waste management sector is necessary, as the traditional mechanisms for collecting information (e.g., hand filling and Excel tables) are becoming outdated due to the rapid change in consumption habits and waste generation worldwide. Technologies are now used to ensure a more efficient service provision and include such things as Global Positioning System (GPS) and Geographic Information Systems (GIS) for waste collection vehicles and location of containers, sensors to measure filling and status of containers, and data communication technologies for the transfer of information and data analysis, among others.

Digital technologies offer the promise of implementing more effective waste management systems, making them more transparent and more economical. These technologies also make them more resource-efficient, by enabling collection managers to better source the valuable material in the waste streams and establish more effective links to other sectors in a future circular economy. The main drivers of digitalization of the solid waste sector, and thus, implementation of digital technologies in LAC are:

i) Cost reductions from pressure to reduce operating costs and generate a differentiation from the competition.

ii) Meeting user expectations, as customers increasingly require real-time information.

iii) Transition to the circular economy, where circular designs of goods and services, and traceability of waste management are essential.

iv) Climate crisis, through the reduction of greenhouse gases within waste management processes by the optimization of collection routes and the prevention of waste generation.

v) Population growth and increased urbanization along with imminent industrialization in the region.

Yet this transition toward digitalization of the sector comes with different challenges for service providers, local and national governments, and communities in LAC, such as:

i) High implementation costs, especially related to the cost of technological devices, and the development and maintenance of these technologies.

ii) The need for digital literacy, that is, having a human team with adequate knowledge and training in the technologies, as well as users interested in the use of technologies.

iii) Concerns regarding cybersecurity, which requires having effective systems for data protection and information privacy.

iv) Adequate integrated solid waste management systems, that is, the respective infrastructure and standardization of processes, among others.

It is quite clear that digitalization in the sector will have a significant impact on decision-making for a dynamic transition to circularity, as data will be generated in an efficient, transparent, and more reliable manner, hence the importance of this technical publication for the waste management sector in LAC.

The information provided in this publication is presented as examples of digital technologies that are currently (until March 2024) operating in LAC. As technological innovation constantly evolves, new tools and technologies will likely be on display in the near future. All references provided in this publication are illustrative and have no commercial purpose or affiliation with the IDB.

2. Smart Waste Technologies: Key Concepts

According to the European Commission (EC), digital transformation is characterized as "a fusion of advanced technologies and the integration of physical and digital systems, the predominance of innovative business models and new processes, and the creation of smart products and services." The solid waste management (SWM) sector is in the early phase of development with respect to digital transformation and can benefit from the utilization of these technologies throughout its chain: cleaning, sweeping, collection, transportation, valorization, and final disposal. Digital technologies have become useful tools for service providers, hence the increasing use of Smart Waste Technologies (SWT), known as digital tools that make it possible to adapt the schemes and innovate in the collection and analysis of information, and contribute to the transition toward digitization of the sector.

Figure 1. Use of smart waste technologies in the waste management chain

Source: Authors' elaboration (2023).

2.1. Generation and Separation at Source

Communication technologies such as waste and recycling apps can be useful tools for connecting with final customers in terms of waste management service information (e.g., collection routes, location of containers, billing information, etc.) and educating customers with the objective of reducing waste generation and increasing waste recovery. Mobile applications and web pages can provide transparent and traceable mechanisms for customer inquiries and positively impact service provision efficiency.

Regarding waste recovery, over the past few years, there has been a substantial focus on increasing participation in residential curbside recycling programs and reducing the amount of non-recyclable items that are placed in recycling containers (SourceIntelligence, 2023). Local governments and waste recovery collection companies are using a variety of communications to educate residents about recycling, including email reminders, social media, and "oops tags." These communications often emphasize which materials should not be placed in a residential recycling container (e.g., plastic bags or batteries) to reduce contamination. The use of these types of communications frequently reduces the amount of non-recyclable materials placed in recycling containers. For example, Washington, DC experienced a 20% reduction in non-recyclables in 2018–19 (Fenston, 2021). Similarly, The Recycling Partnership reported a 40% reduction in contamination in several Ohio communities, which also increased the value of their recyclables by US$20 per ton (The Recycling Partnership, 2020).

In some parts of LAC, as in other developing nations, the informal sector performs recycling collection or identifies recyclables at disposal facilities. Some LAC countries are providing technical support as a way to formalize the informal sector, as well as encouraging it and citizens to use recycling apps and other tools to improve local recycling efforts. Some examples of these technologies are listed in the Annex.

The information generated can be used to send "push messages," create personalized invoicing, and establish a transparent communication system for customer service and among relevant stakeholders. There are some startups/enterprises in the LAC region that provide services such as those described in the Annex.

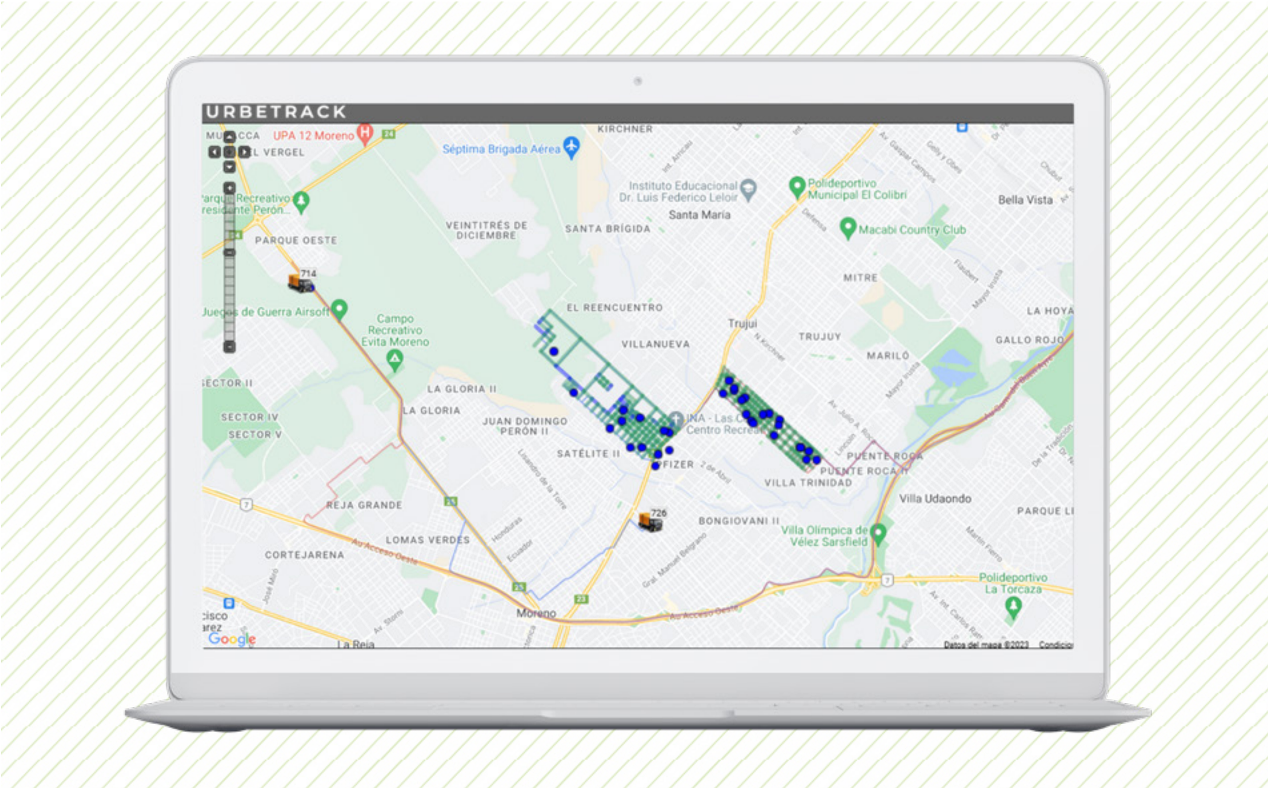
In addition, some solid waste collection service providers have websites, which are also technological tools where content regarding the proper way to separate solid waste can be viewed from smart phones. Likewise, the services provided by these companies can be consulted in real time, in the form of information on collection service schedules and frequencies, as well as service rates, and virtual customer service, among others.

2.2. Cleaning

Smart technologies contribute to more efficient systems and the optimization of resources, especially in cleaning activities[3] (manual and mechanical), and in the control of improper disposal of solid waste. For example, hardware (GPS) is installed in manual and mechanical sweeping equipment, street cleaning, maintenance of green areas and development of software (dashboard) as a tool for auditing and supervision for service providers. The use of mobile Apps is also a trend in cleaning service as tools for the digitalization of daily service, service provision reports, and customer service among others. An example is detailed in Chapter 6.

[3] Cleaning activities include street and public facility cleaning services such as street sweeping, litter basket service, litter collection from public facilities, public structure washing, green areas pruning, etc.

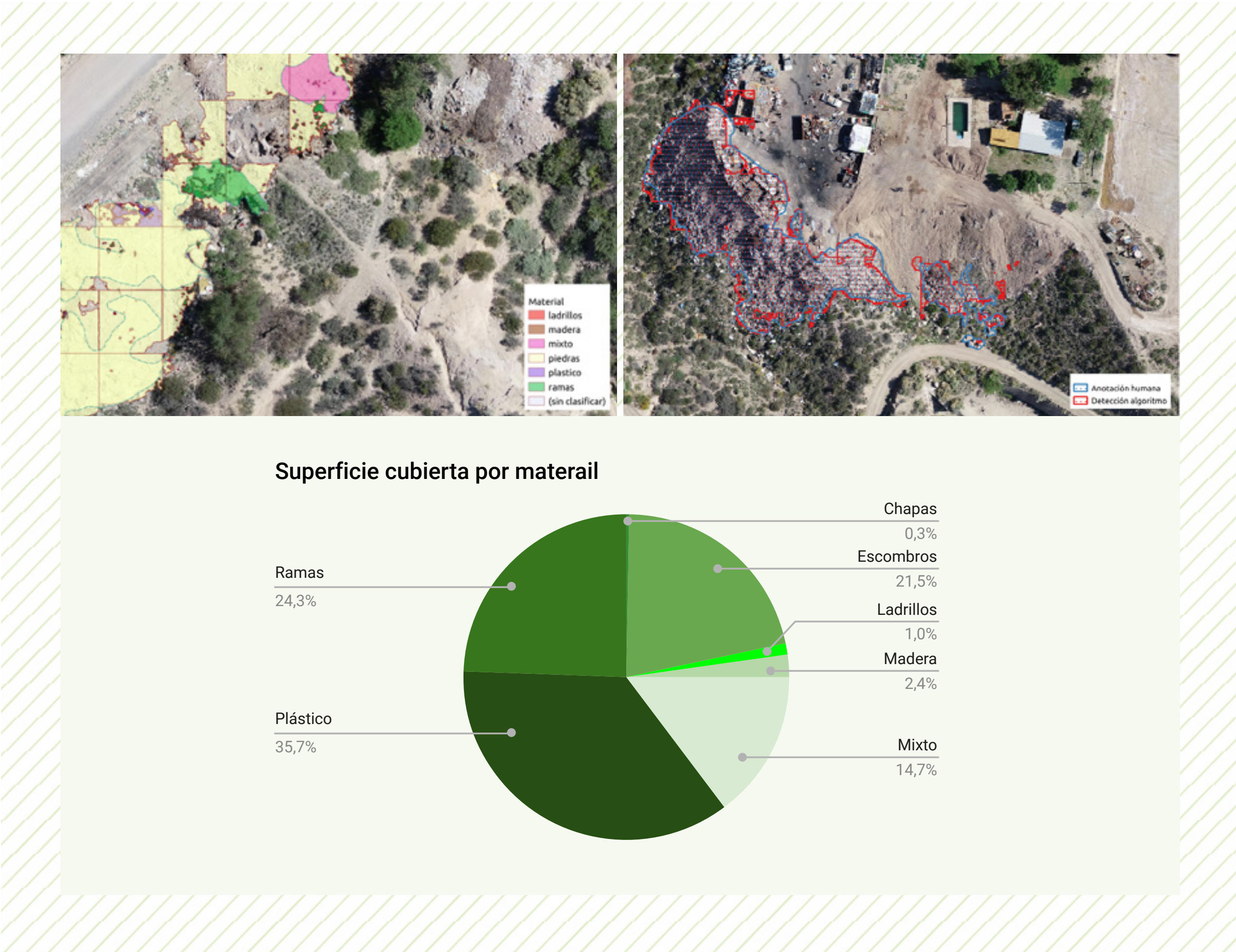
Figure 2. Use of smart waste technologies in public area cleaning, Argentina



Source: Source: Personal interview with Urbetrack Product Manager Gabriela Yael Spector, conducted by Paula Guerra, November 23, 2023.

Digital technologies, such as Artificial Intelligence (AI) are currently used to identify waste accumulation in urban areas and illegal dumping sites. Trained models have been designed for this purpose in Latin America, especially in Argentina, and are currently used by national and local governments, as well as in training sessions for municipal officers.

Figure 3. **Automatic detection of landfills and micro dumps, Argentina**



Source: Fundación Bunge y Born (2023).

2.3. Temporary Storage

SWTs are mainly used in "smart containers" for waste collection, where sensors can be used to measure weight and/or volume, and tools such as RFID chips or QR codes can be used to identify the location of the container, a common tool for Internet of Things (IoT) and the design and implementation of "smart collection routes." AI tools can be used to forecast waste generation, identify the type of waste disposed in containers, and trigger an "alarm" when materials other than the ones approved are disposed of. There are already some companies in the region that provide this type of primary information service (intelligent container system) for intelligent waste collection routes, and some of them are listed in the Annex.

2.4. Collection

Smart technologies contribute to the provision of more efficient systems, with greater optimization of resources and less environmental impact. The use of SWT in collection service has a positive impact on efficiency in controlling operations, increasing the useful life of vehicles, generating less environmental impact, and having greater traceability and transparency in the management of the service. The contribution of these technologies is applied to the design of optimal routes, real-time monitoring of operations, telematic systems for vehicles, real-time weighing of waste, among others.

As an example, collection vehicles can be equipped with sensors. Apart from the standard suite of sensors built into trucks, there are several sensors specific to the waste industry such as a balance checking the weight of collected waste, RFID sensors for identifying individual garbage bins and GPS sensors to track vehicle location.

What is known as the CleANopen standard, "CAN-Bus," has been established for the integration of sensors into garbage collection vehicles (CIA, 2019). CAN-Bus specifies the body controller (BC) and several functional entities as well as internal communication for functions such as bin-lifting, measuring, or the crane-unit.[4] Route planning is also an integral part of the waste collection process and benefits from digital tools based on GIS to optimize routes and save operation time.

Chapter 5 provides a description of the technologies used in the municipal solid waste collection service.

2.5. Recovery

In the field of solid waste and recyclables processing, robots equipped with AI software and capabilities are playing increased roles in the sorting of solid waste and recyclables. In addition, optical sorting systems equipped with air pulse jets are growing in popularity. These new digital technologies are helping to improve the quality of baled commodities and increase efficiency at recycling facilities. The data is also collected and analyzed to make projections for the recycling industry, using AI and data analysis tools.

2.6. Final Disposal

Final disposal processes are increasingly relying on new technologies for landfill surveying, mapping, waste compaction, and monitoring and control of operations. Drones are used to conduct aerial site surveys on a regular basis to determine and improve waste compaction and airspace utilization. Drones can also identify possible areas in which to implement new final disposal sites through analysis of geo-spatial information regarding connectivity, road infrastructure, geography, population, etc. Likewise, landfill compactors are equipped with GPS and GIS, providing operators with real-time data and information regarding waste compaction at the landfill working face. Sensors and satellites are generally used for monitoring greenhouse gas emissions and temperature control in landfills.

2.7. Commercial Management/Customer Service

Digitalization is transforming many paper-based processes that involve retaining or sharing information across different industries. The waste sector is also undergoing this change. Processes like billing, accounting, controlling, order processing, documentation, subcontractor management and others are being digitized. This improves the efficiency and accountability of the system.

[4] See https://www.bde.de/.

3. Business Intelligence Tools

The digital transformation of the waste management sector is setting the stage for the development of BI tools to improve the efficiency and cost-effectiveness of waste management services, as this chapter will discussed.

BI tools are types of software used to gather, process, analyze, and visualize large volumes of past, current, and future data to generate actionable business insights, create interactive reports, and simplify the decision-making processes.[5] "Business intelligence (BI) tools leverage software and services to transform data into actionable insights that inform an organization's strategic and tactical business decisions. BI tools access and analyze data sets and present analytical findings in reports, summaries, dashboards, graphs, charts and maps to provide users with detailed intelligence about the state of the business. The term "business intelligence" often also refers to a range of tools that provide quick, easy-to-digest access to insights about an organization's current state, based on available data (Schwartz, 2021).

BI tools are used to collect and process large amounts of unstructured data from internal and external systems, including books, journals, documents, health records, images, files, email, video, and other business sources. BI tools provide a digital way to process data to find information primarily through queries. These tools also help prepare data for analysis so a solid waste manager can create reports, dashboards, and data visualizations. The results give both employees and managers the power to accelerate and improve decision-making, increase operational efficiency, assess new revenue potentials, identify market trends, report meaningful KPIs, and identify new business opportunities.[6]

As an example, in 2023, the IDB launched the Solid Waste and Circular Economy Hub, a platform that includes data analyzed by Power BI, providing evidence of the evolution of the waste and circular economy sector, its link with sustainable development goals, mitigation and adaptation to climate change. It seeks to support countries in their digital transformation for design and implementation of effective public policies and innovative management models in the information age. At the same time, it becomes a regional meeting point to improve statistics on waste and circular economy.

[5] See https://www.datapine.com/articles/best-bi-tools-software-review-list.

[6] See https://azure.microsoft.com/en-us/products/power-bi-embedded/#layout-container-uid18e.

Figure 4. Solid waste and circular economy hub designed with business intelligence tools

Source: IDB (2024).

Typically used for more straightforward querying and reporting of business data, BI tools can combine a broad set of data analysis applications including ad hoc analysis and querying, enterprise reporting, online analytical processing (OLAP), mobile BI, real-time BI, operational BI, cloud, and software as a service BI, open-source BI, collaborative BI, and location intelligence. It can also include data visualization software for designing charts, as well as tools for building BI dashboards and performance scorecards that display business metrics and KPIs to bring organizational data to life in easy-to-understand visuals.[7]

BI tools have two sides: predictive and insightful (prescriptive). A *predictive* BI metric has a KPI to measure against, with tolerances and limits of acceptability. *Insightful metrics*, however, are more of an art form. With BI, managers can examine data over time, look for trends, variations, and outliers, and develop new KPIs to better predict or anticipate changes or trends.

BI tools can take advantage of AI, which has assumed a dominant role reviewing live transactional data to identify patterns, behaviors, and anomalies over time, while generating intuitions about massive amounts of data. The next generation of AI is helping managers see things in data that would take years of experience to understand. For example, a waste collection service manager

[7] See https://azure.microsoft.com/en-us/products/power-bi-embedded/#layout-container-uid18e.

who established an institutional KPI of 1,000 tons of residential waste collected for a Wednesday in September would have developed that KPI through years of experience. When extreme conditions exist, like the recent pandemic, humans often take too long to adjust the KPIs they have become dependent upon to drive business decisions. Adjustment, then, comes at a high cost of friction and potential losses. Using AI to review data and look for shifts in patterns enables managers to access a superior analysis of vast amounts of data. This analysis can be used to identify the best service outcomes possible, or directly drive a desired outcome (Schwartz, 2021). A review of the most relevant BI tools is provided below.

3.1. Data Types and Sources for Business Intelligence

As stated above, BI tools are used to collect and process large amounts of unstructured data from internal and external systems, including books, journals, documents, health records, images, files, audio, webpage, email, video, and other business sources.

With respect to improving the provision of solid waste collection services, table 2 shows the types of data that are likely to be of use.

Table 2. Examples of data types and business intelligence analysis for solid waste management

Type of Data	Detailed data gathering
Population/Employment	Population data can be used to estimate residential waste generation rates based on per capita waste generation (by weight) data. If weight data is not available, volumetric estimates can be developed based on container volumes of trucks and/or waste containers using locally measured or published bulk density data. Employment data and income data can similarly be used to develop estimates of commercial waste generation rates. The use of drones and geospatial information can provide input for population estimation, through analysis of housing roofs, and its extrapolation to the population.
Street Characteristics	Data on street characteristics and conditions can be particularly useful to optimize collection route design. For example, backing up, left turns and truck turnarounds can be minimized by using this data.
Street Centerline	The availability of centerline data for the service area is the most important factor when considering an automated routing system.
Sales	Sales data for grocery and retail stores can sometimes be correlated with residential and commercial waste generation rates.
Housing Starts	Housing starts can be used to estimate construction and demolition waste volumes and tonnages and anticipate future residential waste growth.

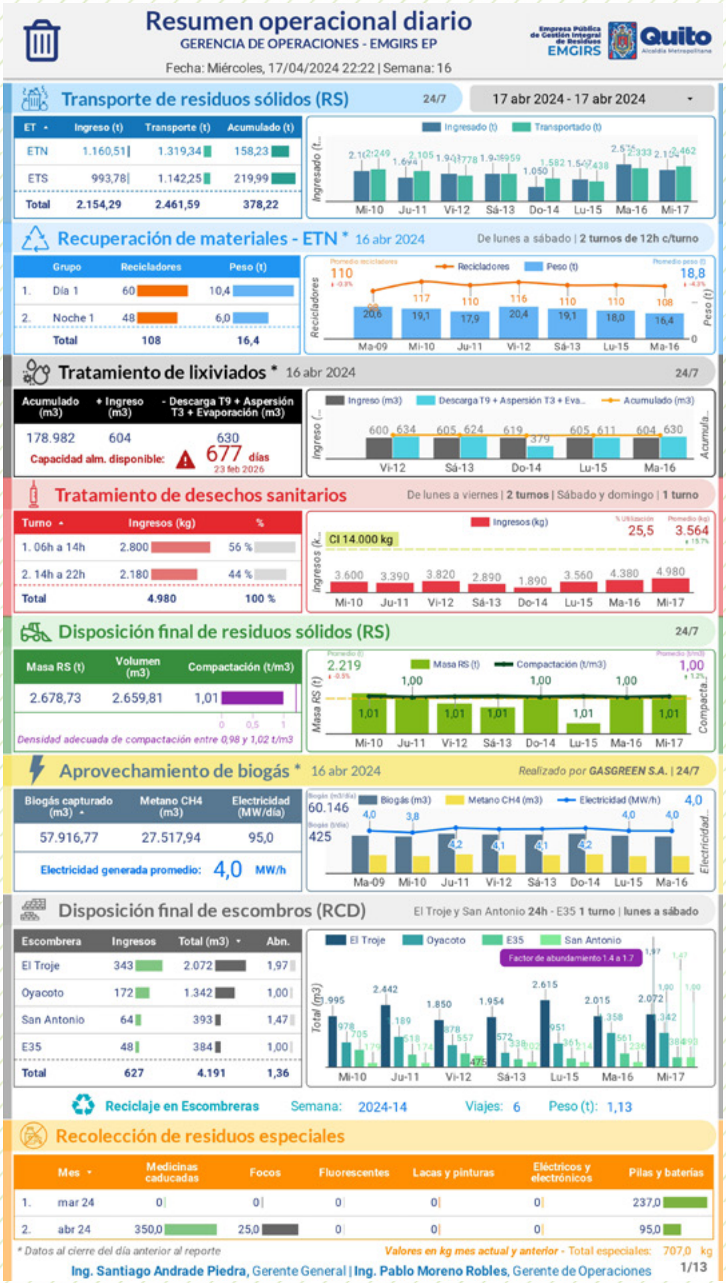
Water Utility	If available, water usage data can be correlated with waste collection data and used to identify trends and problem areas.
Electric Utility	If available, residential electricity usage data can be correlated with waste generation and collection data and used to identify trends and problem areas.
Economic Forecasts	Key economic parameters such as GDP can be correlated with waste data and used to identify general trends or problem areas. Economic trends can also be correlated to waste generation data.
Traffic	Traffic data can be used to make waste collection more efficient by avoiding historical and current areas of high traffic congestion when providing collection services.
Air Quality	Air quality data can be used to analyze the impact of solid waste collection and disposal on the attainment of local air quality goals and to identify strategies—such as conversion to natural gas—that are designed to mitigate these impacts.
Community Sustainability	Data on a community's sustainability goals can be useful in measuring the impact of solid waste collection services on the achievement of these goals. For example, level of education, years of education, number of libraries can also be correlated to waste generation data.
Community Circular Economy	Data on the community's circular economy goals can be useful in measuring the impact of solid waste management services on the achievement of these goal. IDB is a development partner in the Development Data Partnership, a collaboration between international organizations and technology companies, facilitating efficient and responsible use of third-party data in international development, where environmental and social data analysis can contribute to research and policy design (Development Date Partnership, 2024).

Source: Authors' elaboration (2023).

There are opportunities to utilize BI systems to estimate the amount of waste that is currently being generated and collected by using web-based housing sales or apartment rental data. This data may be useful in predicting neighborhood waste generation patterns by analyzing changes in apartment rentals in areas where trash bin overflow problems are occurring, and determining if there is a correlation between the apartment rental data and the trash bin overflow problems. Analyzing these changes in a standardized way could provide important benefits and useful data in urban areas in LAC.

As explained, through the use BI, data analysis can be easily displayed in dashboards with relevant KPIs that enables a better decision-making for waste management service providers. Nowadays, BI tools are comprehensive and easy to access and operate, in many cases, basic software is free, and customers can upgrade when needed. Some service providers in LAC have started to use BI software to produce relevant data related to waste collection, fleet management, and infrastructure (container) maintenance, human resource management, route design, etc.

Figure 5. Waste service provider dashboard developed with business intelligence tools



Source: Personal interview with Empresa Pública de Gestión Integral de Residuos Sólidos de Quito (EMGIRS) Operations Manager Pablo Moreno, conducted by Paula Guerra, February 28, 2024.

4. Digital Technology Tools

This section provides examples of software and hardware tools used in solid waste management and potential enablers of efficient transition towards digitalization and circularity.

4.1. Software

How software is designed and implemented in solid waste management services is undergoing a major change. One factor behind this change is the evolution of programming languages. In the last decade or so, there has been a radical shift in how applications are being built. Many of the existing "legacy systems" in waste management are meant to handle single-purpose functions, not meet the dynamic and interconnected demands the industry now wants. The transition from old and static to open and dynamic software is important to consider and ensure that software systems can be replaced or linked with other systems and present compatibility between different field equipment, operating systems, or file formats. This is good news for waste management operations that often face difficulties with complex interconnected software and challenges with outdated legacy systems.

As an example, AI and machine learning are enabling applications to go from being "passive" (doing tasks according to a protocol based on predefined commands) to being more active and autonomous. For software developers and IT teams, AI offers several appealing possibilities for making applications faster, more scalable, and more efficient. AI is emerging in software solutions for waste management, specially applied as robots and waste stream monitoring in waste sorting plants. AI capabilities are increasingly available in the cloud, based on open "question-answering systems" and ready-made algorithms such as IBM Watson and Google Cloud AI.

Some examples of software used to enhance waste management efficiency are described below:

4.1.1. ERP Systems

Waste management is an important area for digitalization, and Enterprise Resource Planning (ERP) systems are essential for this. These systems offer integrated control of main business processes in real-time, allowing for smooth integration with other software and technology. By using ERP systems, waste management companies can effectively manage and track every step of their operations, from waste collection and transportation to recycling and disposal. This not only enhances the efficiency of waste management processes but also allows companies to make decisions based on data, ultimately supporting digitalization of the sector (Mavropoulos and Waage, 2020).

4.1.2. Customer Management Systems

Customer management systems, or Customer Relationship Management (CRM) systems, are software platforms that manage a company's interactions with existing and potential customers. These systems use data analysis of customers' past behavior with a company to enhance business relationships, especially focusing on customer retention and ultimately increasing sales growth. In waste management, CRM systems can help service providers check sorting quality, track how often a container is set out for collection, and track how much it weighs. This makes service billing easier and supports the use of incentive-based invoicing. By using CRM systems, waste management companies can communicate better with customers, raise customer satisfaction levels, and ultimately help digitalization of the industry (Mavropoulos and Waage, 2020).

4.1.3. Project Management Software

Project management software (PMS) helps with the planning, coordination, and control of projects within or across organizations. There are many types of tools, each with different project management methods and functions such as cost calculation, timing, teamwork, communication, decision-making, and time management. For solid waste management, PMS can be helpful for activities such as replacing trucks, building facilities, and handling the work of waste collection staff (Mavropoulos and Waage, 2020).

4.1.4. Data Lakes and Warehouses

As the amount of data grows, it is essential to manage information efficiently. There are two common concepts in use nowadays: data lake (unprocessed raw data) or data warehouses (structured, refined data). Both systems can gather data from various sources within an organization and use the data for reporting and analysis. The reports produced from complex queries within a data warehouse can help make better and faster business decisions. Some data warehouse software comes with dynamic dashboard tools that help display the data (Mavropoulos and Waage, 2020).

4.1.5. Field Reporting Software

Field workers and drivers working in the operations will need to coordinate their work. There are different solutions for waste management that use mobile devices in the vehicle. This works in real time and offers a complete view for the worker, with integration into the back office. This way, schedules can be changed, orders can be sent, and feedback can be given in a centralized location. With sensors in mobile devices like smartphones and tablets, field applications can also report on location automatically. In many modern garbage trucks, which are like moving collection machines, the system is connected to provide continuous feedback on different events (Mavropoulos and Waage, 2020).

4.1.6. Marketplace Software

A recent trend is the emergence of online platforms that enable information exchange between customers, producers, and service providers. Online systems for booking waste disposal containers have become popular in the waste market; new digital platforms allow private individuals or construction companies to order waste removal services for various kinds of waste through an app. The container size can be selected and ordered online, and either delivered or picked-up as needed (Mavropoulos and Waage, 2020).

4.2. Hardware

4.2.1. From Servers to Clouds

Cloud computing allows convenient network access on-demand, anytime and anywhere, to a shared pool of configurable computing resources. Cloud computing is used in the waste management industry in various applications. Examples include storage and processing of sensor data or software solutions for the management, collection, administration, and documentation tasks. Cloud-based software can be billed on a pay-per-use or time limited license or can be open-source so that only the service fees for software administration and used infrastructure are billed.

4.2.2. From Centralized to Distributed Architecture

A transition is occurring from centralized setups to distributed systems, a shift in which all the system components are located on different networked computers and where communication and coordination of actions occurs by passing messages to each other to achieve a common goal. Within digitized systems, a portion of processing occurs not in the cloud but at the edge (the processor is physically situated close to the equipment), resulting in a reduction in response time and bandwidth saving. In waste management operations, equipment is frequently scattered across extensive geographical areas, hence, processing power locally at the plant/container site can significantly impact efficiency (Mavropoulos and Waage, 2020).

4.2.3. RFID Tagging Systems

RFID waste management solutions support identification and traceability of waste streams. Tags attached to waste containers enable operators to monitor sorting quality, track the number of times a container is put out for collection, and track the weight of its contents. Waste bin RFID tags simplify service billing and support implementation of incentive-based invoicing. There are lots of vendors selling RFID tagging systems, and most container/cart manufacturers as well as RFID manufacturers offer them. RFID technologies and remote digital cameras could be used to identify and quantify overflow problems and on-demand routing software could enable overflow bins to be serviced more efficiently.

A growing number of municipalities have installed bin sensors in waste containers, some of them solar-powered, that communicate with the service provider and inform it when the container is full. These sensors are usually in public collection bins and commercial waste containers, although they are being installed in an increasing number of residential containers and roll off containers. These sensors allow providers to track inventory, participation, and verify service; and play an important role in the design of smart routes for waste collection services, enhancing efficacy and reducing environmental impact in transportation.

5. Digital Tools and Innovative Practices for Solid Waste Collection

Recent years have seen the growth and spread of numerous innovative developments and best practices in solid waste collection. New technologies provide waste operators with a wide array of different benefits, including GHG emissions reduction, reduced operational costs, and increased safety operations for workers. Some of these technologies focus on increasing efficiency and reducing transportation costs, by facilitating the introduction of smart collection systems. A "smart" waste collection system can reduce the frequency of trucks inefficiently servicing partially full containers; virtually eliminate overflowing bins and provide traceability systems which improve knowledge of service demand and optimize collection activities, through more efficient route planning.

In this chapter specific examples of innovation and technology in waste collection services are given, software and hardware tools are detailed, and examples applied by service providers in LAC are displayed.

5.1. Computerized Data Collection and Routing

The transition from manual data collection and routing to computerized data collection and routing for solid waste collection services has been taking place in the past decades. Two of the major tasks associated with this transition are the implementation of automated routing software and computerized fleet management systems.

5.1.1. Automated Routing Software

Automated route planning for solid waste collection involves the completion of three steps:

1) Identify the pickup points and likely amounts of waste to be collected from each point.
2) Group together pickup points to form collection rounds that can be served by a single collection vehicle.
3) Plan the route of each collection round, taking account of distance traveled, trips to disposal facility, traffic levels, and safety to the public and waste collectors.[8]

Automated routing uses computer technology to develop balanced areas and produce a detailed path route structure. The principles are the same as for manual routing, but they are applied using computer algorithms. The computer mapping system usually applied is the Geographic Information System (GIS). GIS is a computerized database that stores mapping information, as well as non-geographic data, and its databases are easily accessible worldwide. There are many powerful commercial software packages available for use with GIS systems. The term

[8] See "9.5 Planning the route for waste collection vehicles" at https://www.open.edu/openlearncreate/mod/oucontent/view.php?id=80575&section=7.

IGIS (integrated geographic information systems) is used to define the merger of traditional management information systems (MIS) with GIS. The final product is a system of desktop applications that can provide spatial information for users without GIS or graphic workstation experience. For example, a solid waste collection service can integrate one-way street and dead-end location information into a GIS to aid in the selection of optimal collection routes.[9]

GIS systems, when supplied with a database of street centerlines, can quickly produce road maps for the entire country, a state, or even a small portion of a city. Existing software applications can examine these GIS-produced maps and generate optimal routes for delivery and collection services. For example, algorithms that generate the routes can be programmed to minimize left turns and repeat distances, avoid streets with no service, and follow other routing principles. In addition, applications can consider traffic patterns, turn restrictions, one-way streets, and dead ends, as well as provide for collection pickup on one or both sides of the street.

Depending on the routing application, numerous hardware and software requirements must be met prior to installation. Customers must also have GIS systems in place to be linked with the routing application. Additionally, databases of street centerlines must be generated or purchased.[10] The availability of centerline data for the service area is the most important factor when considering an automated routing system.

Some software solutions can create routes based on parameters, such as level sensors or requested container collections. These solutions can help waste collectors reduce the number of vehicles, staff, and fuel they need. Systems may also improve overall service to customers by avoiding missed bins. A key feature in route planning software is an optimization algorithm. The system helps find the best route for collection. These systems can often mix automated routes and manual routes – depending on service requirements. The route optimizer will use a geographical data source and can consider start and finish location, collection points, road types, time of day, and vehicle capacity. Route planning software offers several benefits, including the ability to optimize routes and schedules, and consider various factors such as traffic, road conditions, and distance. This can help reduce fuel costs, improve delivery times, and increase overall efficiency, particularly for logistics and delivery companies.

Routing software is typically designed to focus on two types of waste collection services: 1) fixed route waste collection, and 2) on-demand services.

- **Fixed Routing Software:** Fixed waste collection routes are routes which involve the servicing of customers that require the same level of service on a regular basis. The collection of mixed waste, recyclables and yard waste from single-family residential households is typically accomplished through the servicing of fixed routes on a weekly, bi-weekly, or monthly basis.

- **On-Demand Routing Software:** For some solid waste collection services, such as bulk waste collection, "pinpoint" routing may be most applicable. In pinpoint routing, a series of stops are routed based upon information generated by customers. Parcel delivery systems use pinpoint routing. Bulk waste pickup services respond to customer calls, and therefore the routes change daily. Pinpoint routing can be generated before sending a vehicle out for the day or in real-time. Real-time pinpoint routing applications monitor

[9] Based on Lesson 9 (Collection Truck Routing and Emerging Technologies) of SWANA Managing MSW Collection Systems: https://swana.org/training-certification/find-a-course/training-course/managing-msw-collection-systems.

[10] See https://www.clarkcountynv.gov/government/departments/geographic_info_systems/index.php.

the location of collection vehicles. When a call is received, the vehicle closest to the caller is dispatched and a map of the shortest route to the customer is generated.[11]

5.1.2. Fleet Maintenance Software

The challenge of maintaining records and scheduling preventative maintenance has been greatly reduced by the development of commercial computer software packages. Available for operations ranging from a handful of vehicles to fleets with hundreds of vehicles, the packages are available in a wide range of prices. Just as routing software is becoming critical to the collection manager for efficient routing, maintenance software is becoming the norm rather than the exception for maintenance managers.

There is a range of software solutions that can provide an overview of all the vehicles and other assets involved in daily waste management operations. By subscribing to data from geo trackers and field equipment, managers can gain real-time visibility over their portfolio, drivers can get driving routes or notifications, and the logistical system can be optimized.

5.2. Truck-Related Technologies

Generally, waste management software is designed to help local government agencies and waste collection companies collect and dispose of waste more efficiently. It typically includes billing services, on-board tablet solutions, route optimization, analytics, and telematics. These technologies, which are often based on cloud computing, are designed to streamline workflow, reduce costs, reduce vehicle miles traveled (and therefore emissions and costs), and make the work safer and more efficient.

Many haulers and municipal agencies use routing software to develop efficient collection routes that maximize productivity and reduce distance traveled. By reducing the number of miles on the routes, the provider also reduces the use of fuel, emissions, and costs. When used with GPS systems, modern routing software provides a way for employers to monitor truck location to ensure that routes are being collected. When combined with bin sensors, these technologies can provide a digital traceability system that facilitates real-time communication between the bin and a collection vehicle, and between the vehicle and the agency/company providing the collection service. This provides operational efficiencies, accountability, and improved collection practices.

A recently issued report from Monterrey, Mexico is instructive, and highlights both the opportunities and challenges associated with improving the efficiency of waste collection in LAC using these tools. Using actual solid waste data from Monterrey and an advanced mathematical model, the report concluded that a 9% reduction in GHG emissions and a 20% reduction in vehicle miles traveled could be achieved (Benítez-Bravo et al., 2021).

A 2018 meta-analysis of approximately 100 articles, books, and reports on solid waste collection in developing countries provides a wealth of data and information on the use of routing software. After reviewing the various challenges that such collection systems face in developing countries, the report concludes “the effective routing of collection trucks” can yield “enhanced performance” (Alhassan Sulemana et al., 2018). The report notes that proper routing “is one of the main and very essential components of solid waste management, and routing has impacts on

[11] Based on Lesson 9 (Collection Truck Routing and Emerging Technologies) of SWANA Managing MSW Collection Systems: https://swana.org/training-certification/find-a-course/training-course/managing-msw-collection-systems.

"labor, operational and transport costs and on society, due to road contamination and negative effects on public health and on environment" (Ibid.). The report observes that research focused on optimal routing of solid waste collection trucks looks at the application of optimal system designs through mathematical programming, specialized software, and incorporation of GIS to enhance collection efficiency.

5.2.1. Bin Sensors and RFID Chips

A growing number of municipalities have installed bin sensors in waste containers. These sensors, which are usually solar powered, communicate with the service provider and notify it when the container is full. These sensors are usually in public collection bins and commercial waste containers, although they are being installed in an increasing number of residential and roll off containers. The sensors allow providers to track inventory and participation, as well as verify service.

5.2.2. Telematics

Numerous haulers and municipal agencies in developed countries have installed telematics systems on collection vehicles. Telematics refers to the use of wireless devices and technologies to transmit data in real-time from a vehicle to the owner of that vehicle. Telematics systems allow employers to track fuel use, weight, speed, and other vehicle performance metrics. These systems can also track vehicle maintenance and provide valuable information about the service life of the vehicles and individual components (e.g., tires).

According to a recent article in a major solid waste industry trade publication, telematics is a "game changer" for the waste and recycling collection industry. The article identifies six tangible benefits associated with telematics for waste collection (Waste 360, 2021):

1) Reduced fuel expenditure by 10% or more by providing individual driver data and fuel usage, including idling, sudden acceleration, hard braking, and off the route driving.

2) Increased productivity (number of customers served) by 12% or more by providing insights on service stop times, waiting times, recurring delays, and route duration comparisons.

3) Reduced vehicle downtime through preventive maintenance that reduces unplanned repairs and missed routes and customers.

4) Improved customer service through better communication on service issues, more accurate time of service, and improved ability to respond to missed collection and special situations.

5) Identified unsafe driving behaviors such as speeding, sudden acceleration, and hard braking or turns, which allows managers to target drivers for coaching to reduce the risk of serious collisions.

6) Provided data on environmental sustainability goals relating to fuel use and emissions.

Telematics is particularly helpful in data-driven organizations that take advantage of the information provided by the systems on the truck and coach their drivers to modify some of their behaviors on the route. In addition, it is important for managers to be comfortable with digital solutions to operational and maintenance issues.

5.2.3. Alternative Fuel Trucks

Most new waste collection trucks put into service in the United States are fueled by natural gas (NG).[12] NG trucks can save money on fuel expenses, have lower emissions, including GHG emissions, and provide quieter operations (U.S. Department of Energy, 2014). NG trucks have much lower emissions than traditional diesel-fueled trucks and are often fueled at dedicated fuel stations owned by the local government or a hauler. At a growing number of landfills, methane generated at the landfill is used to fuel NG trucks, creating a true closed loop (Tomich, Vos, and Underwood, 2024; Johnson, 2019). Large solid waste companies in the United States are investing in systems to harvest and use "renewable" natural gas from landfills in their collection trucks.

Currently, in some LAC cities, companies in charge of urban solid waste collection services have been implementing vehicles with NG engines in their fleets, given the low cost of this fuel compared to diesel. In cities such as Medellín, Colombia, Empresas Varias de Medellín modernized part of its fleet in 2016 with forty vehicles having NG engines to provide waste collection services. Additionally, the company Bioagrícola del Llano, which provides solid waste management services in the city of Villavicencio in Colombia, modernized part of its fleet with seven new compactor vehicles with a capacity of 14 tons, based on NG under Euro VI technology. This technology offers a significant reduction in noise generation and emissions, minimizing the environmental impact: 90% less smoke, 50% less particulate matter, 20% less carbon dioxide (CO_2) emissions and 80% less nitrous oxides (NO_x).[13]

A growing number of cities in the United States, Canada, and the United Kingdom are testing and piloting electric garbage trucks (EV) (RECI, 2021).[14] These vehicles cost more than $500,000 each and require electric charging stations that are costly as well (average charging times for EV trucks are often two to seven hours). When evaluating EV trucks, some of the critical issues to evaluate include payload, operating range, and total cost of ownership. Although the purchase price is high, energy and maintenance costs are comparatively lower than diesel trucks. Cities in LAC may want to monitor trends in EV truck usage for potential consideration of a pilot program in the future.

Rio de Janeiro began deploying EV collection trucks in late 2019, where the Municipal Urban Cleaning Company of Rio de Janeiro (COMLURB) added nine electric trucks to its fleet. The trucks are used for waste collection in one of Brazil's largest metropolitan areas. These trucks have a storage capacity of 15 cubic meters, their low noise levels make the trucks ideal for night routes in residential areas, while their zero-emission capability creates a healthier living environment for city residents and better working conditions for garbage collectors.[15]

5.2.4. Backup Cameras

One of the most common types of accidents or claims in solid waste collection involves trucks that are backing up. Most collection trucks go backwards at some point during their route, and visibility behind the truck is limited. As a result, many solid waste fleets in developed countries have installed backup cameras that provide the driver with a line of sight behind the truck. These cameras help prevent many accidents and injuries. With a growing number of pedestrians

[12] See https://ngvamerica.org/vehicles/refuse/.

[13] See Bioagrícola del Llano: https://www.bioagricoladelllano.com.co.

[14] See https://www.transportation.gov/rural/ev/toolkit/ev-basics/charging-speeds.

[15] See https://bydelectrico.com/ec/2019/10/07/byd-entrega-a-rio-de-janeiro-la-mayor-flota-de-camiones-de-residuos-electricos-fuera-de-china/.

distracted by cell phones, having a backup camera and an audible backup alarm on a truck is increasingly important.

5.2.5. In-cab Cameras

Over the past decade, one of the most important safety innovations introduced in the U.S. solid waste industry has been the installation of cameras inside the cab of waste collection vehicles. The cameras face both the driver and the front of the truck. The camera is connected to telematics on the truck and is usually set to record a short period before and after an event. Events can be selected by the service provider and typically include crashes, hard stops, hard turns, exceeding the applicable speed limit, and other variables. The cameras serve several important purposes. First, the driver of the truck will be less likely to engage in unsafe behaviors such as texting, talking on a cell phone, or not wearing a safety belt. Second, the outward facing camera provides video that can help resolve disputes over the cause of an accident. Many claims by other drivers involved in waste collection accidents have been favorably resolved because of the video evidence provided by these cameras. Third, if a driver arrives at a customer site and the waste container is overflowing or is in the wrong location, the driver can use the camera to take a photograph documenting it. This can be a valuable customer service tool.

Companies and local governments that have installed cameras in the cab of their collection vehicles and combined them with telematics have seen dramatic reductions in unsafe driving behaviors. One provider reports a 59–75% reduction in distractions, speeding, fatigue, and close following distances, which can contribute to costly collisions (Redling, 2018). Other providers have reported more than a 50% reduction in unsafe behaviors following installation.

5.2.6. Scales

Some trucks in developed countries have scales on them that allow the operator to know the weight of the truck as it is collecting waste. In most developed countries, it is illegal to operate a truck that exceeds a certain weight. For example, in the United States, federal limits are 80,000 pounds gross vehicle weight, 20,000 pounds on a single axle and 34,000 pounds on a tandem axle.[16] Overweight trucks are correlated with increased damage to roads and highways, and longer stopping distances.

It is possible that knowing the weight of the solid waste from a specific customer, as measured by the scale on the truck, could be used as a cost recovery mechanism by local service providers. This may be particularly true if there is an applicable tariff.

In LAC, ongoing pilots are being implemented in Montevideo, Uruguay by ISBEL (https://isbel.com/en/) using different type of scales in the collection truck compactor and container lifters and analyzing the best options for the service provider.

5.3. System-Related Best Practices

5.3.1. Improving Data Collection: Waste Composition Studies

To perform appropriate solid waste management planning, including the size and location of waste processing and disposal facilities and the number of trucks and workers needed, it is essential to know how much waste and the different types of waste that is being generated.

[16] See https://worldpopulationreview.com/state-rankings/truck-axle-weight-limits-by-state.

Numerous states and local governments in the United States have performed waste composition studies to better understand the quantities and types of waste being generated, to make informed policy decisions and investments.[17][18]

Although it is recommended that waste composition studies be performed every five years, financial limitations often make it difficult to conduct these studies with that frequency. In a waste composition study, the following parameters are often measured:

1) Percentage of recyclable materials (e.g., metal cans, cardboard, glass, plastic, and other recyclables)

2) Percentage of food waste and other organic material

3) Percentage of e-waste (e.g., computers, cell phone, televisions)

It is important to account for daily and seasonal variation when conducting a waste composition study. This is achieved by sampling waste across different seasons, as well as on different days of the week. A high-quality waste composition study will identify differing quantities of materials generated in different neighborhoods and will provide insights into how successful a community is at diverting recyclables from disposal. As explained above, digital technologies such as BI and AI are now used to predict waste generation using historical data and algorithms related to population patterns.

5.3.2. Public Surveillance Cameras

In most major cities, there is a system of public and private cameras that records what occurs on many streets. These cameras are not networked, but they provide some benefits as they can show illegal activity or assist in investigating an accident. For example, in some cities, the local police department and government agency regulates solid waste collection and routinely requests video footage of accidents involving solid waste collection trucks from security cameras.

Cameras can also help deter illegal dumping. In both developed and developing countries, illegal dumping is a serious problem and contributes to environmental and public health hazards. In the United States, much of the illegal dumping occurs at night by residents using cars, so license plate readers are an important tool for utilizing the video footage and identifying illegal dumpers.

5.4. Best Practices Regarding Solid Waste Facilities

5.4.1. Transfer Stations and Regional Approaches to Waste Management

Over the past few decades, an increasing percentage of waste in the United States and Canada is transferred from waste collection trucks to larger waste hauling trucks before being transported to treatment or disposal facilities. At these facilities—transfer stations—collection trucks dump their loads, and waste is placed into larger long-haul trucks or railcars for shipment. This provides cost-savings, less fuel usage, and a reduced impact on the environment (fewer trucks going to and from a landfill). Transfer stations are often located in cities close to major highways so trucks can access them while minimizing impacts on nearby businesses and residents.

[17] https://www.seattle.gov/utilities/about/reports/solid-waste/composition-studies#:~:text=CDL%20waste%20composition%20studies%20are,for%20this%20significant%20waste%20stream.

[18] See https://www.pca.state.mn.us/air-water-land-climate/understanding-solid-waste.

The growth of transfer stations reflects an increased regional approach to solid waste management in the United States and Canada. As cities and counties closed their older landfills, they were replaced by a regional approach in which multiple communities, often located in different states, send their waste or recyclables to well-located, modern processing facilities. For example, in the Washington, DC area, recyclables from Maryland, Virginia, and the District of Columbia are processed at the same recycling facility located in Maryland. Although transfer stations and recycling facilities are occasionally located on adjacent properties, this is not typically the case. This is because the company that owns and operates the transfer station is often not the same one that owns and operates the recycling facility. However, when a local government owns and operates both a transfer station for solid waste and a recycling facility, these facilities are more likely to be in the same location.

Some local governments in the United States have chosen to formally work together on solid waste management issues. In some states, counties have combined to form regional waste "authorities" or "districts," which are responsible for solid waste management in those locations. In Ohio, 15 of the 52 solid waste management districts are responsible for multiple counties (Ohio USEPA, 2017). In two small states (Delaware and Rhode Island), there is a state-wide solid waste authority responsible for solid waste disposal in those states.

The concept of a National Solid Waste Management Authority (NSWMA) is not entirely foreign to LAC. Belize and several Caribbean nations have such authorities. In Barbados, the Sanitation Service Authority that implemented new RFID-enabled bins for residential collection in 2021 manages solid waste on the island. In Jamaica, the NSWMA provides solid waste management services, as residential and commercial waste collection services, composting, and disposal. There is a St. Lucia Solid Waste Management Authority that provides collection and manages two waste disposal facilities on the island.[19] There is also a Virgin Islands Waste Management Authority covering the U.S. Virgin Islands that includes landfills, drop-off facilities, and a transfer station.[20]

In the United States, nearly all states both receive waste from other states and send waste to other states. Some North American cities send their waste to distant landfills in other states that are hundreds of kilometers away (e.g., Boston, New York, Washington, DC, Toronto). Generally, this is because landfill disposal in these other states is less expensive than it would be closer to densely populated urban locations.

5.4.2. Material Recovery Facilities

There has been significant growth in the number of recycling facilities in the United States over the past few decades. These facilities divert waste away from disposal and put recovered materials into the circular economy. This protects the environment, preserves landfill capacity, reduces GHG emissions, and creates jobs. Several private companies are making substantial investments in recycling infrastructure in the United States. For example, Waste Management recently announced it intends to spend $800 million to upgrade its recycling facilities in the United States and Canada by 2025 (Rosengrenm, 2022).

Approximately 24% of the municipal solid waste collected in the United States is recycled, and about 8% is composted, according to the USEPA's annual report, *Facts and Figures on Materials,*

[19] See https://www.sluswma.org/.

[20] See http://www.viwma.org/index.php.

Wastes, and Recycling.[21] The USEPA's report contains extensive data on waste generation, recycling, landfill disposal, waste-to-energy, and materials management. Most newer recycling facilities in the United States are "single stream" material recovery facilities (MRFs). Single stream means a variety of recyclables are placed in a single container by the resident or business owner for collection. These facilities typically receive a mix of discarded paper, plastic, metal, and glass and process it through a variety of mechanical and human processes to generate commodity-grade materials that are sold to end markets.

A growing number of MRFs in the United States, Canada, and Europe are introducing robotics and AI to improve efficiency (Quinn, 2021). The growing labor shortage in the United States has made robots increasingly attractive to some MRFs, though this may be less of an issue in LAC. A small percentage of U.S. curbside collection systems and MRFs are "dual stream." In a dual stream system, paper and cardboard are collected and processed separately from other discarded recyclables.[22] Dual stream proponents assert that this system reduces contamination and results in higher quality material (Deer, 2021).[23]

In a growing number of communities in the United States, glass is no longer collected in curbside recycling systems (Farnsworth, 2021; Jacoby, 2019).[24] Instead, residents are asked to bring glass bottles to drop-off sites. This segregates the glass from other recyclables, which lowers processing costs, reduces transportation costs (glass is heavy) and maintenance costs at MRFs (glass damages the equipment), and makes both the glass and the other recycled material more valuable. For example, in Virginia, several neighboring cities and counties with a combined population of nearly two million people collectively decided in 2019–2020 to no longer accept glass in their curbside recycling collection (Fenston, 2020).[25] Similarly, several communities near Pittsburgh, Pennsylvania do not accept glass at curbside and instead encourage residents to bring their glass bottles to a central drop-off location (Koscinski, 2022).

[21] See https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/national-overview-facts-and-figures-materials#NationalPicture.

[22] See https://www.montgomerycountymd.gov/SWS/recycling/dual-stream.html.

[23] This article asserts that some local governments are moving from single stream to dual stream in response to changing recycling markets.

[24] According to the Glass Packaging Institute, the number of communities removing glass from curbside recycling collection programs declined in 2022.

[25] See "Glass Recycling Pilot Program" of the City of Falls Church Virginia at https://www.fallschurchva.gov/2038/Glass-Recycling-Pilot-Program.

6. Case Studies

6.1. Argentina: Collection Tracking

The LAC region has experience in the use of digital systems and data analysis developed and implemented by several operators specialized in management and measurement systems to improve the efficiency of solid waste management operations. In Argentina, some municipalities such as Buenos Aires, San Miguel, and Rosario, already have SWT in the form of geolocation and volume sensing in waste containers, digitalization of work plans, design and implementation of intelligent collection routes, telemetry for equipment maintenance, and mobile apps for operations certification, among others.

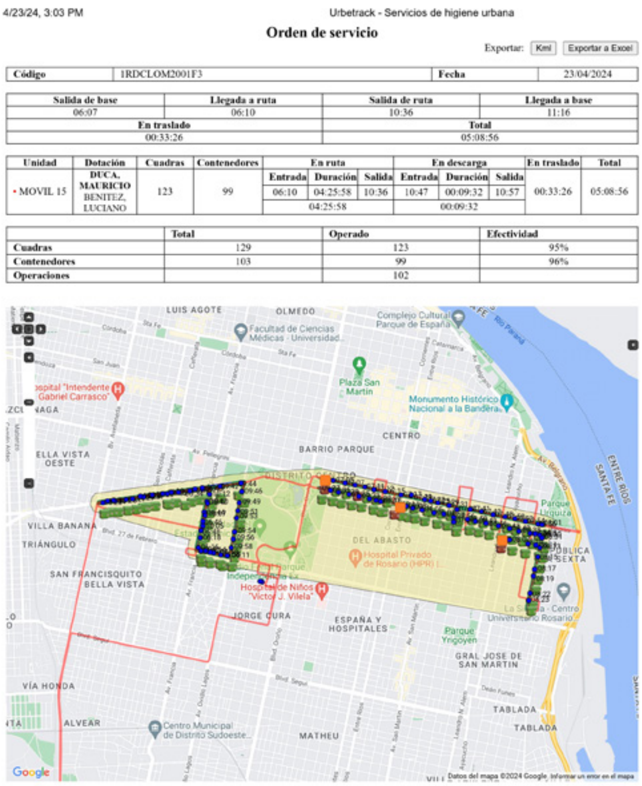
The digitalization of the information generated allows the integration of systems, the centralization of information for online control, and the generation of dashboards with KPIs for better decision-making. In addition, indicators have been incorporated that contribute to environmental care, such as measuring carbon footprint, strengthening environmental awareness to achieve differentiated collection, and processing these materials for sale, promoting the circular economy.[26]

Figure 6. City of Buenos Aires waste service dashboard

Source: Personal interview with Urbetrack Product Manager Gabriela Yael Spector, conducted by Paula Guerra, November 23, 2023.

[26] Personal Interview with Urbetrack Product Manager Gabriela Yael Spector, conducted by Paula Guerra, November 23, 2023.

Figure 7. **Rosario Municipality waste collection service order**



4/23/24, 3:03 PM Urbetrack - Servicios de higiene urbana

Orden de servicio

Exportar: Kml Exportar a Excel

Código	1RDCLOM2001F3	Fecha	23/04/2024

Salida de base	Llegada a ruta	Salida de ruta	Llegada a base
06:07	06:10	10:36	11:16
En traslado		Total	
00:33:26		05:08:56	

Unidad	Dotación	Cuadras	Contenedores	En ruta			En descarga			En traslado	Total
				Entrada	Duración	Salida	Entrada	Duración	Salida		
MOVIL 15	DUCA, MAURICIO BENITEZ, LUCIANO	123	99	06:10	04:25:58	10:36	10:47	00:09:32	10:57	00:33:26	05:08:56
				04:25:58			00:09:32				

	Total	Operado	Efectividad
Cuadras	129	123	95%
Contenedores	103	99	96%
Operaciones		102	

Source: Personal interview with Urbetrack Product Manager Gabriela Yael Spector, conducted by Paula Guerra, November 23, 2023.

6.2. Ecuador: Empresa Pública de Aseo del Municipio de Rumiñahui

In Ecuador, the Empresa Pública de Aseo del Municipio de Rumiñahui (EPAR by its Spanish acronym), began its transition to digitization in 2021. With an investment of less than USD 20K in digital technologies and with "in house" development, it has managed to digitize its operation, diversify its services, and increase its efficiency. The utility company needed to standardize its processes, which were essential to determine the technologies that would be in line with its reality, and to optimize implementation costs.

The technological tools implemented are easy for operators and citizens to handle. For example, the technologies are anchored to smartphones and easily accessible by users. The service provider has implemented a telemetry system for fleet and container maintenance, digitalization of work schedules and communication and customer service channels. The incorporation of QR codes for reporting container status by the public has optimized the maintenance service and increased efficiency per workday by 62%, from an average of 22 to 36 containers serviced per day.

Figure 8. **Collection system using digital technologies**

Source: Personal interview with Empresa Pública de Aseo del Municipio de Rumiñahui (EPAR) Operations Manager Pablo Moreno, conducted by Paula Guerra, June 1, 2023.

Figure 9. **Vehicle fleet maintenance system**

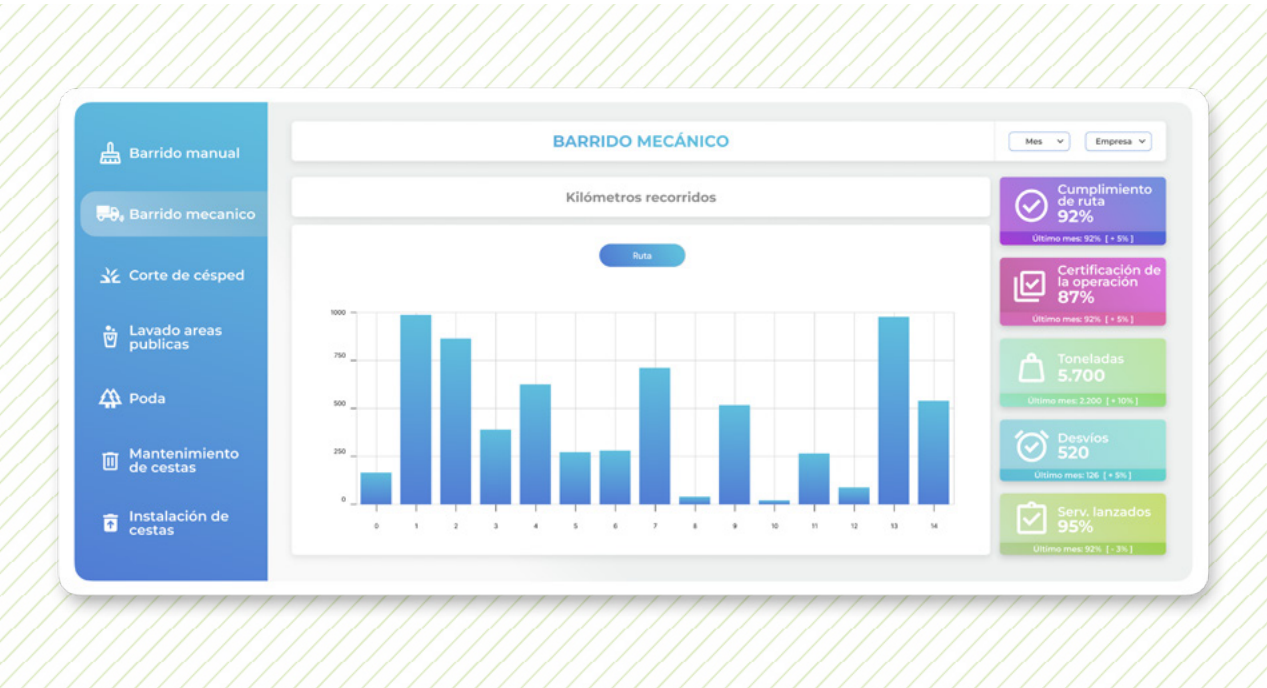
Source: Personal interview with Empresa Pública de Aseo del Municipio de Rumiñahui (EPAR) Operations Manager Pablo Moreno, conducted by Paula Guerra, June 1, 2023.

6.3. Colombia: Pilot in Cleaning and Sweeping Services using Smart Waste Technologies

During the second half of 2023, an SWT pilot was carried out in sweeping and cleaning activities in three cities in Colombia: Soacha, Chía and Medellín. Each of the cities has socio-environmental and geographic differences that were considered when creating a representative sample of service provision.

A review was conducted on the sweeping and cleaning activities, digitalization status of route planning, KPIs, and equipment available to service providers. Based on this information, the necessary hardware was installed, such as: i) GPS in mechanical sweepers, ii) portable GPS for manual sweeping, iii) sensors in equipment for mechanical sweeping, lawn mowing and cleaning public spaces (hydro washing). After this digitization work and hardware installation, the entire cleaning logistics cycle was monitored for punctuality, time and kilometers, kg collected, etc. This data was analyzed and was able to provide an indicator of effectiveness (percentage of service compliance by comparing what was planned with what was accomplished) using digital technologies. This information is reflected in dashboards by type of activity that allow the measurement of trends and improve decision-making.

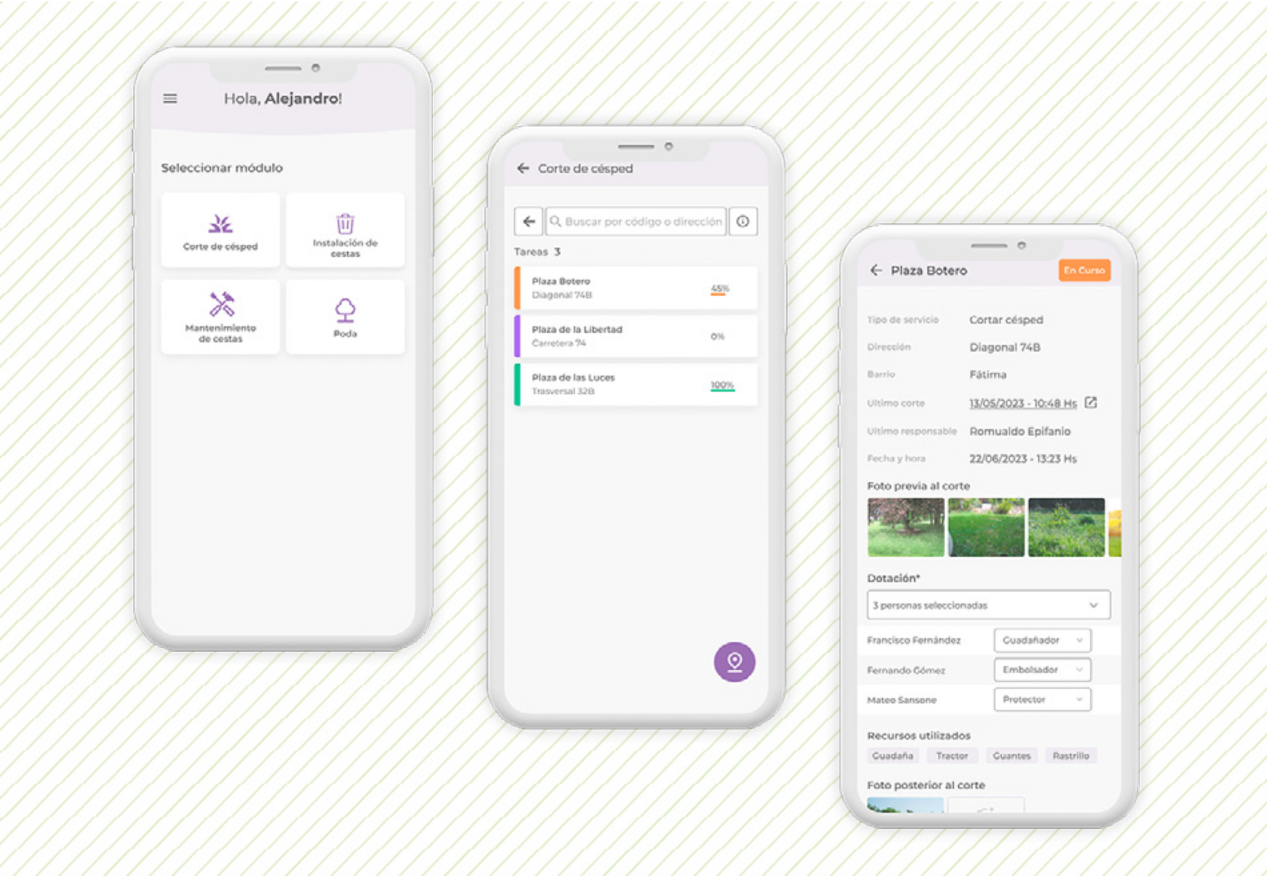
Figure 10. Dashboard with relevant KPIs using digital technologies



Source: Personal interview with Urbetrack Product Manager Gabriela Yael Spector, conducted by Paula Guerra, March 13, 2024.

To ensure satisfactory and reliable certification of urban cleaning activities, development of a mobile App was proposed, which would be centralized and integrated with the fleet tracking web platform. The end user of this App would be managers of the cleaning service. The information would be digitized and very useful for better decision-making.

Figure 11. Visualization of proposed mobile app for cleaning services



Source: Personal interview with Urbetrack Product Manager Gabriela Yael Spector, conducted by Paula Guerra, March 13, 2024.

The following benefits have been identified in keeping with the LAC region cases using digital technologies in cleaning services:

- **Cleaning service provider:** A 30% optimization of the work plan, evidenced in a decrease in kilometers traveled, savings in the use of fuel, and payment of overtime work. In other words, this type of platform ends up paying for itself.

- **Governmental (regulatory) entities:** Allows online control of the service, verification of the agreed frequencies and measurement of their effectiveness, which could allow governments to pay companies for the service actually provided in the case of contractors, avoiding fixed amounts. Furthermore, they can carry out preventive inspections using the mobile App, which generates a 25% reduction in the number of complaints by citizens.

- **Citizens (final users):** Improved quality of service and environmental benefits are also important since the latter generates a decrease of more than 10% of CO_2 gases, accompanied by less noise pollution and less traffic.

Smart Waste Technologies are part of the multi-sector approaches to building smart cities. They focus on understanding the habits and behavior patterns of citizens to meet their needs in a sustainable way. New technologies through IoT devices provide valuable information to improve waste management and help strategic and efficient decision-making.

6.4. Bogotá, Colombia: Operation of the Public Solid Waste Management Service

Some cities in LAC have taken steps to digitalize the sector, such as the case of Bogotá, Colombia, where the Information System for Management and Operation of the Public Sanitation Service (SIGAB), by its Spanish acronym, has been implemented to consolidate information on the operation and management of the service provided by concession holders in each solid waste management service area. The information is available in real time, facilitating the monitoring of activities of different service providers in a timely and efficient manner.

SIGAB enables the consolidation of information on solid waste management services and brings citizens closer to the various solid waste management operators in Bogotá in a transparent way using a variety of digital tools, such as:

- The *Ventanilla Única del Servicio Público de Aseo* (VUSPA), by its Spanish acronym: Single portal of the public solid waste management service, where users can communicate, enter complaints, claims and requests, and consult waste collection routes and schedules.
- App: Application for citizens to have the ability to access the entire system from anywhere and is a mechanism for customer service. The App can be downloaded for Android and iOS.
- Open Data: Access to public information regarding service provision
- Portals: To access news in an agile and simple way.
- Dashboards: To interactively display collection routes and statistical data regarding service provision
- Chat: To communicate in real time with system officials and customer service.

SIGAB systems enables a monitoring center with the capacity to track in real time the entire waste collection and cleaning fleet for each concession holders. The system shows the geographic position and exact location of the vehicle, and gives information on monitoring route time, speed, fuel consumption per kilometer traveled, monitoring the departure from the collection service zone/area, among others. The concession holder's information system is 100% web based. Similarly, the service providers have an automatic system for managing corrective and preventive maintenance of the entire fleet of vehicles used for performance of the sanitation contract.

In relation to financial and commercial management, concession holders have systems that support all financial and commercial processes for optimal management of Bogota's solid waste management service.

Furthermore, the system allows regulatory entities to have access to all information on the activities of the solid waste management service in Bogotá. It also allows coordination of all actors involved in waste generation (residential, commercial, multi-user, small producers), through registration, information updating and consultation of the various stakeholders.

SIGAB guarantees that the waste collection service in Bogotá is carried out under the terms of the contract in an effective, efficient, and transparent manner for the citizens and the oversight of regulatory authorities.

6.5. Barbados: Radio-frequency Identification in Residential Bins

In Barbados and other Caribbean locations, residential bins with Radio-frequency Identification (RFID) chips are being provided to residents for waste and recycling. The Barbados example provides a timely case study for others in LAC to consider.

In 2021, the national solid waste authority in Barbados distributed waste containers and recycling bins with RFID chips to more than 100,000 residential customers, and RFID readers were installed in collection vehicles to track collection frequency. These improvements were intended to provide actionable data that the authority could use to make changes to routes to reduce costs and improve efficiencies (Newamericas, 2021).

The initial results of this improvement to the residential waste collection system in Barbados are very positive. The RFID system is providing useful data to the authority about the amount of waste and recycling being collected, which has resulted in a change in routing, and a reduction in the number of trucks utilized, as well as their emissions and costs. There was initial resistance from some residents to having a tracking device on their waste or recycling bin, but the contention has largely been overcome. There was also some resistance to change, at the authority level, but by partnering with a well-regarded private sector company that educated authority employees and others, workers saw improvements that helped them adjust to the new system. The company that helped the Barbados waste authority implement the use of RFID in waste collection is starting a similar effort in St. Kitts.

Concurrent with the RFID rollout, an anti-litter campaign was initiated in Barbados in November 2021. "Don't Waste Barbados" featured several corporate and governmental partners, beach clean-up events, heavy use of local and social media, and a novel pilot program in which 300 schoolchildren geotagged litter found throughout Barbados.[27] Combining anti-litter messaging with modernization of residential collection systems can be an effective way to engage residents and others and encourage them to support these changes and goals.

6.6. Charlotte, United States: Collection Route Planning

Charlotte is North Carolina's largest city and commercial hub. In addition to providing weekly waste collection services such as mixed waste and yard waste, the City of Charlotte's Solid Waste Services (SWS) department provides extra services such as small business waste removal, bulky waste removal, and dead animal pickup when requested by residents. Since 2018, SWS has used new software for collection route planning and scheduling of this service (OptimoRoute, 2020). The city is required to plan and route up to 2,000 stops for 15 vehicles every day. Using the new software has enabled the city to reduce route planning time for this service from six hours to two hours per day. A key feature of the program is how easily stops can be inserted into already planned routes. The shorter waste collection route planning process enables city staff to spend more time on other responsibilities such as dispatch communication with drivers and handling customer service inquiries. Additionally, because the new software is cloud-based, multiple staff users can access the software from any computer. The City of Charlotte's waste collection services utilize numerous software programs and systems, and this new software has been found to seamlessly integrate with these existing programs. As a result, city employees have found that their entire workflow process functions very efficiently. The city's new software minimizes manual data entry and provides the city with a completely automated waste collection service order.

[27] See "Don't waste Barbados: The anti-littering initiative that's pro-Barbados," at https://www.dontwastebarbados.com/.

7. Recommendations

The implementation of proven or emerging technologies and innovative practices for solid waste collection in LAC provides several important benefits, including more efficient collection systems, increased recycling and waste diversion, reduced impact on the environment, and improved safety performance. In addition, these technologies enable digitalization of the sector, impacting data gathering and analysis for better decision-making and more efficient service provision.

Regarding the use of BI tools, the digital maturity of waste management service providers in terms of internet access, hardware, equipment, and infrastructure is important when deciding on the best software installation option. As such, a general classification of digital maturity within service providers can be defined as:

- **Early stage:** Service providers are using manual methods to design solid waste collection routes and collect, store, and analyze solid waste collection data. There are no GIS capability resources in these operations.
  Consequently, it is recommended that efforts be focused on transitioning to the use of computerized data collection, storage and routing systems, as a first step before considering utilization of BI tools until this transition is completed.

- **Medium stage:** Service providers in this stage are likely to have computerized data collection and routing systems and access to GIS resources. Their staff are also likely to have some IT skills and internet services are likely to be available. Finally, operational services are likely to use computers to collect and store service data and to route solid waste collection vehicles. Consequently, a focus on transitioning their current computerized systems from silo-based systems to integrated and advanced digital collection management systems is recommended. Managers should learn about the availability and capabilities of BI tools. However, they should also understand that the digital transformation of their systems is likely to involve time and money to accomplish and should be prepared to make these investments.

- **Advanced stage:** Service providers in this stage have full GIS capability and excellent internet services along with highly trained IT staff. These entities are in a good position to explore the capabilities and benefits BI tools can bring to their waste collection systems and position them to play key roles in their circular economies.

In terms of SWT implementation and the transition to digitalization of the sector, when considering innovation to their waste collection systems, waste management service providers should conduct an objective assessment of their local capacity to ensure the success of their implementation and whether there is a reliable long-term source of funding to support the process. Communities differ significantly between countries and within the region, hence the ability to acquire new technologies and make operational changes to their collection systems. For example, Managua, Nicaragua and Montevideo, Uruguay may have similar populations, but their solid waste systems, funding sources, and capabilities are very different, so they cannot be expected to implement new technologies or innovative practices in the same way or at the same time.

The transition to digitalization is a progressive process and must be adapted to the customer. The reliability of digital solutions is enhanced when they focus on pain points and significant needs. The best way forward is a step-by-step approach, which should take local capacity into account in the technology selection process. As an example, for waste collection service, the right starting point is usually to first digitalize the asset/container management, to ensure a good base of operations. Then, more flexibility can be added to operations by knowing the number of daily collections and analyzing the response from citizens and communities. Bin sensors can also help improve collection frequencies for larger containers. MSW management in LAC would benefit from the implementation of fleet management software specifically designed for garbage trucks, the use of RFID tagging systems and waste container service tracking software as well as routing software to balance and design routes. However, the most important condition that service providers must achieve prior to the implementation of digital technologies lies in the standardization of processes and services, hence the importance of strategic planning to ensure the continuity of operations and the availability of necessary equipment and human resources.

8. Conclusions

In recent years, there have been significant advances in implementing innovative practices in the solid waste sector around the world. Currently, there are clear examples of the use of technological tools in several cities, especially in more developed countries, such us the United States and Canada, which have made it possible to visualize the impact of more efficient, safe, and transparent systems in municipal waste management, thus enabling the transition toward the digitization of the sector and a circular economy. Latin America and the Caribbean is beginning to move in the direction of innovation processes in the solid waste sector, so the need to have information on global trends in smart technologies becomes essential to identifying the best practices and tools available in the market based on the characteristics of each territory.

The future of solid waste management is digital, and therefore, industry 4.0 or smart technologies are beginning to generate significant interest in the service provision sector in the region. Municipal waste management service providers must move toward operational processes that not only reduce costs, but also meet the expectations of users in terms of obtaining real-time information, as well as generating less environmental impact and contributing to the transition to a circular economy and climate change mitigation. In the LAC region, data collection and analysis are essential to ensure the traceability of waste management processes, the generation of indicators, and the monitoring of management systems. Efficient, timely and reliable information will contribute to the design and implementation of public policies and strengthen the transition to a circular economy; hence, the importance of incorporating smart technologies in the provision of municipal solid waste management services.

The challenges facing digitalization of the sector are significant in LAC, not only because of the cost of technological devices, but also because of the development and maintenance of the digital technologies and systems themselves. Likewise, a digital literacy process is required of the population, related to knowledge and training of the professionals offering solid waste services, but also to develop the interest of the target population in the use of digital technologies. Additionally, data protection and information privacy strategies must be designed and implemented through plans and programs focused on cybersecurity; and ensure an ecosystem for digitization, such as internet access, energy, interfaces between systems and applications, among others. Finally, it is important to have a standardized system to provide municipal solid waste services and the necessary infrastructure. However, examples in the region show this process is advancing in the region with solutions that are adapted in budget and requirements to the LAC context.

Each city and country in the region have its own characteristics, and therefore, the transition to digitalization of municipal solid waste management services is not, and will not be, homogeneous; so the incorporation of technologies and digital development should be done gradually. In this document, special emphasis has been given to determining the use of technologies based on the technological “maturity” of the service provider and the community to be served, to ensure a safe and efficient transition to the digitization of the sector.

The incorporation of innovation processes in public policies of the region’s solid waste sector is essential for the viability of direct budget and administrative processes that allow municipal solid waste service providers to venture into smart technologies in a sustainable manner, and to enable the implementation of scalable projects at the local and regional level. The transition to digitalization of the sector requires a shared effort among all actors in the municipal solid waste chain, and therefore, the promotion of these channels of knowledge, communication, and collective development.

9. Bibliography

Alarcón, P., S. Acosta, L. Breukers, M. Correal, L. Durón, G. González, C. Hernández, C. Piamonte, A. Rihm, A. Rojas, and C. Sagasti. 2023. Evaluación regional de flujo de materiales: residuos sólidos municipales para América Latina y el Caribe. Washington, DC: BID. Disponible en: https://dx.doi.org/10.18235/0004841.

Alhassan Sulemana, E., A. Donkor, E. K. Forkuo, and S. Oduro-Kwarteng. 2018. Optimal Routing of Solid Waste Collection Trucks: A Review of Methods. *Journal of Engineering*, Vol. 2018, Article ID 4586376. Available at https://doi.org/10.1155/2018/4586376.

Benítez-Bravo, R., R. Gómez-González. P. Rivas-García. J. E. Botello-Avellaneda, O. F. Huerta-Guevara, A. M. García-León, and J. F. Rueda Avellaneda. 2021. Optimization of Municipal Solid Waste Collection Routes in a Latin American Context. *Air Waste Manag Assoc*. 2021 Nov; 71(11):1415-1427.

Berg, H., J. Sebestyen, P. Bendix, K. Le Blevennec, and K. Vrancken. 2020. *Digital Waste Management*. Mol: European Environment Agency; European Topic Centre on Waste and Materials in a Green Economy.

Chen, Ch. y H.-T. Pao. 2022. The causal link between circular economy and economic growth in EU-25. *Environ Sci Pollut Res Int*, Oct;29(50):76352-76364. Available at https://pubmed.ncbi.nlm.nih.gov/35668259/.

CiA (CAN in Automation). 2019. CiA® 422 series: CANopen application profile for municipal vehicles. Available at https://www.can-cia.org/can-knowledge/cia-422-series-canopen-application-profile-for-municipal-vehicles.

Deer, R. 2021. Why U.S. cities are ending single stream recycling. *Roadrunner Modern Waster Recycling*, July 8th, 2021. Available at https://www.roadrunnerwm.com/blog/why-cities-are-ending-single-stream-recycling.

Ekins, P., T. Domenech, P. Drummond, R. Bleischwitz, N. Hughes, L. Lotti. 2019. The Circular Economy: What, Why, How and Where. Paris: OECD. Available at https://www.oecd.org/cfe/regionaldevelopment/Ekins-2019-Circular-Economy-What-Why-How-Where.pdf.

El Tiempo. 2016. Emvarias estrena flota de carros a gas. *El Tiempo*, October 28th, 2016. Available at https://www.eltiempo.com/colombia/medellin/emvarias-estrena-flota-de-carros-a-gas-34867.

Farnsworth, T. 2021. Why Are Some Curbside Services No Longer Accepting Glass? *Recycle Nation*, February 11th, 2021. Available at https://recyclenation.com/2021/02/why-are-some-curbside-services-no-longer-accepting-glass/.

Fenston, J. 2020. Most Local Glass Isn't Recycled. Northern Virginia Jurisdictions Are Changing That. *NPR*, February 3rd, 2020. Available at https://www.npr.org/local/305/2020/02/03/802234307/most-local-glass-isn-t-recycled-northern-virginia-jurisdictions-are-changing-that.

-------. 2021. D.C. To Recognize 'Superstar' Recyclers in Each Ward. WAMU 88.5 American University Radio, February 7th, 2021. Available at https://dcist.com/story/21/04/07/dc-recycling-inspection-superstars/.

Greenwalt, M. 2017. A Look at Route Optimization Solutions for the Waste Industry. *Waste 360*, June 26th, 2017.

IDB (Inter-American Development Bank). 2024. Undated. Solid Waste and Circular Economy Hub. Washington, D.C.: IDB. Available at https://hubresiduoscirculares.org/en/.

Jacoby, M. 2019. Why glass recycling in the US is broken, *Chemical and Engineering News*, February 11th, 2019. Available at https://cen.acs.org/materials/inorganic-chemistry/glass-recycling-US-broken/97/i6.

Johnson, M. 2019. Fueling Trash Trucks With RNG. *BioCycle*, May 6th, 2019. Available at https://www.biocycle.net/fueling-trash-trucks-rng/.

Koscinski, K. 2022. Environmental groups and Pittsburgh officials call on Pennsylvania to modernize its recycling system. *WESA On Point*, May 26th, 2022. Available at https://www.wesa.fm/politics-government/2022-05-26/environmental-groups-and-pittsburgh-officials-call-on-pennsylvania-to-modernize-its-recycling-system.

Mavropoulos, A., and A. Waage. Nilsen. 2020. *Industry 4.0 and Circular Economy*. Kindle Edition. Hoboken, NJ: Wiley.

Newsamericas. 2021. The Future of Barbados Does Not Include Waste. May 7th, 2021. Available at https://www.newsamericasnow.com/caribbean-news-barbados-news-the-future-does-not-include-waste/.

NMED (New Mexico Environment Department). Undated. Plan de gestión de residuos sólidos e informes. Webpage consultation. Available at https://www.env.nm.gov/solid-waste/solid-waste-management-plan-and-reports/.

Ohio USEPA (Ohio Environmental Protection Agency). 2017. Solid Waste Management Districts. Ohio, OH: Division of Materials and Waste Management, Ohio EPA.

OptimoRoute. 2020. Waste Collection Service Finds the Features They Need to Get the Job Done. *OptimoRoute*, October 26th, 2020. Available at https://optimoroute.com/waste-collection-route-planning/.

Quinn, M. 2021. Searching for operational insight, MRFs comb data from AI. *WasteDive*, October 6th, 2021. Available at https://www.wastedive.com/news/mrf-robotics-ai-data-recycling-everest-amp-rumpke/606978/.

RCI (Radio Canada International). 2021. Electric vehicles will change how cities look. Just ask the Scottish city of Dundee. RCI, November 12th, 2021. Available at https://ici.radio-canada.ca/rci/en/news/1839407/electric-vehicles-will-change-how-cities-look-just-ask-the-scottish-city-of-dundee.

Redling, A. 2019. How new waste truck technologies are changing fleet management. *Waste Today*, July 19th, 2018. Available at https://www.wastetodaymagazine.com/news/video-telematics-waste-collection-fleet-vehicles/.

Rosengrenm, C. 2022. Waste Management planning $1.6B in ESG investments, says automation and attrition could phase out upward of 7,000 jobs. *WasteDive*, February 2nd, 2022. Available at https://www.wastedive.com/news/waste-management-q4-2021-esg-rng-recycling-automation/618103/.

Sayer, P., and T. Olavsrud. 2021. Top 12 BI Tools of 2021. *CIO*, January 15th, 2021. Available at https://www.cio.com/article/222558/top-business-intelligence-bi-tools.html.

Schwartz, E. 2021. What Does Business Intelligence Mean for the Waste and Recycling Industry? *Waste Advantage Magazine*, December 30th, 2021, Available at https://wasteadvantagemag.com/what-does-business-intelligence-mean-for-the-waste-and-recycling-industry/.

SourceIntelligence. 2023. Packaging EPR Laws in the U.S. *SourceIntelligence*, April 6th, 2023. Available at https://blog.sourceintelligence.com/packaging-epr-laws-in-the-us.

SWANA (Solid Waste Association of North America). 2016. *Managing Municipal Solid Waste Collection Systems: Course Guide*. Silver Spring, MD: SWANA.

The Recycling Partnership. 2020. The Recycling Partnership is Transforming for Good. *The Recycling Partnership*, May 19th, 2020. Available at https://recyclingpartnership.org/the-recycling-partnership-is-transforming-for-good/.

Tomich, M. P., P. R. Vos, and J. D. Underwood. 2024. The Refuse Revolution Leading the Way to a Sustainable Future. *Energy Vision*, January 8th, 2024. Available at https://energy-vision.org/wp-content/uploads/2021/12/The_Refuse_Revolution.pdf.

TouchStar Technologies Ltd. 2020. Vehicle life tracking, route planning, analysis and optimization using cloud computing Waste Logics Software Ltd. (UK): Management software for multiple devices including functions such as real-time order management, route planning and optimization, customer self-service, order-tracking, and evaluation. Manchester: TouchStar Technologies Ltd.

UNEP (UN Environment Programme). 2023. Unlocking Circular Economy Finance in Latin america and the caribbean: The catalist for a positive change. Nairobi: UNEP. Available at https://www.unepfi.org/publications/unlocking-circular-economy-finance-in-latin-america-and-the-caribbean-the-catalyst-for-a-positive-change/.

United Nations. 2022. La Tierra se enfrenta a una triple crisis planetaria. New York: United Nations. Available at https://unric.org/es/la-tierra-se-enfrenta-a-una-triple-crisis-planetaria/.

U.S. Department of Energy. 2014. Clean Cities U.S. Department of Energy, Case Study—Compressed Natural Gas Refuse

Fleets. Available at https://afdc.energy.gov/files/u/publication/casestudy_cng_refuse_feb2014.pdf.

USEPA (U.S. Environmental Protection Agency). Undated. Facts and Figures about Materials, Waste and Recycling. Washington, DC: EPA. https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/national-overview-facts-and-figures-materials#NationalPicture.

Waste 360. 2019. The Most Advanced Fleet Maintenance Software for the Solid Waste and Recycling Industry, *Waste 360*, March 12th, 2019. Available at https://www.waste360.com/fleet-technology/the-most-advanced-fleet-maintenance-software-for-the-solid-waste-and-recycling-industry.

-------. 2021. Six Reasons Why Telematics is a Game Changer for the Waste & Recycling Industry. *Waste 360*, September 16th, 2021. Available at https://www.waste360.com/fleet-technology/six-reasons-why-telematics-is-a-game-changer-for-the-waste-recycling-industry.

10. Annex

All references provided in this publication are illustrative and have no commercial purpose or affiliation with the IDB.

Topic/Category	Description
Communication and education apps	*Ecolana* The platform indicates the nearest sites where recyclable waste can be delivered. The residential generator of waste must verify which materials are received at each collection center. According to the material and quantity, payment is made to the recyclers. These materials are then sent from the collection centers to the recycling centers for valorization. This application is available Google Play and App Store.
Communication and education apps	*Ecoins* This app educates users on how to separate solid waste for valorization and where to drop it off, depending on the material sorted. The user earns “ecoins” points for each drop-off, which can then be redeemed for sponsor products. This application is available Google Play and App Store.
Communication and education apps	*ReciclApp* With this app, users can select a date and time for a recycler to come to their home or business and pick up the separated waste for recycling. It has a gamification process, through “Recikarma” points that can be redeemed for products made out of recycled waste. This application is available App Store, Google Play, or App Gallery.
Communication and education apps	*Recypuntos* This application is available for Android and iOS and can be downloaded through Google Play. Earn points and prizes in the ReciApp. This app is available on iOS or Android.
Communication and education apps	*ReciVeci* This tool connects citizens with grassroot recyclers to recover recyclable materials and deliver it directly and safely into their hands, dignifying their work while citizens. This application allows to connect the generator (home, company, or any person), with the multiple existing solutions in the country in terms of waste.
Communication and education apps	*Scrapp* This App allows consumers to scan the bar code on a product or container to determine whether the item is recyclable and where it can be recycled.
Communication technologies	*LIME*, a service provider in Colombia and Argentina https://www.lime.net.co/page/index
Communication technologies	*Renca*, municipal service provider in Argentina https://renca.cl/renca-limpia/
Temporary storage	*BlauCorp* in México https://www.blaucorp.com/es
Temporary storage	*Urbetrack* in Argentina https://www.urbetrack.com/
Temporary storage	*Isbel* in Uruguay https://isbel.com/sobre-isbe/

Temporary storage	*Big Belly* in USA https://bigbelly.com/
Temporary storage	*Rubicon* in USA https://www.rubicon.com/
Recovery	*Grey Parrot* With the use of AI, it can track more than 67 types of waste with 98% accuracy in sorting plants, displaying mass, count, financial value, food-grade, brand, etc.
Final disposal	*Geotropics* Landfill data gathering using drones and GIS produced a centimeter-accurate topographic model and high-resolution aerial imagery for the technical process to close the Duquesa Landfill in the Dominican Republic.
Commercial management/ customer service	*Solu5IInco* for commercial management of waste collection services. The system monitors and controls commercial management of operating companies by handling user services, invoicing, portfolio, collection, consumption, cut-off, reconnection, portfolio management, and reports. It also has integrated tools such as: a) Tariff System: to manage and calculate collection service rates b) Information analysis and follow-up: to follow-up and control the formats required by control and surveillance agencies c) Plan validator: to guarantee the integrity of the data reported to the control and surveillance agencies d) Consolidation of operations: to consolidate the information of each of the client's operations, facilitating display of information, consultation of statistics, and goal fulfillment, among other useful data for administration of the business.
Commercial management/ customer service	*SOLIN CLOUD* is an open, customizable, modular, and integrated software that allows control the subscribers of the solid waste management service by cycles, routes, neighborhoods, zones, and categories. Efficiently manages the processes of billing, user services, portfolio, and collections, and handles alternatives for taking and recording readings, both manually and by portable terminals. The system allows the individual management, by subscriber, of the contributions and subsidies account, thus enabling generation and support of the account for municipal administration. The system is integrated with subsystems for the administration and control of accounting, treasury and accounts payable, accounts receivable and collections, payroll, billing and sales, etc.
Commercial management/ customer service	Another software is *AMERIKA*, which has the commercial module that carries out this management in the processes of cadastre, contacts, user service, reading and inspection, billing, on-site billing (Online), collections, agreements and deferrals, cuts, reconnections, fraud, re-settlements, letters to customers, customized reports module, portfolio reports, mobility applications for field work, electronic billing, correspondence management and an APP to perform operations (consultation and payment of invoices) from mobile devices (Android and iOS).

BI tools	Microsoft Power BI serves as an analytics tool, facilitating reporting, data mining, and data visualization to offer valuable business insights. With Power BI's user-friendly interface, businesses can seamlessly connect to various data sources and craft personalized dashboards and reports. Originally an Excel add-on, Power BI has evolved into an independent platform, which caters to the needs of organizations, ranging from small businesses to large enterprises, at a relatively affordable cost. With the Power BI Desktop app, users can analyze and visualize data from local or cloud sources, publishing their reports to the Power BI platform. It offers data preparation, visual-based discovery, interactive dashboards, and augmented analytics. There are three versions of Power BI: 1) The free Desktop version is for individual use; 2) The Pro version offers upgraded capabilities for enhanced analytics—this version makes collaborative analysis easier, for a monthly fee, leveraging Microsoft Office365, SharePoint, and Teams to control access to raw data and published reports; and 3) the Premium plan, that operates on a capacity-based model, providing enterprise-level insights, supporting on-premises deployment and featuring a dedicated cloud infrastructure that caters to the requirements of organizations with more extensive data needs.[28] This version makes self-service data prep possible with prebuilt connectors to corporate data held in Microsoft Dynamics 365, Azure SQL Data Warehouse, or third-party sources such as Salesforce (Sayer y Olavsrud, 2021).
BI tools	Domo is a cloud-based business management suite that accelerates digital transformation for businesses of all sizes. It performs both micro and macro-level analysis to provide teams with in-depth insight into their business metrics as well as solve problems smarter and faster. It presents these analyses in interactive visualizations to make patterns obvious to users, facilitating the discovery of actionable insights. Through shared key performance indicators, users can overcome team silos and work together across departments.[29]
BI tools	Visual Analytics is a solution designed to swiftly address intricate inquiries derived from datasets of varying sizes. It facilitates guided exploration, interactive dashboards, smart visualizations, and self-service analytics, catering to users with diverse technical skill levels. By promoting data literacy and visibility, SAS Visual Analytics empowers users to gain valuable insights. The tool's versatile and scalable design ensures that users, regardless of technical expertise, can make informed business decisions through enhanced data transparency. Operating on a cohesive in-memory architecture, SAS Visual Analytics fosters intelligent actions driven by insightful data analysis.[30] SAS offer business intelligence solutions through its Visual Analytics tool, which is available on the cloud and delivered through the microservices-based SAS Viya platform. The tool is designed to automatically emphasize critical relationships within data. The latest version introduces automated suggestions for relevant factors, accompanied by insights presented through visualizations and natural language. Notable features include sentiment analysis for extracting data from social media and other texts, automatic chart generation, mapping capabilities, and self-service data preparation. Deployment options for SAS Visual Analytics encompass on-premises setups, public or private clouds, and the Cloud Foundry platform as a service. Visual Analytics is tailored for users within large enterprises, aiming to meet the diverse analytical needs of this target audience (Sayer y Olavsrud, 2021).

[28] See https://www.selecthub.com/c/business-intelligence-tools/.

[29] See https://www.selecthub.com/p/business-intelligence-tools/domo/.

[30] https://www.selecthub.com/p/business-intelligence-tools/sas-visual-analytics/.

BI tools	Tableau is a comprehensive data visualization and analytics solution that empowers companies to make informed, data-driven decisions. This platform seamlessly integrates information from diverse sources to provide operative, real-time insights. Tableau facilitates data exploration through user-friendly features like drag-and-drop filtering and natural language queries, catering to users of varying skill levels. With robust customization and security options, Tableau provides users with control over data visualization which enables the creation of impactful dashboards and stories that effectively communicate business narratives. The Tableau Creator package (desktop version, Prep, and a Creator license of the server or online version) offers a comprehensive solution for those seeking a powerful and versatile analytics tool.[31]
BI tools	MicroStrategy stands as a data analytics platform that provides actionable intelligence to organizations, regardless of size. The platform enables users to tailor data visualizations and construct personalized real-time dashboards. By leveraging data connectivity, machine learning, and mobile access, MicroStrategy offers users extensive control over their insights. Targeting the Business Intelligence (BI) market across diverse industries, MicroStrategy offers deployment options including cloud, on-premises, and hybrid, providing users with a versatile range of choices.[32] MicroStrategy's platform includes a user-friendly drag-and-drop interface, facilitating the creation of customized data visualizations and the development of personalized real-time dashboards. One of its notable features is federated analytics, enabling customers to maximize their investments in data sources like Tableau, Qlik, and Power BI. This capability allows users to blend data from various sources to construct comprehensive reports and gain valuable insights. Additionally, the platform incorporates an enterprise semantics graph, which indexes data assets. This enrichment process enhances data silos with location intelligence and real-time telemetry, contributing to a more robust and insightful analytics experience (Sayer y Olavsrud, 2021).
BI tools	Dundas BI is a powerful browser-based analytics solution that enables users to generate interactive dashboards, customize their visualizations, build reports and drill down into data. It is flexible and scalable, with a responsive design that lets users integrate data from any kind of source in real time. Accessible from any device, it functions on its own, or users can embed it into other kinds of software.[33] Dundas BI, developed by Dundas Data Visualization, is primarily used for creating dashboards and scorecards, with the added capability of performing both standard and ad-hoc reporting. The platform facilitates analysis and visualization through a web interface that dynamically adapts to users' skill levels. Power users and standard users have different feature availability. In a recent version, Dundas BI introduced a new in-memory engine, natural language query capability, point-and-click trend analysis, support for Linux, and an application development environment for creating customized analytic applications. Dundas BI is tailored for 19 industries, including clean tech, mining, and construction. While it caters to large enterprises, it particularly excels in providing embedded Business Intelligence (BI) solutions, showcasing its specialization in this area (Sayer and Olavsrud, 2021).

[31] See https://www.selecthub.com/p/business-intelligence-tools/tableau/.

[32] See https://www.selecthub.com/business-intelligence-tools/microstrategy-vs-qlik-sense/.

[33] See https://www.selecthub.com/p/business-intelligence-tools/dundas-bi/.

BI tools	Sisense is a comprehensive data analytics platform designed to democratize data discovery and analytics by offering an embeddable, scalable architecture. Powered by in-chip technology on the back end, analysts can seamlessly blend large datasets from diverse sources into a unified, cohesive database for the entire organization or agency. On the front-end, users with varying technical skills can create visualizations, reports, and dashboards to explore and share insights, driving businesses forward. The Fusion offering, Sisense's AI-driven, cloud-native analytics solution, integrates into business workspaces, allowing teams to access key metrics and data insights within their workflow. Suitable for organizations of all sizes, Sisense offers flexible deployment options. It can be deployed on-premises, as a private cloud-hosted Software as a Service (SaaS), as a fully managed SaaS, or through a hybrid strategy. The platform is available through annual subscription pricing and is offered in three packages: (1) BI & Analytics Teams; (2) Product Teams, focusing on embedded analytics; and (3) Cloud Data Teams, offering code-driven cloud analytics.[34]
BI tools	TIBCO Spotfire is a complete business intelligence and data discovery platform that can perform various functions, including in-depth analysis and robust visual reporting, all powered by artificial intelligence. It offers data streaming technology, which can support insights with AI, big data integration, and integrate with the IoT. Spotfire is suitable for large organizations while also scaling well to small organizations, making the software flexible and keeping users in control of their data.[35]
BI tools	Google Cloud, is a modern BI solution that makes insights more accessible by offering advanced data analytics and machine learning capabilities. Through its cloud platform, Google Cloud provides scalable infrastructure and powerful data processing tools that enable waste management companies to analyze large volumes of data, derive valuable insights, and make data-driven decisions to optimize their operations. By leveraging machine learning and AI tools, service providers can improve route optimization, enhance equipment maintenance, and better forecast waste volume patterns. This helps reduce costs, minimize environmental impact, and enhance overall service effectiveness.[36]
ERP systems used in waste management	SAP Waste and Recycling: This ERP system provides a comprehensive solution for managing waste and recycling processes, including logistics, billing, and compliance.
ERP systems used in waste management	AMCS: This ERP system offers a platform for managing all aspects of waste and recycling operations, including customer management, route planning, and material trading.
Cloud based software	MOBA (Germany): cloud computing for container management, customer management, tracking, navigation, and route planning (MOBA - Mobile Automation, 2020).
Cloud based software	AMCS Group (Ireland): connection, standardizing and optimizing internal procedures (AMCS Group, 2020).
Cloud based software	Samsara Networks Inc. (UK).
Cloud based software	Rubicon Global Holdings LLC. (USA).

[34] See https://www.selecthub.com/p/business-intelligence-tools/sisense/.

[35] See https://www.selecthub.com/p/big-data-analytics-tools/spotfire/?from_category=69.

[36] Chat GPT, personal communication, February 21st, 2024.

Cloud based software	TouchStar Technologies Ltd. (UK): Vehicle life tracking, route planning, analysis and optimisation using cloud computing are Ltd. (UK): Management software for multiple devices including functions such as real-time order management, route planning and optimization, customer self-service, order-tracking, and evaluation (Waste Logics Software Ltd., 2020; Berg et al., 2020).
Tracking	*SIGMA Ingenieria* has developed the GeoAseo software, which allows traceability of the planned versus executed collection operation in Colombia. The software is used in 16 solid waste collection operations, covering the routes of more than 500 collection vehicles, and has multiple operation functionalities, such as: i) digitalizing daily operations and tracking planned routes and its execution; ii) telematics of the vehicle; iii) operation supervision; iv) on-line vehicle tracking, among others.
Tracking	*BEE2WASTE* software enforces the control and monitoring of waste collection. This cloud-based management software allows intelligent planning of collection circuits whereby service providers can plan collection routes based on learning the behavior of historical data patterns and in real time (i.e., for each collection route, operators can work with variables such as: i) date and time of collection, ii) zone, iii) waste types to be considered, iv) containers to be considered by their fill level %, v) vehicles to be used, vi) operation center to which the vehicles belong, vii) preferred flow, and viii) possible waste compression rates. The software's modules also allow establishment of: **Container Volume Levels and Predictive Planning** that generates real-time information on the current filling level of selected containers in each area. **Container Inventory and Operation** that allows loading collection points into the system, including all details regarding installation point (type of containers, model, types of waste, etc.); such information can be loaded manually or automatically through RFID reader. **Analysis, KPIs and Dashboards** that provides the most frequently used performance KPIs for municipal waste collection, which are automatically updated; also allows the creation of tailor-made KPIs such as accumulated tons (overall, by waste type, etc.), incident level, collection cost per collected ton or per number of inhabitants, efficiency KPIs and CO_2 emissions.
Fleet management software	*AMCS Route* Planner is an optimization system for both residential and commercial waste routes. It is equipped with route optimization algorithms tailored to the solid waste collection industry. Together with its intuitive user-interface, it provides a useful solution for driving efficiency gains in collection. Part of the solution includes route optimization systems for managing static and dynamic routes. The core service provides two full master plan optimizations per year for commercial routes. The optimization is delivered on a fixed, three-year service contract based on an annual service fee. This planner provides local government agencies and haulers with full control of the cost associated with the service (Greenwalt, 2017).
Fleet management software	*FleetRoute* is built on technology, solving high density routing problems for many applications including the waste and recycling industry. FleetRoute can be purchased as a license so users can create their own routes or utilize the team of professionals at C2Logix to create the routes for them. FleetRoute will create completely customized routes based on a haulers' or local government's specific requirements—including using street data, and the unique parameters of their fleet and work force. The program will calculate the fine details that go into creating real and balanced routes that mimic the reality on the street.

Fleet management software	*RouteSmart Technologies* provides route optimization solutions designed for municipal and private organizations to improve residential and commercial waste, bulky waste, recycling, green waste, organics collection, street sweeping, and snowplow route operations. RouteSmart offers on-premise solutions for route balancing and sequencing, as well as cloud-based services for daily dynamic routing. RouteSmart for ArcGIS has the tools to solve complex routing challenges by continually updating and enhancing powerful algorithms and optimization techniques that model the unique constraints of routing high-density neighborhoods and meeting the demands of commercial service.
Fleet management software	*EasyRoute* helps haulers and local governments design more efficient solid waste collection routes. By optimizing routes, they cut costs by reducing the number of vehicles needed, miles traveled, fuel used, and overtime paid. Used by hundreds of waste professionals, at private haulers and in municipal departments, this route optimization software helps users design better routes.[37]
Fleet management software	*OptimoRoute's* route optimization software enables more efficient and effective waste collection route planning and scheduling and considering all workflow constraints and improving operational efficiency.[38]
Fleet management software	*Dossier Systems*, provides fleet maintenance software and solutions for the solid waste industry. The range of services offered includes preventative maintenance scheduling, parts management, and fuel management. By utilizing Dossier's solutions, fleet personnel can effectively manage costs and ensure the safety and efficiency of their fleets (Waste 360, 2019).
Fleet management software	*Noregon* provides waste management companies software for garbage truck diagnostics and repairs. Called JPRO Professional, the software provides in-shop diagnostic solutions for all makes and models of commercial vehicles. JPRO plugs in and reads the entire vehicle, including engine, transmission, and anti-lock brake system, all in about a minute. It then provides accurate and detailed definitions of more than 99% of DTCs. The comprehensive diagnostic software identifies every issue, so managers can both find and fix more to increase uptime and efficiency. Combined with NextStep Repair, a step-by-step repair guidance tool, maintenance personnel can accurately troubleshoot, and access information needed to complete repairs quickly. With JPRO and NextStep, mechanics have immediate access to real-time diagnostics and repair instructions.[39]

[37] See https://www.goeasyroute.com/solutions/overview/.

[38] https://optimoroute.com/business-type/waste-collection/.

[39] https://www.noregon.com/faqs/#jprofaq/.

Fleet management software	*SoftFlot maintenance software* has more than 1,800 users in Mexico, Central and South America. This system offers a maintenance management module, which shows the status of each vehicle's systems, so that tasks can be scheduled at the most appropriate time and with the least impact. The system lets work orders be assigned for each vehicle by type of maintenance and displays the status of the order (whether open or closed), the number of days the work order has been in progress (open or closed), number of vehicles by type, and maintenance performed per month. In addition, it displays the costs associated with each vehicle in terms of labor and spare parts, as well as all maintenance costs associated with a given vehicle over a period of time, among other useful screens for monitoring and decision- making. This system offers a tool that allows SoftFlot's administrator to evaluate employee performance in resolving incidents, as well as to obtain detailed control of parts and fluids used daily in the workshops. Additionally, it has a tire catalog module, where users have access to data on each vehicle's tire and its general condition (used, new, reserve, etc.), as well as the purchase cost, distributor and warranty. The system provides the ability to analyze each vehicle's performance, optimizing costs. It allows decision making as it generates reports, graphs, data import and export processes, etc.
Fleet management software	Fracttal One is an intelligent software for managing maintenance of physical assets, is 100% mobile, online and in the cloud. This system can upload the assets of the collection company, which in this case are the vehicles, their location, an image, technical data, etc. It has a human resource module where data on maintenance personnel is entered (name, title, photo, digital signature, hourly rate for this resource) which allows the system to display figures for the total cost of this resource when a work order is assigned. The software generates a task plan (type of task, whether preventive or corrective, anticipated duration of maintenance, maintenance downtime, frequency), then includes the subtasks to be performed by technicians and resources required to obtain the maintenance numbers at the cost level. The system displays all pending activities, and assigns and transfers work orders, assigning resources and technicians responsible for their execution. Finally, the system can be used to review management results through the intelligence module, where different types of analysis are available to improve and provide feedback on maintenance management, as well as to learn about fleet maintenance costs and take action to replace equipment or revalue suppliers of spare parts and subcontracted services. This system is used by companies such as Veolia.
Weight control systems in waste collection fleet	Ecoload (Ecoequipos SAS0 based in Colombia, offers the Smart City electronic on-board weighing system, which provides data on the weight of rear-loaded containers per user, records the date and time of collection, and allows the control of overloading in the collection vehicle. It also allows the driver to select net, gross, collected or delivered weights.
Weight control systems in waste collection fleet	MOBA (Mobile Automation), based in Belo Horizonte, Brazil, and in Santiago, Chile. This company has more than 40 years of experience in the development and manufacture of installed weighing technology for various equipment. The MOBA installed weighing line for waste trucks is installed on the chassis and can precisely and accurately weigh all waste collected during the route, eliminating the need for stationary scales. It provides collection data that is sent to the installed display and can be stored on the device or transmitted remotely to the management software, providing the ideal basis for fair, transparent, and proportional charges based on the weight collected.