

UNIT 12 APPLICATIONS OF TECHNOLOGICAL TOOLS IN WASTES MANAGEMENT

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12.1 INTRODUCTION

The digital transformation of society and economy has already established itself as a pivotal development of the twenty-first century, impacting every aspect of everyday life, the economy, politics, and so on. This applies to waste management, including waste reduction, as well as the broader idea of a circular economy. Digital innovations offer a more productive waste management regime, including safer, more transparent, more cost effective, and resource-efficient systems, improved procurement of valuable materials in waste streams, and a more effective connection to other sectors in a future circular economy.

With the modern world's rapid march toward an urban future, the amount of municipal solid waste (MSW), one of the main by products of urban life, is growing much faster than the rate of urbanization. MSW production on a global scale is estimated to be about 1.3 billion tonnes per year, or 1.2 kilograms per capita per day. Ten years ago, the rate of waste generation was around 0.64 kg per capita per day or 0.68 billion tonnes per year. According to a World Bank estimate by 2025 solid waste production will be 1.42 kg per capita per day or 2.2 billion tonnes per year from 4.3 billion urban residents.

Solid waste management (SWM) is the one service that almost every municipality provides to its residents and it is perhaps the most important municipal service and a prerequisite for other more complex municipal services such as health, transportation and education. The complexities and challenges of SWM for municipalities are continually growing as a result of urbanization. It has now become a top priority for SWM authorities, especially in low and middle income countries to improve their services.

SWM's ultimate goal is to monitor, collect, handle and dispose of solid waste produced by various population groups in a cost effective, environmentally and socially acceptable manner. Municipalities are grappling with the problem of optimizing solid waste collection routes, which has a variety of implications for collection quality, expense and pollutant emissions. Many studies on optimization problems such as vehicle routing, capacitated vehicle routing and vehicle routing with time windows have been conducted in order to minimize costs, reduce emissions and better serve customers and depots via optimized routes. However, most of the studies considered static data rather than real time dynamic data for optimization.

Local governments are typically allowed to handle MSW to resolve the aforementioned issues and their laws grant them exclusive rights to waste after it has been put outside. Because of the rising demands for automated data collection, detection, communication, storage and analysis in conjunction with swift and parallel computing, information and communication technology (ICTs) are becoming more important in dealing with the growing problems in SWM. However programs that do not use ICTs have a number of drawbacks, like site selection, collection monitoring, intelligent recycling, inadequate waste disposal and so on. ICTs can assist in overcoming these obstacles and establishing a sound SWM system.

Information and communication technologies (ICT) make it easier to capture process and communicate information. Because of their unrivalled capacity to provide instant access to information from a remote location at a relatively low cost, ICTs provide a creative way to

solve SWM issues. Municipalities can be able to achieve more sustainable cities if there is a clear incentive to use ICTs to achieve comprehensive SWM goals.

ICTs are becoming more important to meet the goals of automated and intelligent SWM systems as the demands for collecting, transmitting and analyzing large amounts of data, as well as fast computational capacity, increase. Though ICTs can address a variety of environmental issues by integrating hardware and software applications, the developing world faces some challenges, which contribute to the continued existence of the 'Digital Divide'. The lack of financial resources, inadequate internet access, a shortage of qualified human capital and a lack of proper policy are the key obstacles to implementing ICT based systems.

Various studies have shown that ICTs can aid in the more efficient management of various types of SWM related issues in terms of expense, time, risk, and the environment. The overall SWM system used to be manual, so there was no precise knowledge about waste generation and processing, resulting in unplanned management. As a result, garbage cans, collection points, disposal points and recycling stations were chosen without proper planning.

Furthermore, waste collection was carried out without taking into account or analyzing demand, and the drivers were in charge of constructing waste collection routes. Garbage bins can be bare or overflowing, resulting in inefficient collection. In certain cases, the resulting disturbed waste proves to be more expensive in terms of re collection effort and environmental risk. However, as cities grow in size, the importance of a well functioning SWM system grows. ICTs are instruments that attempt to exhaust all options for finding a workable solution. However, determining which technology combination would provide the best solution for an efficient SWM system is difficult. Till now many systems have been proposed to settle associated issues and maximize waste management efficiency.

The aim of this chapter is to guide the reader by providing an in depth discussion of available ICTs applied to municipal SWM, as well as literature on how ICTs have been used to solve SWM problems. The classifications in this chapter allow you to choose the right ICTs (or a combination of ICTs) for a specific problem solution. If a solution for site selection, collection vehicle tracking, or waste collection vehicle routing is desired, an ICT or a combination of ICTs that meets those criteria can be easily selected.

Objectives

After studying this unit, you should be able to

- Understand about Digitalisation.
- Know about the various Drivers and Inhibitors in waste management digitalisation.
- Understand various digital technologies being used in waste management.
- List and describe various examples of digital technologies being used in waste management.
- Choose the right ICT for a specific problem.

12.2 BACKGROUND INFORMATION ON DIGITALISATION, WASTE MANAGEMENT AND WASTE PREVENTION

This section provides background information on the topics underlying this unit. Digitalisation, waste management and waste prevention are defined and described.

12.2.1 Digitalisation

“A convergence of advanced technology and the incorporation of physical & digital systems, the predominance of creative business models & new processes, and the emergence of smart products & services” is how digital transformation is characterized. It's important to distinguish between the terms “digitisation” and “digitalisation”. Digitisation, according to the Organisation for Economic Cooperation and Development (OECD), refers to the transfer of information or data from analogue to digital format, while Digitalisation, refers to the adoption or increased use of digital or computer technology (by an organization, an industry, or a country) and thus defines more generally the way digital technologies are affecting economy and society.

According to the OEC widely accepted today, this digital transformation can spur innovation & productivity growth across many activities, transform public services, and improve wellbeing as information, knowledge and data become more widely available. The digital transformation is a complex and fast moving phenomenon with far reaching implications, including business processes and models. As a result, the rate of technology adoption can be influenced by a variety of factors, including the type of industry in which a company operates. Although no single indicator can accurately represent the speed at which technology develops

and spreads, combining indicators can reveal how different sectors are faring in terms of technology adoption. The digital intensity of industries can then be divided into quartiles ranging from most to least digitally intensive, allowing cross-country comparisons over a range of dimensions.

To provide an overview of current digital technology implementation in the waste field, it is first necessary to identify and distinguish the concepts of waste management and waste prevention.

12.2.2 Waste Management and Waste Prevention

Waste management is defined as “the discipline associated with control of generation, storage, collection, transport or transfer, processing and disposal of waste materials in a way that best addresses the range of public health, conservation, economic, aesthetic, engineering, and other environmental considerations. Its scope includes planning, administrative, financial, engineering, and legal functions”

Waste prevention is defined as measures taken before a substance, material or product has become waste, and those reduce:

- i. the quantity of waste, including through the reuse of products or the extension of the life span of products;
- ii. the adverse impacts of the generated waste on the environment and human health; or
- iii. the content of harmful substances in materials and products.

The waste hierarchy shifted waste management's focus away from trash processing to value creation. As a result, the emphasis shifted from high volume, low value materials to low volume, high value materials like copper and gold. They are present in electronic garbage and used cars, and they all require substantial processing to extract the metals. Waste disposal has become increasingly difficult and capital-intensive. As a result, a desire for productivity arose, prompting a never ending search for new technology. At the same time, this produced a tension between waste regulations and market forces such as resource recovery and recycling. Waste was no longer retrieved at its source, but instead at a location with a higher selling price, lesser quality or fewer environmental laws.

The waste management industry is currently undergoing rapid transformation into a circular economy. The driver is increasingly becoming the constraints on materials, rather than the importance of, say, recycling in and of itself. Chrome, cobalt, fluoride, and rare earth elements are only a few examples of scarce resources. This inspires a new policy concept that considers not just how we can use more recycled materials, but also how materials and goods are used. It asks how we can extend the life of goods and maintain the value of materials during their life cycle.

SAQ 1

- a) Explain the need of adopting ICT in solid waste management.
- b) Differentiate between Digitisation and Digitalisation.
- c) Explain Waste Management and Waste Prevention.

12.3 DRIVERS AND INHIBITORS OF THE DIGITAL EVOLUTION OF WASTE MANAGEMENT

Digitalisation is not an end in itself; its implementation in the waste management field should be based on its potential to generate new opportunities or solve current problems. This segment discusses the major drivers which can take the form of opportunities and challenges and inhibitors of the digital transformation of waste management in order to better understand where those opportunities and challenges exist and what the limiting factors are.

Before delving into particular digital technology used in waste management, it's critical to comprehend the fundamental factors that have aided or hindered waste management's digitalization thus far.

12.3.1 Drivers

Opportunities, where the application of digital technologies immediately enhances a particular environment or process, or challenges, where present unfavourable trends might be reversed or mitigated, are examples of driving forces. The majority of these drivers are not uniformly distributed; rather, they behave differently in different locations depending on factors such as population, economic strength, and so on. Urbanisation, demographic change, skill shortages, novel legislation, cost pressures, citizen and customer demands, and new business models have all been recognized as drivers in this respect, and are discussed in greater detail below:

Cost pressure: Cost pressure is caused by competition among commercial trash companies and money allocation for the public waste sector, respectively. Increased efficiency through digital technology can help to counteract this. The change from labour to capital is also an important issue in the business market, which can act as a driving force for digitalization.

Business models: New digital business models emerge as a result of digitalisation, typically established by new competitors. Established players will be forced to follow suit, resulting in more widely used digital tools. While the garbage sector is less affected than other industries because waste cannot be virtualized, some areas of the business are affected. Trading on virtual platforms, in particular, is becoming more popular.

Customer expectations: Many consumers have become accustomed to receiving near real-time updates on order status or the ability to monitor their utilities as a result of digitalization. These expectations are likely to apply to the waste sector as well, and can only be addressed by digital solutions like tracing and tracking or interconnected telematics. Some governments already have real-time information about the delivery of some services, such as waste collection.

Climate crisis: The aim to minimize greenhouse gas emissions implies that land filling (and the associated methane emissions) will be phased out in favour of preventing and recycling garbage, or incineration when necessary.

Extended producer responsibility (EPR): In the current materials management policy setting, EPR technologies have demonstrated their worth. To fulfil the political goals, such EPR schemes will be applied to a wide range of products. Digital technologies can aid in the tracking, monitoring, and transfer of materials and products throughout their life cycle in this situation.

Waste amounts: In the following years, waste volumes are predicted to increase significantly. In a circular economy, handling and lowering these volumes will necessitate significant knowledge (analysis) and management measures, both politically and economically. Digital technologies like data analytics and enhanced logistics can help deal with the essential operations much more efficiently.

Urbanisation: From rural to urban areas, the population has migrated dramatically. In many parts of the world, this trend is projected to continue in the near future. As a result, population density disparities widen, resulting in densely populated cities and their surroundings and

sparsely populated countryside. In locations where population density is increasing, traffic intensity is also increasing, posing problems for waste collection services. Furthermore, plant capacity will need to be expanded. These issues can be addressed with technologies such as digitally improved logistics; traffic oriented collecting methods, automation, and robotics. Conversely, decreasing population densities result in decreased rates of garbage collection and treatment capacity utilization. Digital technologies can help solve such problems by employing advanced logistical techniques like waste pickup on demand.

12.3.2 Inhibitors

While there are numerous elements that favour and drive digitalization, there are also some that slow it down or hinder the use of digital tools due to particular issues. It's also crucial to comprehend these factors, as they have an impact on the efficacy of digital technologies and the likelihood of their application.

Digital literacy: To install and manage the digital technologies, skilled personnel with digital skills are required. However, there is currently a great need for such employees across the whole labour market, and as a result, competition for these abilities is intense. It is particularly difficult for the public sector, which pays relatively low and fixed wages, to compete for these workers. Subcontracting or outsourcing these tasks could be a viable solution to this problem, but it would have an impact on the cost structure. In general, it may be claimed that, especially in a rapidly changing digital age, worker training will be critical. Furthermore, a shift to digital technologies may result in a shift in employment organization. In collection and sorting, low-skilled or uneducated workers could be replaced with fewer but higher-skilled technology experts.

Costs: Digital solutions frequently require a significant upfront investment that pays dividends over time. This will result in a delayed change in technology, notably on the part of public actors, especially with functioning technologies remaining in place.

Security: The essential tasks of waste management, as a critical infrastructure, must rely on operational and secure software and technology. IT system security is crucial because these infrastructure systems are high-priority targets for foreign offensive IT-warfare activities or other groups and individuals. Software must therefore be well designed and carefully tested. Longer development timeframes and greater development costs result from these scenarios.

Digital ecosystem: Many new digital solutions require an established digital ecosystem to function well, as most of these solutions cannot be built alone and rely on a well-balanced system of regulatory frameworks, broadband access and mobile network coverage, data interchange standards, interfaces, and public digital literacy. A lack of interfaces between different software systems and applications inside organizations, as well as between phases in the production and waste management cycle, has been identified as a major impediment in previous studies.

12.4 OVERVIEW OF DIGITAL TECHNOLOGIES AND THEIR CURRENT USE IN WASTE MANAGEMENT

With the introduction of the first semiconducting transistors, a trend began that has continued to this day and is not expected to slow down very soon- digitalisation. In its early days, technology was primarily employed to compute numbers in mathematics. The ability to collect bigger volumes of data was enabled by the connection to sensors, which created the groundwork for digital process automation and control engineering, which has altered most of the manufacturing industry. At the same time, networks have evolved, starting with local networks that connected computers via cables and eventually leading to the internet, which now connects billions of wireless devices.

Thanks to the trend of miniaturisation and the ongoing cost reduction, digital technology is applied everywhere: worn on the wrist as a smart watch, tracking animal movements all over the world, or travelling to the borders of our solar system as satellites.

Robotics, the internet of things, cloud computing, artificial intelligence, and data analytics are some of the most important technology innovations currently in use. They are discussed in more depth in the sections below due to their importance, including in the subject of waste management.

The subject of e-commerce and trade digitalization is another significant technical breakthrough of our time. The shift from retail to online enterprises has had a significant impact on a variety of industries, resulting in new business models and the recognition of data as a valuable commodity. This trend has progressed to the point that digital companies now have the biggest market capitalization. Simultaneously, the field of finance has undergone a similar transformation. Algorithms and computers compete against one other in high-speed trading to rule today's stock market. The rise of Bitcoin in recent years has demonstrated that digital, self-contained currencies may be established. Due to the high number of returned

deliveries that are destroyed rather than resold, e-commerce has already had a significant impact on waste streams and waste management. Every year, almost 20 million items are destroyed in Germany, accounting for approximately 4% of all returned goods.

Another key advancement in surveillance technologies and targeted advertising is automated data processing and evaluation. In 2018, the People's Republic of China built over 200 million surveillance cameras and is working hard to make use of the data. The microphones, cameras, and location sensors integrated into cell phones and smart home equipment around the world are not constantly monitored, but intelligence services may simply access them. Surveillance also plays a role in waste management when sensors are used to monitor containers for level of filling and functional status. Also, behaviour towards waste can be measured and analysed, for example, the sorting behaviour of households or littering in public spaces.

Because of the growing relevance of digital technologies in personal and commercial life, there has been a steady increase in demand for digital security, another critical area of digital technology. The barrier to attack promising targets is minimal since cybercrime can be easily perpetrated without being physically present at the place. As a result, great strides have been made in the development of cryptography methods. Vulnerabilities are frequently caused by bad software implementation or incorrect use of software.

Robotics, the Internet of Things (IoT), Geographical Information Systems, Geographical Positioning Systems, Remote Sensing, Artificial Intelligence, and neural networks are covered in greater depth in the next six subsections. These innovations are expected to have a significant impact on the waste management business.

12.4.1. Robotics

For robots, there is no universally accepted definition. Instead, there are numerous definitions that differ substantially in terms of autonomy, application area, and capabilities. The following are two definitions:

Robot Institute of America defines robotics as “Reprogrammable, multifunctional manipulator designed to move material, parts, tools, or specialised devices through variable programmed motions for the performance of a variety of tasks”.

VDI Guideline 2860 defines as “Industrial robots are universally applicable automatic motion machines with several axes, whose movements are freely programmable (i.e., without

mechanical intervention) with regard to the sequence of movements and paths or angles, and are sensor-guided if necessary. They can be equipped with grippers, tools or other manufacturing equipment and can perform handling and/or manufacturing tasks”

The majority of these definitions, on the other hand, are for certain sorts of robots, referring to machines that have a variety of action alternatives and can perform these actions more or less independently. In recent years, significant advances in mechatronics, sensor technology and production, as well as computer science, have substantially enlarged the boundaries of robot autonomy. Even although some robots, such as the Mars rover or deep-sea diving robots, are designed to perform jobs that people cannot, most robots are designed to replace human labour. This typically applies to tasks that have a few comparable processes and where necessary judgments are made based on clear, digital guidelines. Parallel to these improvements, the cost of the necessary hardware has reduced to the point that specific robots are now affordable to ordinary people - a vacuum cleaner robot can be purchased for around Rs. 25,000. The number of robots in many industries has expanded rapidly as a natural result of this significant price decrease. Even though the use of robots in waste management is relatively uncommon compared to other industries, this development has had tremendous impact.

Robotics is a two-faced technology when it comes to waste management. On the one hand, automation technology, which can be considered as robotics, has resulted in significant improvements in the pneumatic sorting process, and we may expect more breakthroughs in this field. These developments enable the production of high-purity waste streams, which are required for an efficient recycling process. Furthermore, robotic technology will most likely facilitate the collecting procedure as well as the logistics involved in waste handling in the future. Robots, on the other hand, are involved in every step of the modern manufacturing process, from resource extraction through packaging and shipment of finished items. This resulted in a significant boost in production as well as the acceleration of miniaturization. However, once utilized and destroyed, all of the commodities produced become garbage. As a result, when looking at the big picture, automation and robots are at the root of an issue that they can help solve.

There are several examples of robotics in the waste management sector as listed below:

- Daisy, a robot, dismantles up to 1.2 million obsolete i-Phones every year, allowing for the recycling of components such as tin, aluminium, and cobalt, which are utilized in the manufacture of batteries (Apple, 2020).
- MAX AI is a robot that uses a vision system that is constantly enhanced by Artificial Intelligence to recognize and sort recyclables (BHS, 2020).
- Remeo and Zen Robotics (Finland): Image recognition and IR scanning are used to create a robotic waste sorting station. In a learning process, one robotic arm can choose more than 2,000 items per hour, increasing its precision typically over 90%(Zen Robotics, 2020).
- Sorting machine for common batteries based on their composition. It can sort up to 500 kg per hour with 97 percent accuracy using Artificial Intelligence (Refind Industries, 2020).
- Street sweepers that are autonomous and self driving (Autowise.ai, 2020 & ENWAY, 2020).
- Refuse truck that is autonomous and self driving (Volvo Group, 2020.)

12.4.2 Internet of Things

The internet of things (IoT) refers to the trend of more and more gadgets being connected to the internet or other networks, even if the connection is not their primary purpose. The digitization and networking of household equipment such as TVs, smart light bulbs, washing machines, and refrigerators that can be accessed remotely or even communicate with each other are examples in the smart home environment. Other examples in the industry 4.0 context include the networking of manufacturing machines and monitoring the entire production environment, as well as the networking of road users and sensors that monitor current traffic status in the traffic context.

The advancement of wireless network and communication technology was a necessity for the Internet of Things (mobile radio, Wi-Fi, Bluetooth, NFC). Other essential components that contributed to this technology include miniaturization and mass production of the requisite hardware. It has only become viable and economical to integrate connectivity and functionality into many gadgets as a result of this advancement. The attraction of this advancement comes from the assumption that the data and functionalities it makes available would provide wholly new insights and opportunities. Predictive maintenance to reduce downtime, smart metering for supply-related power consumption and traffic jam reports

based on user movement patterns are all examples of this type of technology. However, there are concerns associated with IoT, such as citizens being completely monitored not only by the government, but also, and most importantly, by companies or criminals who acquire unauthorised access to the data acquired in this fashion. Another issue is device security; for example, corrupted IoT devices are utilized in distributed denial-of-service attacks, and it is possible to see the live stream of thousands of surveillance cameras with inadequate access restrictions.

The waste and recycling business can benefit from IoT in a variety of ways, including sensor-enabled containers, simple electronic document processing, and vehicle networking to improve logistics. Sensor-enabled containers capture information like container location and fill level. This information is sent to a central unit, where it is used to improve workflows such as pick-up routes. In some innovative cities, this technology is being used at an early level. RFID tagged rubbish bins, for example, can help with electronic documentation. They make it simple to document failures in collection or sorting, as well as the detection of unpaid waste bins. The technology has been proved and used for years; for example, Germany has several million RFID enabled garbage containers in use. Related technologies, such as cyber physical systems and digital twins, are projected to help with information flow in the long run, facilitating recycling. Below are several examples that are already available, as well as several that are under development.

Smart bins (remotely monitored and managed waste bins, enabled by level measurement): Bigbelly Inc. (USA), Ecobins (Croatia), EConX Waste Solutions B.V. (Netherlands), Nordsense (Denmark), Oneplus Systems Inc. (USA).

C-trace GmbH: Ident-system (RFID-based identification systems for identifying bins and counting emptying) and weighing system for weight-based billing are incorporated into software modules for garbage vehicles.

Smart Recycling AB (Sweden): Emptying logistics are optimized using level sensors and container GPS coordinates.

StalkIT AS (Norway): By measuring and communicating location, movement, and temperature, items such as containers can be traced and tracked.

TeXXmo Mobile Solution GmbH: “IoT Button”, a physical button that can be programmed to start pre-determined activities, such as container collection.

12.4.3 Geographical Information System

A Geographical Information System (GIS), often known as geospatial or geographically referenced data, is a computer-based information system that can collect store, manage, integrate, alter, analyze, and display geospatial or geographically referenced data. The value of GIS systems rests in the ability to organize these data into thematic layers by creating digital maps. Visually analyzing data aids in the identification of patterns, trends, and linkages that may not be apparent in tabular or written form. A GIS typically comprises four types of components: spatial data production, data management, cartography and display, and data analysis. Data capture, quality assessment, input data, and format conversion are all part of the spatial data generation process. The spatial data in GIS might be in one of two formats: vector data or raster data. All vector attributes are related to the same coordinate in vector data format, and maps are formed up of points, lines, or polygons. The maps in raster data format are made up of a series of grid cells, each of which has a colour value that represents what is contained in that cell. GIS in conjunction with other spatial and communication technologies aids in the capture, communication, and analysis of spatial data for the planning and design of many applications. SWM, urban utilities planning, natural resources management, transportation, forestry, natural catastrophes prevention, geology, and many facets of environmental modelling have all seen success with it. Researchers in several studies developed an innovative dynamic scheduling and routing approach combining GIS to reduce MSW collection operating costs and pollutant emissions in Barreiro, Portugal. The research proposes a novel way for lowering operational expenses and pollutant emissions associated with waste collection and transportation. For efficient waste collection, it combines dynamic scheduling and routing. The traversed routes optimization approach uses a GIS and total spent time and covered distance as optimization criteria. As part of the optimization process, the model examines variables such as fuel usage, pollutant emissions, truck speed, and transported capacity. The subject of glass garbage collecting and transportation is evaluated experimentally. The strengths of the system are its GIS integration and powerful dynamic scheduling and routing models. However, the system only uses data from a small number of data collecting devices. Furthermore, it could only be used for the specific type of glass waste bin.

12.4.4 Geographical Positioning System

The GPS (Global Positioning System) is a global navigation and positioning system based on a constellation of several satellites and ground stations sent into orbit by the US Defence Department. Although the GPS was originally intended for military use, the US government later decided to make it available to civilians as well. Since then, GPS has been widely employed for a variety of civilian purposes on land, sea, and in the air. The GPS system is split into three subsystems: the space subsystem (satellites), the control subsystem (ground stations), and the user subsystem (users) (GPS receivers). The space subsystem consists of 24 satellites that operate at a distance of 12,000 miles upon the Earth's surface. These satellites are arranged in such a way that a GPS receiver in any location on the planet can receive signals from at least four satellites at any given moment. Satellites broadcast low-power radio signals that require line-of-sight. The control subsystem directs the satellites and delivers correct orbital and temporal information. There are five stations spread over the globe. Every individual user with GPS who may make queries about his or her spatial information is part of the user sub-system. The use of GPS in conjunction with other spatial and communication technologies, particularly GIS, aids in the tracking of collection vehicles and trash bins for the purposes of observing position and collection time. It works well with a variety of SWM systems to ensure that activities run smoothly while lowering costs and effectively managing vehicles and staff. The researchers created a system that focuses on GPS and other traceability technology for optimizing solid waste collection routes and costs in a study. Bins installed with sensing technologies, as well as a vehicle equipped with a GPS receiver, RFID receiver, weighing system, GPRS module, and a mobile laptop running vehicle traceability software. The control server parses GPRS/GPS network data to collect data from bins and truck locations. The GIS subsystem and the routing sub-modules access the central database, which contains bin positions and local maps. The well-defined architecture for enabling traceability and monitoring, as well as the suggested dynamic scheduling and routing models, are the strengths of the system.

12.4.5 Remote Sensing

The modernized use of aerial sensing technologies for identifying and classifying items on the earth surface from a remote platform via signal propagation such as electromagnetic radiation from satellites or planes is known as remote sensing (RS). The electromagnetic radiation gathered by RS is converted into a digital image that can be superimposed with

additional spatial data in RS. Sensors, data communication tools, image processing tools, and a working platform are usually included in an RS device bundle. The researchers used leachate and gas emissions from landfills used for domestic waste disposal to construct a methodology for landfill site selection in a study. In a metropolitan area of Jiangsu Province, China, the system analyses remotely sensed environmental elements in close vicinity to landfills and evaluate compliance of their placement and leachate quality with applicable national standards. The study used remote sensing technologies and a GIS database to analyze whether data from five landfills in the Wuxi and Suzhou metropolitan areas of Jiangsu province complied with national environmental and public health standards. The strength of the system is the creation of a remote monitoring framework for choosing a landfill site that takes into account man-made environmental problems in order to avoid potential health problems. Disposal site selection, environmental features and impact monitoring for solid waste disposal sites, and environmental effect assessment of buried waste are all applications of RS based systems in SWM.

12.4.6 Artificial Intelligence and Neural Networks

Intelligent systems, in general, are distinguished by their capacity to solve issues independently and effectively. Artificial intelligence is attempting to do this through the use of digital solutions. There are several ways, the most well-known of which is machine learning utilizing neural networks. It relies on the use of data or examples rather than explicit programming to solve problems. Classification/pattern recognition is a good example, and it's also utilized in waste management. Neural networks are commonly utilized for this task; they are made up of interconnected layers that calculate the input data. These neural networks are trained using a large amount of data. We use the terms "deep network" and "deep learning" to describe the huge number of these levels. On the one hand, the precision of the networks is determined by how the layers are connected, but on the other hand, it is mostly determined by the amount and quality of data utilized to train these networks.

Sorting applications that use image recognition, autonomous vehicles and sweeping robots are examples of AI applications in the waste management sector. AI may also make it possible for collection to occur at the most appropriate periods (route optimisation and predictive pick-up). The existence or collection of data sets, such as by equipping collection trucks with sensors, is a necessity for this. Customer service can also benefit from AI, such as

when speech recognition is used to route a call to the appropriate staff or while training chatbots. This program has the potential to improve service and reduce communication in municipal service centers, as well as service departments. Furthermore, citizen information services such as proper domestic sorting, household waste management, and so on can be provided more efficiently. In Hamburg, artificial intelligence is being utilized to classify illegally deposited waste using picture recognition in order to facilitate disposal. Specific examples include,

Autowise.ai (China), Enway (Germany): Cleaning vehicles that are autonomous and self-driving that undertake cleaning jobs in commercial or public spaces.

Volvo Group and Renova (Sweden): Autonomous, self-driving refuse truck for curb side collection (Volvo Group, 2020). An increase in reverse driving enables time savings.

Remeo and Zen Robotics (Finland): Image recognition and IR scanning are used to create a robotic waste sorting station. Gripping robots scan waste and arrange it into several containers. Adaptation to new sorting fractions can be simply implemented with the help of AI.

Stadtreinigung Hamburg (Germany): For illegal littering, AI image classification is used. Citizens can use their smart phones to photograph illegal littering. The photos are classified by software, which then sends them to the relevant agent.

SAQ 2

- a) List and describe the various factors that aid waste management digitalization.
- b) List and describe the various factors that hinder waste management digitalization.
- c) Write short notes on Robotics, Geographical Information System and Remote sensing

12.5 APPLICATIONS OF DIGITAL TECHNOLOGIES IN WASTE MANAGEMENT

Several applications are shown in these sections that demonstrate how digital technologies are used for various activities in the waste management business. Each type is presented in aTable1 to facilitate comparison and provide a rapid summary.

Table 1: Digital Technologies in Waste Management

Type	Features	Technologies Used	Benefits for Waste Management
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<p>Robotic Waste Recycling System</p>	<ul style="list-style-type: none"> • Using camera and near-infrared (NIR) input data, an AI system can be trained to sort a waste stream. • Waste is transported on a conveyor and then sorted into different bins using an x-y-z axis robotic system. 	<ul style="list-style-type: none"> • Sensors • AI Image classification • Robotics • Data Analytics 	<p>The technology can quickly adapt to new waste streams and can sort waste into different fractions with excellent purity. As a result of the increased purity, high grade secondary material is produced and the recycling process requires less down cycling.</p>
<p>AI based sorting technology for plastic waste</p>	<ul style="list-style-type: none"> • Plugin into existing sorting lines as an add-on to existing sorting technology • By giving the classification algorithm more features, it enhances sorting accuracy. • is a machine learning algorithm that is learned using a huge amount of sample data. • Negative sorting of PE silicone cartridges and 2K adhesive cartridges at the actual stage 	<ul style="list-style-type: none"> • Sensors • Data analytics • AI image classification • Automation 	<p>Impurities that would otherwise go undetected can now be discovered due to this technology. Even small concentrations of rejected compounds, such as silicone in PE cartridges, might have a severe impact on recycled quality.</p>
<p>AI-based litter identification</p>	<ul style="list-style-type: none"> • Citizens can take a picture of illegally discarded waste and report it using this app for mobile devices. • The photo and GPS coordinates of 	<ul style="list-style-type: none"> • Mobile device including camera and GPS sensor • Data analytics • AI image 	<p>The system decreases the amount of human labour required to process reports of illegal littering. It is used to plan out the proper removal procedures ahead of</p>

	<p>the cluttered location are sent in. The images are classified by an AI system before being forwarded to the appropriate person in charge.</p>	<p>classification</p>	<p>time.</p>
<p>Autonomous refuse truck for waste collection</p>	<ul style="list-style-type: none"> • Normally, competent drivers and co-drivers are required for collection; however, this technology enables for less experienced employees and single crewed driving. • When emptying bins, collection employees can walk alongside the autonomous truck, reducing the amount of time spent getting in and out of the vehicle, which can be a health concern and a source of accidents. 	<ul style="list-style-type: none"> • Sensors • Data Analytics • Autonomous Driving 	<p>By decreasing the crew required for a waste collection vehicle, autonomous driving for rubbish collection can help to alleviate labor shortages in the waste sector in some areas. Additionally, there may be cost savings connected with the technology, allowing funds to be allocated to more critical duties. By decreasing the crew required for a waste collection vehicle, autonomous driving for rubbish collection can help to alleviate labor shortages in the waste sector in some areas. Additionally, there may be cost savings connected with the technology, allowing funds to be allocated to more critical duties.</p>
<p>Automated vacuum collection</p>	<ul style="list-style-type: none"> • Different sorts of home waste are collected in colour bags at street collection locations. • Using suction, an 	<ul style="list-style-type: none"> • Sensors • Data Analytics 	<p>The technology has the ability to reduce the traffic impact of waste collection while also allowing for the design of urban quarters without taking into</p>

	<p>underground tube system pulls the bags to a central place where they may be readily collected.</p> <ul style="list-style-type: none"> • A scale and an RFID identification device are employed to collect real-time data on garbage volumes. • According to the manufacturer, this can be utilized to modify user behaviour and increase recycling rates. 		<p>mind the demands. It's possible that waste volumes can be reduced.</p>
Bin sensors	<ul style="list-style-type: none"> • Sensors gather vibration data from waste bins. • Analysis and real-time visualization of container levels to boost waste logistics efficiency • In the analytics platform, data is analyzed using AI. 	<ul style="list-style-type: none"> • Sensors • Data analytics • AI algorithms • Cloud computing 	<p>Improved logistics through waste collection route optimization, which reduces needless traffic and, as a result, air pollution and associated costs are reduced</p>
Software as a Service Mobile application	<ul style="list-style-type: none"> • On demand waste collection with a mobile app • A digital marketplace (similar to an auction) that connects a network of waste collectors with (mostly commercial) 	<ul style="list-style-type: none"> • Cloud computing • Data analytics • Automation 	<p>This application seeks to save businesses money on waste removal (orders are made only when needed). Traceability along the waste recycling value chain is made easier for these enterprises, in addition to greater convenience.</p>

	clients (caterers, SMEs, hotels, etc.)		The profits from recovered materials are split between commercial waste generators. This could also be a motivator to improve the waste collection quality.
Software as a Service Intelligent Waste Transport Optimisation	<ul style="list-style-type: none"> Automated scheduling based on real-time data for waste transportation planning optimization The solution includes fleet management, route planning and optimization, and routing services, and is supplied as an integrated part of the service provider's platform or as a third-party ERP system interface. Based on recurring client visits, the master routes are created and optimized in the route planning system. The master routes are then passed automatically to the Fleet Planner, which handles both operational planning and actual 	<ul style="list-style-type: none"> Cloud computing Sensors AI algorithm Data Analytics 	Waste collection operations will be more efficient, and the number of vehicles required will be reduced, lowering associated transportation emissions.

12.6 SUMMARY

Individual digital technologies are now capable of dealing with every aspect of the waste management system, from operational and logistical activities such as collection and sorting to communication. In general, the main focus in each case is on increasing efficiency through automation or support, although improving service is also crucial. However, there has yet to be developed a completely integrated digital system that encompasses the entire waste management industry. This gap is expected to be bridged by emerging technologies and their integration. Furthermore, while highly automated or even autonomous systems are expected to develop, completely autonomous collecting vehicles may be ten to twenty years away..

Economic drivers such as cost pressure, environmental drivers such as climate protection and the growing importance of the circular economy, and drivers from other sectors such as urbanisation have all been recognized as drivers for the deployment of digital technology today and in the future. Knowledge gaps about the usage and implementation of digital technologies, as well as its chances and opportunities, are frequently mentioned as inhibitors. Furthermore, the lack of appropriate digital infrastructure, such as mobile communication networks, is an issue.

Digital technologies have been shown to present numerous prospects for waste management, waste prevention, and the circular economy. Digitalisation and automation help waste management to expedite processes, allowing it to handle increasing volumes of garbage and materials while also supporting its shift from waste handling to material management in a circular economy. Robotics, the internet of things, cloud computing, and artificial intelligence are currently the important digital technologies in the field of waste management.

Tasks that are hazardous to humans can be automated, processing efficiency can be raised, waste streams can be purified more effectively through enhanced sorting, and the portion of waste that is recycled rather than burnt or land filled can be enhanced. Furthermore, citizen and consumer communication can be improved and streamlined.

Even while public actors gather and make waste data available, there is still a significant knowledge gap that has to be filled through research. In order to reduce our society's environmental impact, further research on digital recycling technologies and waste

prevention is needed, with a focus on waste prevention and the full circle. A horizon scanning analysis should be performed in order to more explicitly detect and recognize digital technologies that can aid in the achievement of the goals specified for sustainable waste management.

Various other industries have seen drastic transformations as a result of new digital opportunities, resulting in wholly new business models. Established players who had dominated their industry for decades have been eliminated as a result of these changes. Similar changes may occur in the waste sector, though they will be less drastic because the primary feature, garbage, cannot be virtualised and municipal players cannot be put out of business.

SAQ 3

- a) List the features and benefits for waste management while using Robotic waste, Recycling system, Autonomous refuse truck for waste collection and bin sensors.
- b) Write short note on the key points to be taken from this unit.

12.7 KEY WORDS

Digitalisation: A convergence of advanced technology and the incorporation of physical and digital systems, the predominance of creative business models and new processes, and the emergence of smart products and services.

Digitisation: Transfer of information or data from analogue to digital format.

Internet of Things: The internet of things refers to the trend of more and more gadgets being connected to the internet or other networks.

Geographical Information System: Computer-based information system that can collect, store, manage, integrate, alter, analyse, and display geospatial or geographically referenced data.

Remote Sensing: Modernized use of aerial sensing technologies for identifying and classifying items on the earth surface from a remote platform via signal propagation such as electromagnetic radiation from satellites or planes.

12.8 ANSWERS TO SAQs

SAQ 1

- a) Refer section 12.1
- b) Refer section 12.2.1
- c) Refer section 12.2.2

SAQ 2

- a) Refer section 12.3.1
- b) Refer section 12.3.2
- c) Refer section 12.4.1, 12.4.3 and 12.4.5 for Robotics, Geographical Information System and Remote sensing respectively

SAQ 3

- a) Refer the table in section 12.5
- b) Refer section 12.6

FURTHER READINGS

1. <https://www.iotforall.com/iot-applications-waste-management>
2. <https://www.rtinsights.com/iot-makes-smart-waste-management-efficient>
3. <https://www.medium.com/smart-waste-management>
4. <https://www.allerin.com/blog/revolutionizing-waste-management-cycle-with-iot>