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Using GIS to Optimal Routing of Solid Waste Collection Trucks

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Abstract: Managing solid waste is a significant issue in many industrialized and developing nations. The greatest and priciest component of waste management is solid waste collection. The improvement of collecting solid waste is very important because of its overall cost reduction and positive environmental impacts. This paper reviews the impact of using GIS-based improvement techniques for solid waste collection. The optimization process using GIS is unique compared to other solid waste collection optimization techniques that provide temporary solutions when applied. GIS provides room for additional parameters to be addressed during the optimization process, including street modeling. GIS has proven its efficiency in optimizing solid waste collection through shortest path selection using the Dijkstra algorithm and modeling processes using model builder.

1. Introduction

Waste is excess material, anything that the owner wants to dispose off, or leftover product or material (Christensen, 2011). The transformation into "waste" may depend on various conditions, including time, location, state of material, income level, and personal preferences (Christensen, 2011). Waste comes from domestic, commercial, and agricultural sources. It might contain chemicals, dangerous items, sewage, food scraps, and packaging materials. It can be a gas, liquid, or solid (Abdulredha et al., 2018, Gupta et al., 2023). SW is any item thrown away that is neither liquid nor gaseous (Gupta et al., 2023). SW is the leftover material from production processes; it can also be referred to as rubbish, garbage, or rubbish, based on the kind of substance and local vernacular or domestic or communal activities (Sulemana et al., 2018). The following factors are used to characterize SW: its sources, the types of waste generated, generation rates, and composition (Ahmade, 2013). Globally, SW has grown to be a persistent problem, worldwide. Because of population growth and urbanization, it has been rising at an exponential rate (Gupta et al., 2023). Iraq's SWs have emerged as a major source of pollution and environmental problems because of the state of the nation, the absence of contemporary waste management systems, and inefficient infrastructure (Ahmed et al., 2020). So, to reduce the dangers to the environment and public health, proper management of SW is essential. SWM is an extremely complicated process for the reason that it includes modern technologies and disciplines for managing development, handling, storage, collection, transfer, transportation, processing, and disposal (Kallel et al., 2016), as depicted in Figure 1.

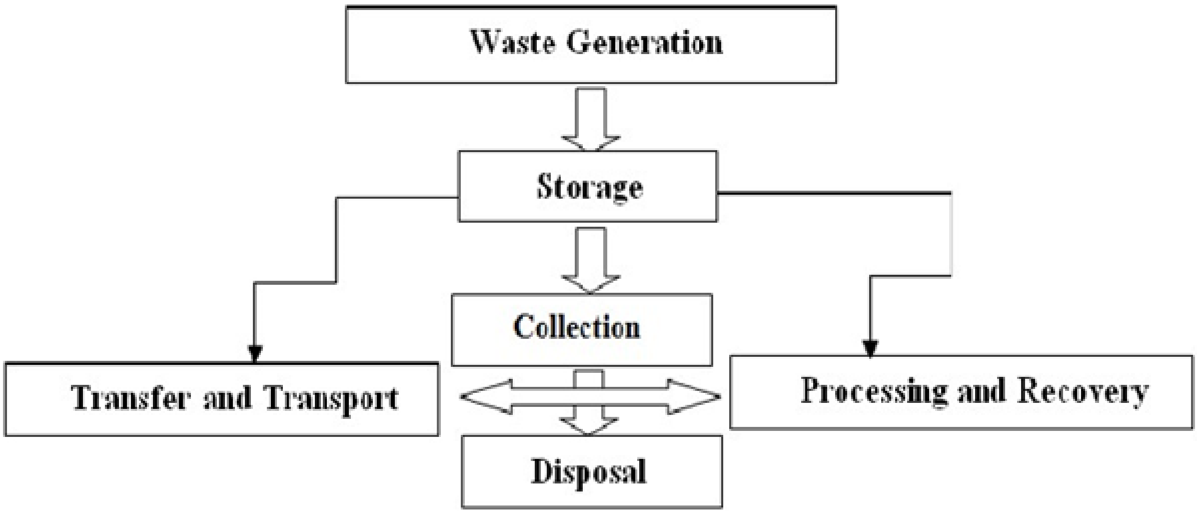

Figure 1: Schematic diagram of SWM (Rishi Rana, 2017)

SWM differs greatly between developed and developing countries, as well as between urban and rural locations (Ahmed et al., 2020). SWM is one of the crucial services that the majority of advanced governments offer (Salomons, 2012). This is beyond the capacity of municipal governments in developing countries to manage SW (Sulemana et al., 2018). One of the primary issues facing emerging economies is the creation of an efficient and environmentally efficient SWM system (Sulemana et al., 2018). The high rate of waste generation, which is a result of population growth and rapid urbanization, limited financing, citizens' bad attitudes toward waste disposal, and a lack of political will, all contribute to the situation (Sulemana et al., 2018). With forty million people living, Iraq is among the nations whose populations are expanding quickly (Al-Mohammed et al., 2022). The projected daily production of trash in Iraq is 31,000 tons; on average, a person creates 1.4 kg of rubbish each day (Al-Mohammed et al., 2022). In Iraq, the process of managing SW is Unfortunately limited three simple stages: collection, transportion, and disposal, because of a lack of infrastructure, machinery, and services, among other factors, but an effective system should handle at least four fractions of the waste's generation: storage, collection, transportation, processing, and final disposal(Ahmed et al., 2020). Any of these processes with poor design might lead to environmental impact and higher operating costs (Sulemana et al., 2018). One of the most critical elements of any SW system of management is the collection and transportation of solid trash (Sahib and Hadi, 2023). Many suggested that collection explains a sizable portion of the entire cost of SWM (Sahib and Hadi, 2023). Reducing collection and transportation expenses is necessary for emerging economies to achieve sustainable SW management (Jay Patel1, 2023).

2. Solid Waste Collection (SWC)

The main point of any SWM system is its collection component, which facilitates the evaluation of the system's overall efficacy and costs. (Kallel et al., 2016). A significant portion of the SWM process is SWC, which is thought to account for up to two-thirds of the total SWM expenditures (Malakahmad et al., 2014). The increasing amount of solid trash generated by global population growth, production, and consumption activities poses a significant socio-environmental challenge for waste collection (Del Carmen-Niño et al., 2023). SWC is essentially the process of collecting waste products from certain locations, like street-side bins, dumpsters, or shared containers, in a methodical manner (Kallel et al., 2016). SW is collected from a variety of sources and transported to a designated place where the collection vehicles' contents are emptied (Sulemana et al., 2018). As a result, Since it uses up the majority of the money that municipalities have set aside for SWM at the expense of other system functions, it is the most costly and significant component of the SWM system.(Kallel et al., 2016), due to a large workload and widespread use of trucks (Sulemana et al., 2018). Thus, the task at hand is to execute the best possible garbage collection and transportation process (including hauling, equipment and manipulation) (Kallel et al., 2016).

Unfortunately, a lot of developing nations face difficulties with SWC and transportation (Wilson, 2007). Because of the enormous costs connected to delivering the service, local governments in underdeveloped nations have been not able to control SW, effectively (Sulemana et al., 2018). Funds allocated for garbage management are becoming less plentiful globally, which makes the situation worse (Sulemana et al., 2018). A portion of the waste produced is collected as a result of inadequate funding for SWM, while the remainder ends up in unapproved disposal sites that pose major hazards to the public's health and the environment (Amoah and Kosoe, 2014). The operational scheduling , vehicle routing of SWC, and transportation are key aspects as well. There are daily schedules for drivers. SWC in their designated operational regions during this process. Previous research has indicated that inadequate infrastructure, low numbers of garbage collection vehicles, inappropriate bin collecting systems, and bad collection schedules all have an impact on the collection processes (Moghadam et al., 2009, Hazra and Goel, 2009). The collection of SW is adversely affected by bad road conditions, among other things like the total number of vehicles on the road (Sulemana et al., 2018). Inadequate road systems result in frequent vehicle breakdowns, raising maintenance costs at the expense of revenue (Amoah and Kosoe, 2014). For example, it is difficult for waste collection trucks to navigate and pick up waste along the city's tiny roadways, giving informal waste collectors a significant competitive advantage (Hazra and Goel, 2009).

A. SWC Strategies

The objective of SWC strategies is to handle community garbage disposal properly and efficiently. A waste collection vehicle begins its journey in the garage, stops at participating homes along the way, and then returns to the collection sites (Maimoun et al., 2016). Once the collecting journey is over, the vehicle takes the rubbish to the post-collection location (such as a waste-to-energy facility, transfer station, or landfill). Once at the post-collection facility, the waste collection vehicle returns to the garage empty (Maimoun et al., 2016). People need to recognize that to maintain the community and environment, a good waste collection service requires citizen cooperation in the provision and usage of appropriate receptacles (Tadesse, 2004). Various SWC system types are being used, as listed below:

1. **Curbside:-** Using this method, Residents fill the containers at the curb with their MSW on the day of collection, and collectors pick them up and load them into their cars. (Yadav and Karmakar, 2020). This method is practical, does not depend on someone being available to turn over the MSW, and enables collectors to work quickly and effectively (Laurieri et al., 2020).

2. **Door-to-Door:-** With this method, generators deliver their individual MSW to the collectors right at the door. Vehicles visit designated collecting places during prearranged times, and they frequently signal their arrival with a particular ring or bell (Ibanez-Fores et al., 2018). This method is affordable, practical for the general public, and prevents stray animal nuisances. However, to give the MSW to collectors, a family member must be present at the residence (Tadesse, 2004).

3. **Backyard:-** Using a tote barrel, collectors enter the premises to gather MSW and move it to a vehicle. (Lella et al., 2017). Residents will find this method quite easy to use since it eliminates the need for street dumpsters. Moreover, this is highly costly due to the significant human effort involved (Yadav and Karmakar, 2020). This method works well in societies where housing is scarce and population density is lower (Lella et al., 2017).

4. **Smart Waste Bins:-** In the SWM field, there are a lot of new technologies available. They appear to be essential to current waste management (Czekała et al., 2023). The goal of reducing trash's negative environmental effects and improving the efficiency of waste collection processes has led to the evolution of SWM technologies in recent years. There are

many different ways, from the traditional methods mentioned above to more recent, sophisticated solutions utilizing cutting-edge technologies.(Czekała et al., 2023). The objective of creating an intelligent container for waste is to offer a simple way to manage every garbage container in a city. It has several sensors and technology installed to aid in more effective garbage management (Gopal Kirshna Shyam1, 2017). These sensors may pick up on a lot of information, including weight, humidity, gas emissions from the waste, and the amount of fill in the bin, among many other things (Afolalu et al., 2021). Using an ultrasonic sensor to measure the separation between the bin's top and bottom and compare it to the present fill level is an efficient way to control the waste material filling level (Ayodeji Noiki1, 2020). Figure 2 show waste bins using smart technology.

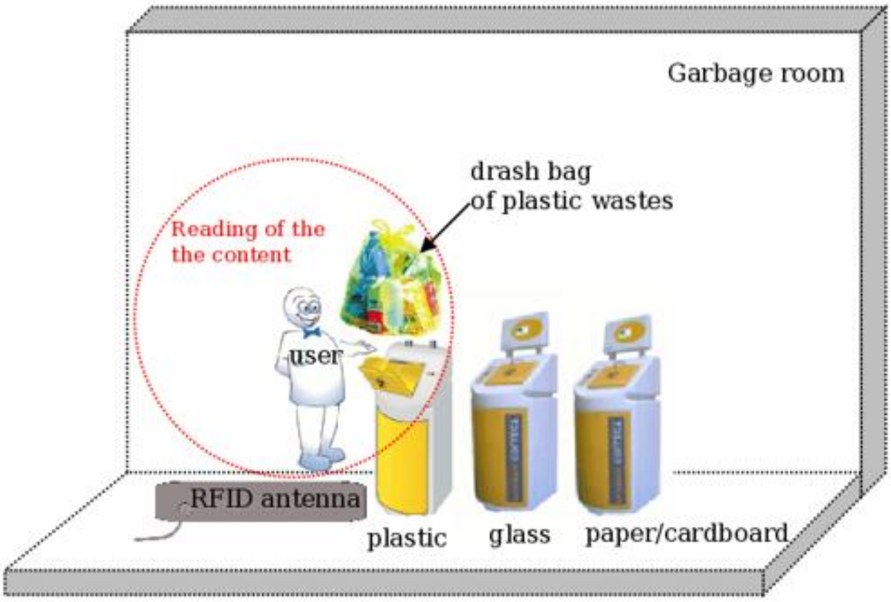

Figure 2: Smart waste bins using radio frequency identification (RFID) technology

Pneumatic:- This system makes use of a system of waste inlets and chutes, underground storage tanks, and urban pipelines. There are numerous locations, both indoors and outdoors, where the waste fractions can be collected. Trash bags are lowered via a chute into subterranean containers, and waste is transferred to a collection plant using a vacuum system collecting schedule (Laso et al., 2019). Electricity is used in this collecting process to gather and compress the various waste streams (Laurieri et al., 2020), as depicted in Figure 3.

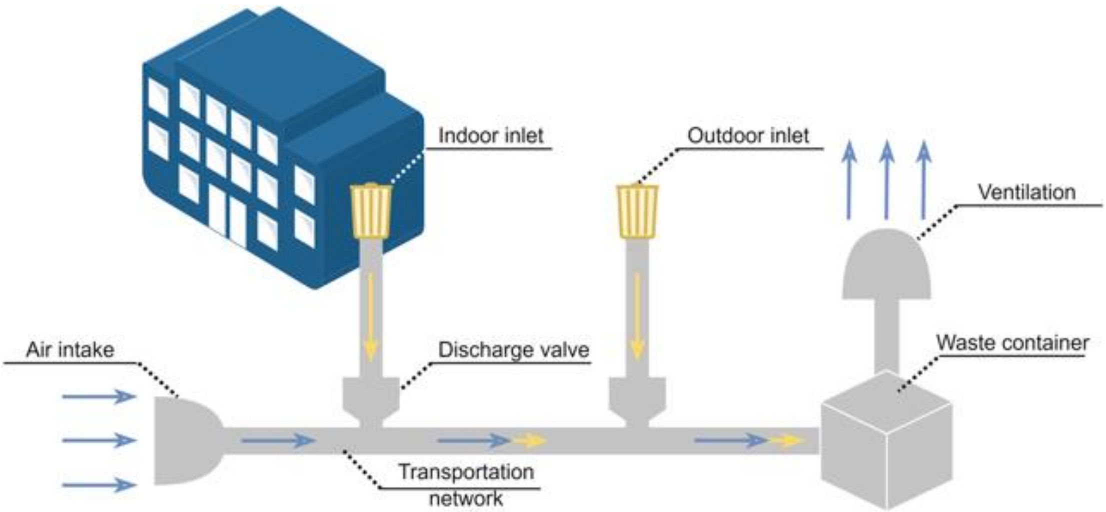

Figure 3: Simplified Pneumatic system diagram (Czekała et al., 2023)

B. Factors Influencing SWC

The constraints that must be taken into account in every particular circumstance are known as the factors. Finding the right range of parameters for the optimization gathering process is not so simple, though by including more variables, the SWC model becomes more useful. The next section discusses the most prevalent factors influencing the SWC system.

1. **Capacity:** The primary concern when dealing with limitation of capacity is the vehicle's ability to carry a certain amount of waste or a total weight during the trip (Rathore and Sarmah, 2019). Occasionally, the volume or capacity of the containers at the transfer station or the pick-up location is also taken into account. To increase the SWC system's reliability, the landfill's capacity restrictions, the type of vehicle utilized and the overall count of vehicles utilized for the collection of waste are taken into (Erfani et al., 2018).
2. **Time:** Time is limited in a number of ways, including the time window, travel time, pickup time, load and unload times, and driver breaks. In order to maximize efficiency in terms of time, fuel consumption, and other relevant factors, The vehicle's trip route is taken into consideration while establishing a time window, the number of vehicles involved, and potential delays caused by traffic signals and pauses. A vehicle's total duration cannot exceed a certain figure, and the time factor is also taken into account when determining the collection time of each bin (Son le and Louati, 2016). The travel time is the time it takes the collection vehicle to move between collection points. The longer travel time reduces the quantity of locations for collection that are supposed to be completed within a specific time frame. Pickup time refers to the period between the emptying of SW from containers and the collection of rubbish. Pickup time comprises the duration of the operations involved in raising, lowering, and lifting the container using a semi-automated system located at the rear of the car. A worker assists in manually raising the container using a semi-automated loading device, and it is then released into the vehicle from the rear (GONULLU, 2011).
3. **Labour constraint:** A variety of studies take into account the number of fleets needed or the working hours of workers when examining the labour element. Every worker is required to put in a set amount of time or perform a set shift. Some writers reserve labor hours to operate the garbage loading truck between the hours of 7 a.m. and 12 p.m. Monday through Saturday (Yusuf et al., 2019). In some circumstances, the necessary workforce size can be determined while accounting for additional costs. It is also possible to evaluate the quantity of trips needed when creating a SWC system. For example, a SWC system that aims to reduce costs and manage emissions can be accomplished while taking labour constraints into account (Owusu-Nimo et al., 2019).
4. **Environment**: Taking into account the SWC system's life cycle, environmental restrictions are selected to minimize adverse environmental effects. Furthermore, these limitations guarantee that the refuse item's composition in the phase of recuperation satisfies the quality criteria standards. Restrictions on greenhouse gas emissions and carbon footprint are integrated to maximize waste management's operating efficiency. Since the acceptable limit of CO2 emissions constraint is applied in this manner, the distance traveled by the number of vehicles for the transfer of rubbish from the depot to the central stations does not increase fuel consumption. (Edalatpour et al., 2018, Vonolfen et al., 2011).
5. **Regulatory constraint:** When creating the optimization goals for the SWC system, a few regulatory restrictions must be taken into consideration. For instance, discarding trash is only permitted during specific hours, and bins need to be emptied after a predetermined amount of time. Additional regulations may require that the vehicle tour starts and finishes at the depot, that only one truck is allowed to visit each stop, that the bin must be fully emptied, that each trip can only have one previous and one subsequent trip, that no stops are permitted when a vehicle is full, and that the waste must be taken to a disposal facility. Furthermore, road

restrictions and rules play a major role in the optimization of SWC (Hannan et al., 2020, Liu and He, 2012).

C. Route Modeling Methodologies and Approaches

SW is thought to be one of the main causes of the increasing rates of climate change and global warming, which has a variety of effects on sustainable development (Gavurova and Megyesiova, 2022). To optimize SWC and reduce environmental impacts, as well as other elements specific to a given trash collection scenario, an effective computerized technique must be investigated (Louati et al., 2018). Poor and costly collection systems are the outcome of choosing the routes that collection trucks travel without applying technology or scientific interventions (Tavares et al., 2009). The efficient routing of collection trucks is one way to guarantee improved performance in the SWC process (Sulemana et al., 2018). Given its substantial effects on business, society, and the environment, routing for SWC is one of the primary and most important aspects of SWM (Agha, 2006). Routing depicts a route between points, such as the routed object's origin and destination (Reinhardt, 2011). Finding the best route from the location to the transfer station and disposal site is the aim of the vehicle routing problem. (Singh and Gupta, 2022). There can be just one vehicle involved in the issue, or there might be several. Finding the shortest path between two points on a map is typically the goal of finding the best route, including minimizing a vehicle's route (Singh and Gupta, 2022). In the developing world, there is no coordinated or methodical method for allocating truck or vehicle schedules for the collection of SW (Kanchanabhan et al., 2011). This is typically based on intuitive approaches and real-world experience, which leads to costly and ineffective practices that hurt the environment, public health, and corporate operations (Khedikar, 2014). To assure resource conservation and environmental protection, numerous research has examined the SWC problem from a mathematical programming optimization perspective, artificial intelligence (AI) techniques, and geographical information system (GIS) -based methodologies (Agha, 2006).

3. Overview of Various Modeling Techniques and Algorithms Used in Waste Collecting.

Many technical, climatic, environmental, socioeconomic, and legal constraints are often present in waste treatment procedures. Using traditional approaches to model, forecast, and optimize such complicated nonlinear processes is difficult. The use of AI techniques to provide various computational methodologies for addressing SWM problems is growing in popularity. (Abdallah et al., 2020). Artificial intelligence is good at handling ambiguity and missing facts, picking up knowledge from experience, and resolving vague problems. Examples of these include features of rubbish forecasting, level of the garbage bin detection, process parameter prediction, vehicle routing, and SWM planning (Ozkaya et al., 2007, Abdallah et al., 2020). For the modeling and optimization of SWM processes, artificial intelligence (AI) systems such as artificial neural networks (ANN), support vector machines (SVM), linear regression (LR), decision trees (DT), and genetic algorithms (GA) have been widely used. (Chatthong, 2014).

ANNs work well for modeling processes with partial or ambiguous data sets, and for handling difficult and imprecise tasks, that call for human judgment (Oliveira et al., 2019). ANNs mimic how a biological nervous system might respond to tasks in the actual world (Duda, 2000). Numerous studies using mathematical modeling and programming techniques have been conducted in response to the demand for the best possible truck routing for the collection and delivery of SW. The most popular routing and scheduling problems that academics use for data collecting include the shortest path problem, traveling salesman problem, and vehicle routing problem. (Gianpaolo Ghiania, 2005, Sulemana et al., 2018). A certain number of vehicles leave the main depot, visit each depot along the way, and then return to the main depot to finish the route. This is the most fundamental and traditional version of the VRP. The goal is to identify these routes with the lowest possible cost (distance). this issue is known as the capacitated vehicle routing problem (CVRP) because it guarantees that the cars do not exceed their capacities when the capacity constraint is introduced (Dereci and Karabekmez, 2022). Akhtar and colleagues presented a Backtracking Search algorithm-based solution to CVRP, utilizing the idea of a smart dustbin to improve garbage collection routes, to minimize travel time and maximize the frequency of rubbish disposal (Akhtar et al., 2017, van Beek, 2006).

In their study, Assaf and Saleh (2017) employed a genetic algorithm to solve the SWC problem for the Palestinian city of Nablus as part of a VRP. The study's objectives are to reduce expenses and the distance garbage trucks travel. Erfani and colleagues used a Geographic Information System (GIS) to tackle the CVRP, or rubbish container collection and storage problem in Ahmadabad, Iran. There has been a 12.5% decrease in the number of tours, a 41% decline in the overall number of personnel, and a 53% enhancement in the total distance traveled (the main objective). Additionally, they confirm that the current rubbish collection system has been deemed insufficient (Erfani et al., 2017).

To solve CVRP, Hannan et al. (2018) introduced the modified particle swarm optimization (PSO) algorithm and implemented ideas such as scheduling and waste threshold levels for various datasets. The strategy, which seeks to minimize the distance travelled to determine the best route, was highlighted as having strong results for waste collection and route optimization. It was also noted as having the potential to be a useful tool for examining the socioeconomic and environmental implications of waste collection systems. The traditional methods are unable to handle unpredictable factors, optimize many objectives simultaneously, and produce good results. Nonetheless, the traditional methods can reduce the number of goals to a single, easier-to-solve weighted sum goal (Hannan et al., 2020). Mixed-integer linear programming (MILP) is a branch of traditional methods. When creating models a problem where factors vary within integers or real numbers, MILP techniques are gaining traction. However, MILP has drawbacks, such as expensive computing effort and elevated dimensions danger (Yousefloo and Babazadeh, 2020). The ideal garbage collection route in Istanbul, Turkey, is determined using MILP-based optimal SWC. The goal of the mathematical model's formulation is to reduce overall energy use (Erdinç et al., 2019). No approach consistently yields the optimal outcome for VRP because it is an optimization problem. Methods or algorithms that yield exact answers are impractical to use in a reasonable amount of time, or they may yield no results at all when the problem gets larger. Heuristic approaches were created to overcome this problem by providing quick fixes and results that are almost ideal (Dereci and Karabekmez, 2022).

In terms of issue complexity and computational time, heuristic approaches outperform conventional approaches (Sebil, 2014). There are two types of heuristic algorithms: simple heuristics and metaheuristics. Simple heuristics are reliant on the problem, while metaheuristics, which aim to maintain high-quality solutions with lower processing times in complex optimization problems, are problem-independent methods (Dereci and Karabekmez, 2022). Generally, the goal of simple heuristics is to produce a workable answer and then attempt to refine it. Several often used basic heuristics are the Christofides, Sweep, Improved Petal, Nearest Neighbor, and Savings algorithms (Christofides, 2022). Conversely, metaheuristics efficiently search the solution space by combining many techniques and enhancing basic heuristics (ROLI, 2003). Among the often utilized metaheuristics are GA, Artificial Bee Colony, Ant Colony Optimization, Tabu Search, Neural Networks, and Simulated Annealing (Han, 2015), which is depicted in Figure 4.

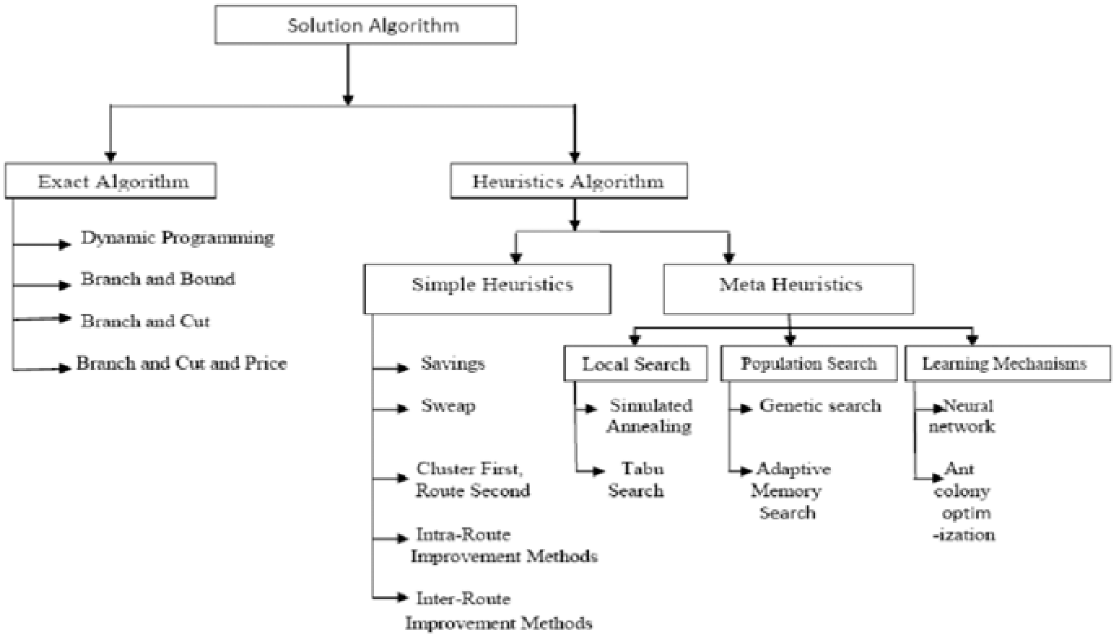

Figure 4: VRP Solution Algorithm (Han, 2015)

A. Genetic Algorithm (GA)

A class of metaheuristic algorithms called GA is employed in natural evolution simulation. (Gandomi et al., 2013). Rather of focusing on improving a single solution, GAs use optimization techniques to enhance a set of solutions or hypotheses in a binary search space (Meyer-Baese and Schmid, 2014). Genetic algorithms mimic natural evolution in an attempt to identify acceptable answers. By genetic operators, new solutions are produced that bear certain traits from their parent solutions. One can choose one of these candidate solutions as the eventual solution (Han, 2015, Beliën et al., 2014). Reproduction, crossover, and mutation are the three operational stages that the GA uses to refine the fitness equation and, as a result, find the optimal solution in the end (Okrah et al., 2023). As an alternative, mutation is carried out by swapping out a few of the string's digits to get new answers. The produced solutions are compared with the objective function of the optimization problem in order to determine the overall fitness of each solution. The group's top responses are selected for the subsequent optimization cycle.

Efficiency, robustness of input data, and ease of programming are some of GA's benefits. However, GAs must be carefully constructed, and choosing the wrong operators can hurt the mode's output(Okrah et al., 2023). By taking into consideration the variables relating to traffic and the locations of trash cans, genetic algorithms have been utilized to design effective routes that minimize the fuel consumption of garbage trucks (Singhal et al., 2019). GA is frequently used to optimize SWC. Using GA, a VRP for SWC is modeled to determine the best routes that is minimizing both the travelled path and operating expenses. The findings show that the journey distance was reduced by 66%, and that the amount of rubbish collected was only collected for 2.3 hours instead of 7 hours (Assaf and Saleh, 2017).

B. Using Ant Colony Optimization (ACO)

The Ant Colony Optimization (ACO) algorithm is one state-of-the-art method for vehicle routing in SWM (Okrah et al., 2023). ACO is a discrete optimization technique where a colony of artificial ants, inspired by real ant characteristics, collaborate to find healthier solutions to various issues (Belfiore, 2013). ACO mimics how ants would behave when looking for food. Ants leave behind a scent trail that other ants follow to find the shortcut when they are looking for food. The ants which use this road to return to the colony will eventually renew the pheromone trail earlier than the ants who choose a longer way, establishing the shortest path (Han, 2015, Beliën et al., 2014). Ant Colony Optimization is depicted in Figure 2.5. Several drawbacks of ANN are addressed by ACO, which has been called among the top-performing new computational instruments for optimizing parameters(Okrah et al., 2023).

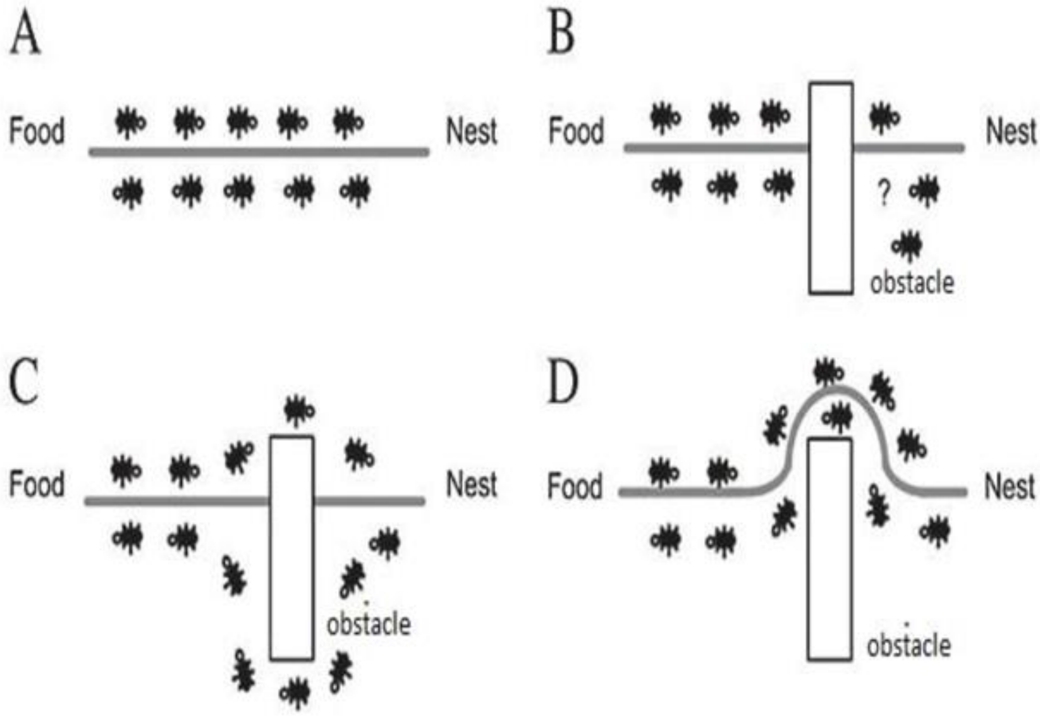

Figure 5: Ant Colony Optimization (Bajpai and Yadav, 2015).

As a result, ANNs with ACO offer a useful method for resolving various kinds of optimization issues. Network issues with the shortest path have been used in the following domains: social networks (knowledge workers), control of infectious diseases, disaster evacuation, transportation, garbage collection, delivery of goods, rail construction, routing in telecommunication networks, email and teleconference (Acquah et al., 2022). Numerous single- and bi-objective modeling issues in SWM have been resolved through the use of ACO (Okrah et al., 2023). In Liu and He (2012) study, a clustering-based improved multiple ACO is suggested as a way to reduce garbage collection route distance. The findings show that the route length decreases by 31.1% and 31.9%, respectively, with and without turn limits. In Galván et al. (2017) study, for garbage collection optimization, two ACO algorithms are proposed, and the outcomes demonstrate gains in terms of route length minimization and route redesigns.

C. Tabu Search (TS)

To enhance the performance of the local search, also known as neighborhood search, the TS is an extra meta-heuristic algorithm that modifies the basic principles of the search. (Shao et al., 2020). The TS method can employ many techniques to identify viable answers that are arranged in a Tabu List table. It draws inspiration from the way humans process information(Mekamcha et al., 2019). In Glover's (1989) original version of the TS algorithm, The process starts with a feasible first answer, S, that is kept as the optimal answer. The set of S's neighbors is constructed at each iteration using only one basic movement. Their best neighbor configuration T, which comes after S, is utilized to assess these configurations using an objective function (Shao et al., 2020). Using TS, a garbage collection synchronization system is suggested to determine the most profitable truck routes. TS uses multi-objective adaptive memory programming (MOAMP) to collect waste containers in rural locations (Gómez et al., 2013).

4. GIS Technology in SWM

GIS integrates hardware, software, and data in a computer-based system to collect, organize, process, evaluate, and present any kind of geographically related data. (Shrivastava et al., 2015). The first step in GIS processing is data preparation and entry, which comprises gathering, preparing, and entering the data into the GIS database system that is required for information generation. Data analysis, or step two, involves reviewing and evaluating the information that has been collected and entered the GIS system. The analytical results are then suitably saved or shown during the data presentation step (Elsai Mati et al., 2022). Its main benefit is that, unlike tabular or written data, it provides a visual output of the data in the form of maps and other graphics, making it easier to see patterns, trends, and relationships. The GIS differs from other information systems in that it combines the benefits of visual and spatial analysis through maps with standard database functions like query and statistical analysis (Wyatt and Farrow, 2011). An essential component of GIS is network creation, visualization, and management. Because GIS work is done in layers, there are fewer opportunities for error or confusion, and the system can coordinate between geographical and non-spatial data. A GIS can be used to combine several data layers to create integrated, realistic digital maps of the surface of the Earth. as depicted in Figure 6.

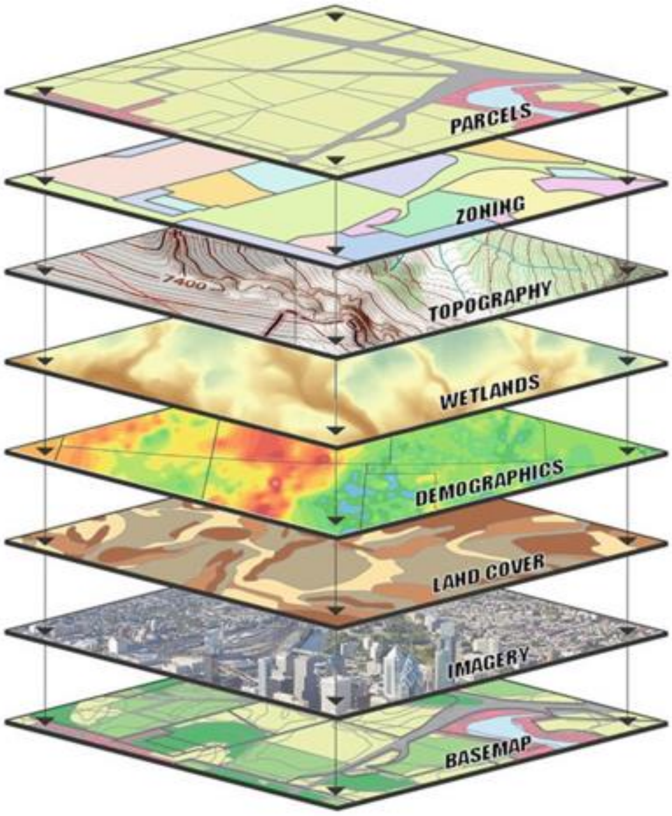

Figure 6: Different layers of data can be combined through a GIS (Kolios et al., 2017)

Systems for geographic information are used in many different technologies, procedures, approaches, and strategies. They are associated with a multitude of applications and activities related to engineering, planning, management, and transportation (Singh and Gupta, 2022). Considering how complex and integrated SWM is, GIS can be useful. Consequently, spatial data forms the basis of planning and monitoring operations. Important facets of SWM include customer service, investigating the ideal places for transfer stations, organizing the routes for trucks carrying waste from residential, business, and industrial clients to transfer stations and from transfer stations to landfills, finding new landfills, and keeping an eye on the landfill (Elsai Mati et al., 2022). A geographic information system is a great tool for managing SW since it helps with technical element planning. Numerous scholars have optimized SWM practice by applying GIS principles (Hannan et al., 2018). For example, garbage truck trip distance is reduced as a result of optimizing waste collection with GIS (Vu et al., 2018). In Ha Giang City, Vietnam, an agent-based model is created to maximize the transportation of solid garbage using GIS analysis. The findings show that the average distance driven by each garbage truck has decreased by 11.3% (Trong et al., 2017). In Son (2014) study, the best options for waste collection and truck routing are found by combining ArcGIS and Particle Swarm Optimization (PSO). Vu et al. (2019) suggested that ANN and GIS can be used to optimize the length and distance of garbage truck routes. To reduce the number of trucks used for waste collection and disposal, efforts have been made in recent decades to minimize the distance between waste collection stations and landfills (Hina et al., 2020). Employed fuzzy strategies for making multi-criteria decisions in landfill site selection where the group hazy, suitability maps are produced via GIS analysis in the worst-case scenario (Asefa et al., 2021).

A. Integration of GIS with SWC Route Optimization

Given the importance of GIS in SWM in all its systems, their importance also appears in systems for improving paths for improving SWC, which is considered one of the very important SWM systems. Since collection and hauling costs make up 85% of total disposal costs, a municipal SWM system can reduce these costs by implementing a route optimization(Billa et al., 2014). Numerous economic benefits are being amplified, therefore. By lessening the detrimental effects of "empty miles" in the SWC and transportation process, route optimization can reduce total expenses (Karki, 2023). When using GIS to optimize vehicle routing problems, factors that are frequently disregarded in mathematical programming, namely: Variable transit street network impedances, one-way streets, speed limits, and turn and height restrictions and restrictions, however, they can be included to model the street network (Arribas et al., 2010).

The Network Analyst extension, which was created using Dijkstra's algorithm, is the primary ArcGIS extension used for network analysis (Desai et al., 2018). Dijkstra's algorithm, a more straightforward method for determining the shortest or least expensive path between two sites, is mostly used by network analysts. This algorithm maintains equilibrium by comparing the near-optimal path to travel with a computationally feasible one (O'Connor, 2013). Creating a network with up-to-date GIS data, identifying nearby facilities, generating a travel network cost matrix, and determining the best locations for facilities using location-allocation are some of the primary tasks of a network analyst. Utilize time windows while booking your car to find the quickest routes.. Data processing requires ArcGIS projections of waste dumps, transport routes, and container layers. The best route for collecting MSW will be chosen based on the information acquired using Arc GIS. The Route Solver, a simpler version of the Vehicle Routing Problem (VRP) solver, is part of ArcGIS Network Analyst, enabling users to find the quickest or shortest route between network points. The Route Solver is depicted in Figure 2.7.

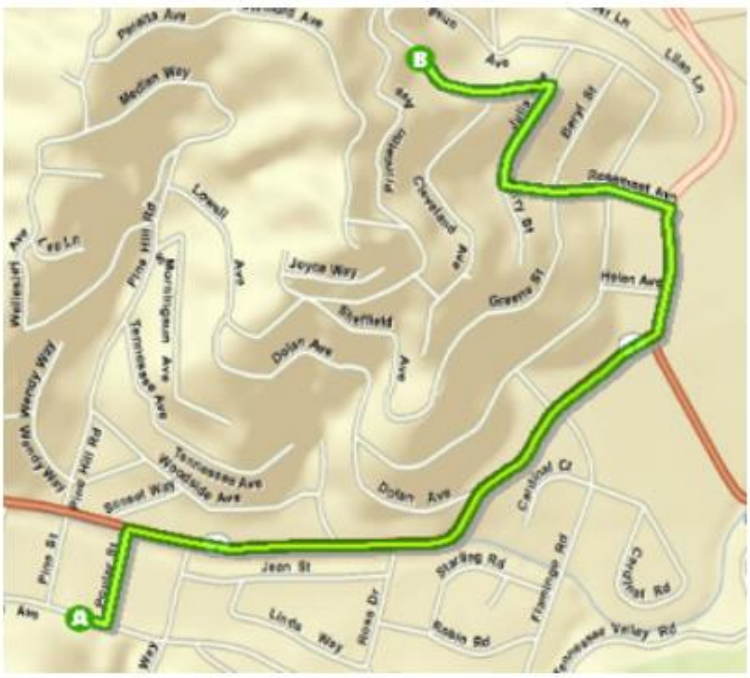

Figure 7: Route analysis **(ArcGIS website, 2023)**

One of the features of the ArcGIS Network Analyst software extension is the VRP solver. Reducing total collection vehicle operating expenses and servicing orders are two of the VRP's functions. The VRP solver took into account various characteristics and cost impedances encountered when traversing the network during the analysis. The primary interface for importing classes and adjusting solver parameters is the VRP's analysis layer, which consists of 13 network analysis classes. Tables and feature layers that are kept inside the analysis layer are represented by these classes. The vehicle routing problem is solved with the use of the network analysis items (ArcGIS website, 2023). O'Connor (2013) found that the VRP solver was not the best option for determining route optimization for a sizable group of points. As a result, it is advised that several conditions be added to ArcGIS Module Builder to improve and automate the optimization process. According to Esri ArcGIS, the researcher can create, modify, and manage models with Model Builder. Models are workflows that connect geoprocessing tool sequences, passing the output of one tool as an input to another. Another way to think of Model Builder is as a visual programming language for creating workflows. In Sanjeevi and Shahabudeen (2016) The ArcGIS generated optimized routes were compared with the current route for each ward. The ArcGIS optimized route length and the current route length are tabulated. 9.93% of the haul distance and 10.05% of the weighted average tone-km are saved when the current and ArcGIS route distances are compared. The GIS offered every road connection between each of the necessary locations.. Figure 8. Show current route versus optimum route.

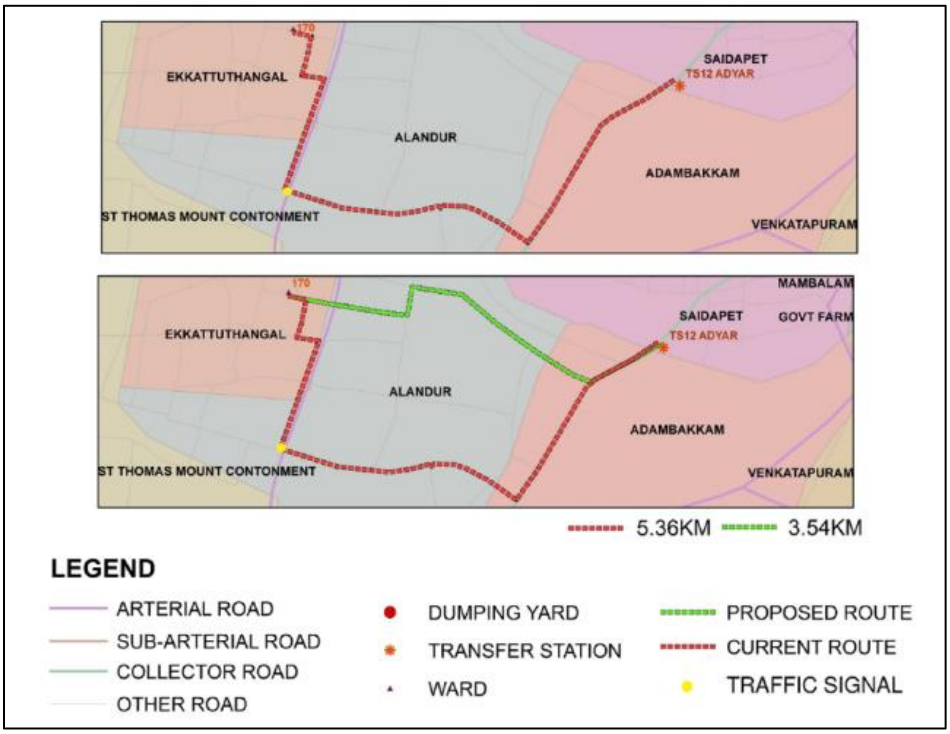

Figure 8: Current route versus optimum route In Sanjeevi and Shahabudeen (2016)

In Sulemana et al. (2019) Using Esri's ArcGIS Network Analyst Extension, the study modeled the current waste collection routes in three local authorities in Ghana and determined the best routes. The study's findings showed that when trucks took the best routes, their weekly trip distance decreased by 81.27 kilometers, or 4.79 percent. Fuel usage and travel time were cut by 145.86 L and 853.59 min, respectively, resulting in savings of 14.21 and 10.81 percent. Figure 9. Show current route versus optimum route. Figure 9. Show current route versus optimum route. Table 2-1 review previous studies and research on SWC using GIS.

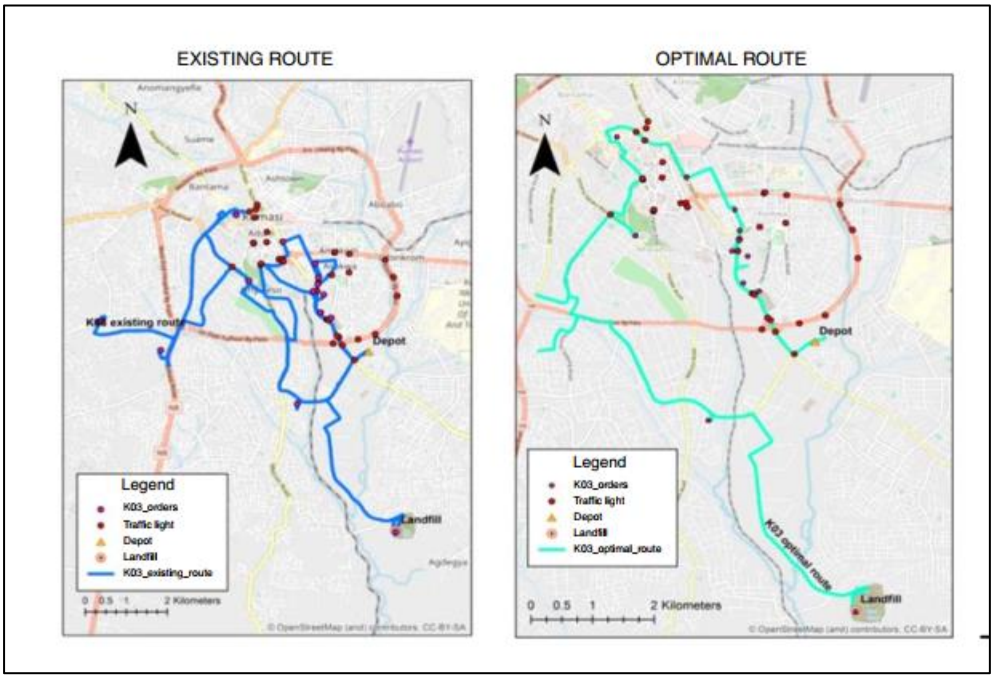

Figure 9: Current route versus optimum route In Sulemana et al. (2019)

Table 1: previous studies and research on SWC using GIS.

Author/s	Approach	The main findings
Arribas et al. (2010)	Suggested a methodology for creating an urban SW collecting system. This approach reduces collection times and operating and transportation expenses and improves the present SWC system by utilizing GIS tools, integer programming, and combinatorial optimization. This methodology gives a Sensitivity and comparative cost analysis of the outcomes, establishes feasible collecting routes, and establishes an appropriate vehicle fleet size.	When this methodology is applied to a study case of a zone in Santiago, the overall collecting system experiences large cost savings
Malakahmad et al. (2014)	Looked into the optimization of SWC routes using the GIS Arc View. Five routes were selected for the trial project from different parts of Ipoh City, and the existing routes were modified to reduce their length and, consequently, the amount of time required to complete the collection.	The route length has been reduced by up to 22%, according to the results. Additionally, the collecting time was cut from 6934 seconds to 4602 seconds.
Son (2014)	focused on the SWC collection in Danang City, one of Vietnam's four largest municipalities. For the Danang city SWC problem, a unique vehicle routing model is provided. An innovative hybrid approach combining ArcGIS and Chaotic Particle Swarm Optimization is shown to produce the best results from Danang's vehicle	The suggested hybrid method outperforms other related methods, such as the manual SWC procedure already in use in this city, according to experimental results conducted on a real dataset from Danang.

	routing model.	
Trong et al. (2017)	Provided a model for municipal SWC optimization using multi-agent-based modeling and simulation, The best course of action is initially developed in a static environment before being integrated into a dynamic one. A case study of Hagiang City, Vietnam, is presented to illustrate the efficacy of the proposed framework.	The cost of SWC is lowered by 11.3% based on the optimized results
(Vu et al., 2018)	Proposed a GIS-based dual-phase model for a study in Vietnam, integrating handcart pre-collection and truck collection phases. The model estimated the total system cost, with a single temporary collection point serving 2,590 people in 0.11 km2.	The model showed a 13.76% reduction in truck travel distances, indicating that the number and distribution of temporary collection points significantly affected the pre-collection and collection stages' cost-effectiveness.
Amal et al. (2018)	Suggested an updated GA for optimizing the route of SWC that is based on spatial GIS. To provide the best answers for cars, the suggested method, known as SGA, adapts the original Dijkstra algorithm in GIS. Then, a genetic algorithm is used to encode a pool of solutions, which are the best routes for every vehicle. Iteratively, it progressed to a better answer and ultimately to the best one. To verify the effectiveness of the idea, experiments are conducted on the case study in the Tunisian city of Sfax.	It has been demonstrated that the suggested approach performs better than both the workable path and the original Dijkstra method.
Rizvanoglu et al. (2019)	Used linear programming and GIS analysis to develop an optimal routing schedule for SWC and transportation in the Veysel Karani neighborhood of Sanliurfa Province, Turkey.	The study found that using these methods, the cost of waste collection and transportation could be reduced by 28% and 33%, respectively, based on existing routes.
Hina et al. (2020)	suggested a routing strategy for collecting truck routes in Pakistan's twin towns, Rawalpindi and Islamabad. The study's application-based VRP, in particular, takes into account several useful guidelines, including commodity type, time windows, vehicle capacity, zone restrictions, and road infrastructure. Eleven routes were chosen for the pilot project in various parts of the twin cities to reduce the route's length and, as a result, the time	The findings show that in Islamabad and Rawalpindi, the travel distance was lowered by up to 18% and 9%, respectively. Also, the collection times for Islamabad and Rawalpindi were shortened from 7.5 hours to 5.8 hours, and 8.3 hours to 7.2 hours, respectively.

	needed to finish the collection.	
Singh and Gupta (2022)	Optimized SWC utilizing the QGIS tool to enhance the effectiveness of Kanpur's ward 95, zone 2 garbage collection and transportation. To determine the appropriate, most efficient transportation routes for the management of SW, the area between the transfer station and the disposal site was modeled independently.	The haul distance reductions for location are found to be 2.19% in this investigation.
Çakmak (2022)	investigated the Hatay province's Iskenderun district, and Denizciler district was selected as an example to illustrate every district feature. The ESRI ArcGIS software's assortment of tools has been used to test the method of optimization. In the latter part of the investigation, trash collection was carried out using the newly created route. Consequently, the practicality of the network analysis-based improvement has been evaluated in actual environments., and it has been found that financial savings in terms of time and fuel are realized.	A 421-meter shorter route was found using network analysis. Considering the length of the existing route, which is 14340 meters, the research produced a 3% improvement.

5. Conclusions

This Paper provides a brief identification to SWM , which is a very complicated process as it involves advanced technology and specializations including generation, treatment, storage, collection, transportation, processing and disposal. However, developing countries face great challenges in SWM compared to developed countries, and Iraq is one of them. SWC is a very important specialization in the field of SWM, and it represents the most expensive and influential part of the total costs of the SWM process. SWC includes collecting waste from different locations and transporting it to a designated place for disposal, which includes multiple strategies aimed at disposing of SWC effectively and properly, including traditional and more advanced methods. SWC routing is one of the most important aspects of the SWM process to reduce the total cost and time of the collection process. The goal of the vehicle routing problem is to determine the optimal route from the site to the transfer station and the disposal site. In developing countries, there are no systematic and coordinated methods for routing SWC vehicles, which leads to double costs and severe negative effects. Therefore, with the development of research and studies to preserve the environment and protect resources, including reducing costs, many studies have studied the problem of SWC from an optimization point of view using mathematical programming, artificial intelligence techniques, and methodologies based on GIS . Using traditional methods to model, predict, and optimize the SWC process is difficult, so artificial intelligence methods that are integrated with advanced algorithms have become more popular as a means of providing different computational strategies to deal with such problems. They are considered the best and most advanced solution compared to using traditional or manual methods that often lead to ineffective results. One of the most advanced methods for optimizing SWC routes is the geographic information system (GIS), which differs from other information systems in that it combines the benefits of visual and spatial analysis through maps with standard database functions such as querying and statistical analysis. The GIS contains a network analysis package which is important in optimizing waste collection routes and its performance is based on Dijkstra's algorithm which can compare the optimal route with the current route.

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