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Municipal Solid Waste Collection and Disposal Approaches: A Review

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Abstract

Solid waste management comprises all efforts geared towards solid waste collection, transportation, recovery, recycling and processing. Developing Countries still grapple with very poor waste management practices. This occurs as a result of poor planning and scheduling, ranging from collection techniques and transportation from the dumpsters to the landfill centers. Lack of timeous solid waste collection and disposal planning and control measures can result in excessive dumpster overflows on one hand. The other extreme of having dumpsters premature for evacuation is also possible. This paper reviews approaches of municipal solid waste management strategies. The data used for the study consist of articles carefully selected from peer reviewed journals with very high impact. The major interest was to ascertain different approaches to solid waste management, with more emphases on municipal solid waste generation, collection, and transportation techniques. There still exist significant gaps between the waste management endeavors suggested in past literatures and the approaches that can be tailored to specific developing locations. This is with due regards to availability of good models, but developed for advanced economies with fully developed public infrastructure. The results show that a robust solid waste management model that can cater for the realities of a developing Municipalities can be explored.

Keywords: Solid Waste, Management Practices, Municipality, Planning

1. Introduction

According to Merriam-Webster's- dictionary, a waste is a refuse from places of human or animal habitation. The World Book Dictionary sees it as a useless or worthless material; stuff to be thrown away. Different organizations also have their own idea of what wastes are. According to the Basel 1989 convention, wastes are substances or objects which are disposed of or are intended to be disposed of or are required to be disposed of by the provisions of national law. Waste is any item that is discarded because it is hazardous or seen to have little or no value. These include solid, liquid and even semi-solid materials arising from domestic, community, industrial, agricultural or human operations According to Reedy (2011), it is any item or object that is no longer appropriate for use in line with owner's consideration Nag and Vizayakumar (2005), says that with the advent of civilization, an increase in the waste generation has been seen all over the world. Population growth and urbanization as a result of industrial revolution brought a shift in the pattern of waste generation leading to more serious environmental issues and of late increased global consciousness on issues like global warming and various forms of pollution are some of the factors driving waste generation Reedy (2011), Nag and Vizayakumar (2005), Agbojeet al.(2014) thus calling for development of an efficient and environmentally sustainable waste management system. Management of solid waste is as old as when animals (including humans) recognized that some items in the environment are meant to be discarded, while others are good for satisfying the requirements of existence. Prior to Industrialization and subsequent migration from rural dwelling to new centers, man generated solid waste and managed same within the confines of the strategies at work at the time. However, Industrialization came along with increased household activities which definitely raise the probability of generating solid waste beyond the control of developed dwellings, where there exists little or no bushes to contain solid wastes. Scientific techniques became evident in other to tackle the challenges posed by constantly generated solid waste starting from Municipality, Provincial and National levels. With the involvement and procurement of vehicles and establishment of waste management authorities by Nations, the next task is how to handle solid waste management capabilities. A lot of approaches have evolved over the years. While the end is not yet in sight, researchers have delved into combinations of developed approaches in an attempt to optimize the management and control of solid wastes generation, collection and disposal. Some of this management efforts will be presented in what follows.

2. Municipal Solid Waste Management

According to OECD, Municipal solid waste (MSW) consists of wastes generated from households, including bulky waste, similar waste from commerce and trade, office buildings, institutions and small businesses, yard and garden, street sweepings, contents of litter containers, and market cleansing, municipal sewage networks and treatment. Municipal solid waste is generally a combination of household and commercial refuse which is generated from the living community. Waste management involves collection of waste, recovery and recycling, transportation and processing- . From Gedefaw (2015), perspective of, waste management processes start at the point of solid waste production, then storage and followed by solid waste collection, transportation and transferring Municipal solid waste management is a major environmental practice in every city in the world, but unplanned increase in urbanization and population have made the practice herculean in some cities. Mismanagement of municipal solid waste can cause adverse environmental impacts, public health risk and other socio-economic problem (Naha *et al.*2015).Also the consequence of poor waste collection and transportation system have seen wastes being dumped into drainage systems, canals thus leading to flooding (Njoku*et al.*2015). Also dumping of wastes at places not designated for such is often an everyday scenario. This is similar to the scenario observed by Gedefaw (2015), while assessing the situation in Gondar town in Ethiopia, which led him to conclude that one of the ways to improve waste management system is by creation of proper awareness, training, implementation of MSWM approach that encompasses all stakeholders.

According to Ghose *et al.* (2006), an effective solid waste management system should include one or more of the following options: waste collection and transportation; resource recovery through waste processing; waste transportation without recovery of resources, i.e., reduction of volume, toxicity, or other physical/chemical properties of waste to make it suitable for final disposal; and disposal on land, i.e., environmentally safe and sustainable disposal in landfills. However, report of works on waste management conducted in municipals and cities in developing countries like Nigeria have shown that the major challenge in waste management lies in collection of waste Aliu et al.(2014). This is because collection and as such transportation of wastes to either recycling centers or dumpsites makes the highest demand on municipal budgets and have the greatest impact on urban living Unhabitat (2010). Collection is often done using disposal trucks (compactors, bicycles, rickshaws) that move from house to

house collecting wastes and before transporting to dump sites or recycling center for activities like scavenging, sorting etc.

3 Solid Waste Management Approaches

Some of the parameters frequently encountered in management of Solid wastes as well as suggested strategies are presented in Figure 1.

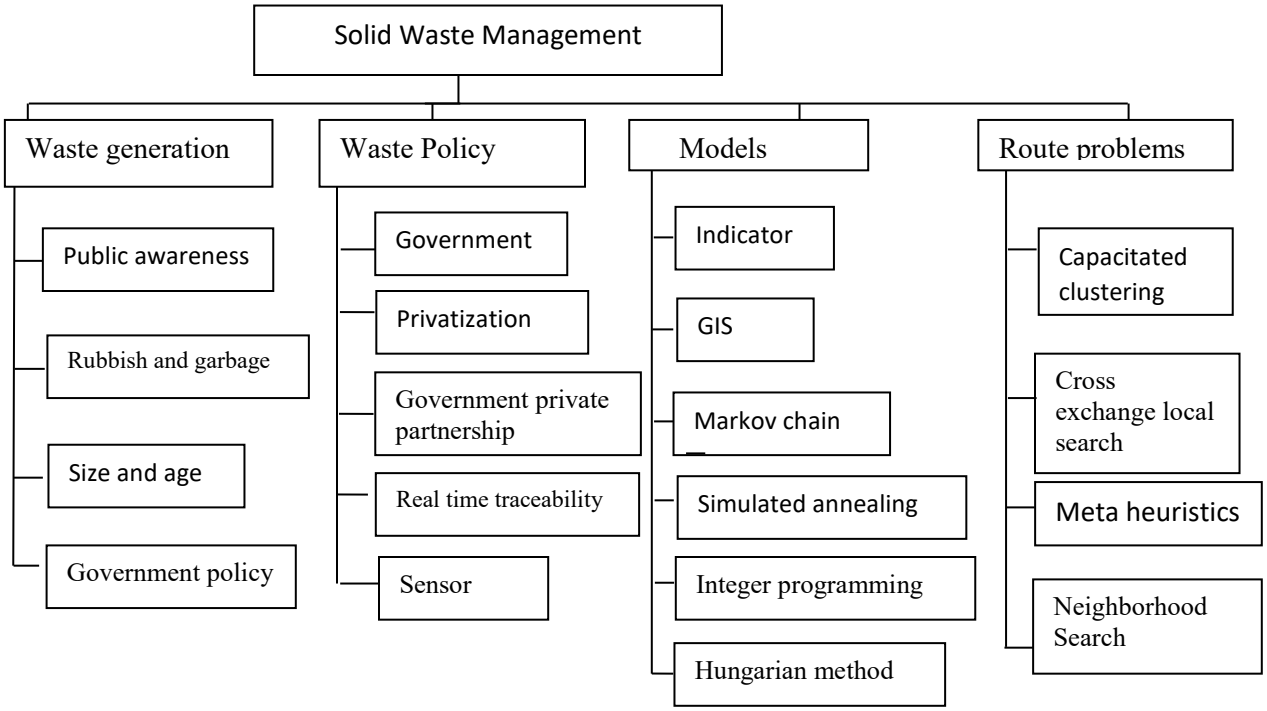

Figure 1. Some Solid Waste Management Parameters and Policies

3.1 Traveling Salesman Problem

Travelling salesman problem as the name suggest looks at finding the shortest possible route between set of stops or nodes (Syberfeldt *et al.* 2015). Travelling salesman approach seeks to find the cheapest route to visit different places and return to the starting point at minimal time. Arrangement of the manner in which this can be achieved develops into what is called a travelling salesman problem (TSP). Mere looking at it posits a simple non-polynomial (NP)-hard problem. However finding the optimal route takes time and the time has been seen to increase with size of the problem. According to Syberfeldt et al (2015) every small TSP involves a large number of optimal routes. A problem with 15bins can have about 6,227,020,800 possible routes thus manually optimizing waste collection problem within a realistic timeframe is practically impossible. With regards to transportation of waste, vehicle routing have often been considered without time windows. But this can only be applicable to residential areas Kim (2006), since waste collection in a municipality entails a combination of both residential, commercial and roll-on-roll off, incorporation of time windows becomes essential. Odewumi (2013), vehicle route planning and scheduling waste collection requires creation of the shortest circuit through the assigned nodes (waste drop points) such that for every waste collection operation, an already filled container at the drop point is emptied into the vehicle (compactor, truck) and the filled vehicle is emptied at the landfill or disposal sites. Solution to TSPs can be gotten using exact method (branch and bound, cutting plane algorithm), heuristic method (nearest neighbor and sub-tour reversal algorithm), and metaheuristics methods like Tabu search, simulated annealing and genetic algorithm (Aremu, 2013).

In the light of the foregoing, the next section examines how solid waste optimization, generation and transportation to the landfill centres were conducted using vehicle routing problem as a subset of travelling salesman.

3.2 Solid waste management optimization

Badran and El-Haggar (2006) worked on optimization of municipal waste management in Port Said – Egypt using the concept of collection stations. In their proposed model, optimization was done by minimizing municipal solid waste management system cost through mixed integer programming. The result showed that best model will be made of 27 collection stations of 15-ton daily capacity and 2 collection stations of 10 ton daily capacity. From their work profit generated was $8418.23USD.Since the rate of waste generation differs from one region to another, waste collection method to be used should also be a function of region in question. Dahlen et al (2007) compared the collection systems for sorted household waste from six municipalities in southern Sweden. In their work, the composition and quantity per person of MSW generated in six municipals in Sweden was given. The result shows that weight based billing method reduced household waste by 50% whereas with curbside collection, more metal, plastic and paper packaging were separated and left for recycling. Inclusion of separate collection of biodegradables in the curbside system led to increase in overall sorting of dry recyclables. Overall they observed that reliable waste composition and generation data is necessary for a vivid comparison of the output of different collection system. Developing countries have been known to be faced with serious waste management issues. From the work of Chukwuemeka *et al.* (2012), the waste management situation in Nigeria has implications on development. The authors opine that poor solid waste management structure hampers sustainable development in the country. Using Enugu state as a stress point, they observed that poor environmental education is prevalent with some of the waste management staff being improperly trained with no avenue to enlighten them on newest waste management methodologies.

Gedefaw (2015), while assessing the current status of solid waste management in Gondar town, Ethiopia observed that urbanization had led to development of slums with poor waste management practices. Mantzaras and Voudrias (2017) worked on the development of an optimization model for the minimization of the cost of collection, haul, transfer, and treatment, as well as disposal system for infectious medical waste (IMW). The candidate locations of the treatment facilities, transfer stations and sanitary landfills were designated, using a GIS-based methodology. Specifically, Map-info software with exclusion criteria for non-appropriate areas was used for sitting candidate locations for the construction of the treatment plant and calculating the distance and travel time of all possible vehicle routes. Microsoft excel software was used as installation platform of the optimization model. For the execution of the optimization routine Evolver software which is based on the use of genetic algorithms and Crystal ball which is based on Monte Carlo simulation was used. The results show that the higher percentage of the total cost was due to the construction of the treatment plant.

3.3 Municipal Solid Waste Generation

As at 2012, worlds' cities generated about 1.3 billion tons of solid waste per year equating to 1.2kg per person per day and this is expected to rise to 2.2billion tones by 2025 (Hoornweg and Bhada-Taata, 2012). Olaniyan *et al.* (2015) studied the solid waste management situation in Ibadan Oyo State Nigeria. Omi-Adio in Iddo local government area, Ibadan, Oyo State was used as study area and the kind of waste generated for 3 months were studied. Result showed that rubbish and garbage had the highest weight percent with waste from ashes, agricultural and health/medical found to be minimal with no occurrence of construction waste. Their study also pinpointed the impact of public awareness as River Omi was being used as dumpsite by some people even after it had previously led to flooding that caused loss of lives and properties. Stephen (2006) draws together the findings of municipal solid waste (MSW) compositional surveys undertaken in the United Kingdom. Questionnaire surveys and analysis of the results suggested that the size and age profile of a household influence the generation of household-collected waste. Other researchers also suggested the waste container provided by the local authority and the socio-economic classification of a household also influence household-collected waste generation, but failed to find this link. Similarly, Mbina and Edem (2015), from the study on the challenges of urban waste management in Uyo metropolis found that about 30,350 metric tons of waste is being generated daily with the poor staffing and inadequate equipment being the major challenge faced (Gedefaw, 2015). Nwachukwu (2010), conducted an empirical analysis of the solid waste generation and disposal in Onitsha metropolis. His work using simple linear regression showed that rate of population growth varies linearly with the rate of waste generation. Also the rate of solid waste disposal

in Onitsha was found to be far behind its rate of generation. Due to the result obtained privatization of the system was recommended.

3.4 Approaches to Municipal Solid Waste Collection

In waste management, waste collection has been widely seen to gulp the largest percentage of money assigned for waste management. According to World Bank estimate, about80-90% and 50- 80% of municipal solid waste management budget in low income and middle income countries respectively- goes into collection of waste. Collection rates have been seen to be as low as 41% for low income countries and as high as 98% for developed countries (Hoornweg and Bhada-Tata, 2012). Thus for cost reduction and proper waste collection, municipal authorities have been forced to develop strategies to ease collection of wastes. Odewumi (2013) using Lagos Nigeria as a case study while looking at existing strategies, proposed the inclusion of the private sector and suggested mode of operations. From his study, he found out that close to two-third of the total waste generated will always end up in unofficial dumpsites or on the street thus highlighting the importance of private sector involvement. However, Aliu*et al.* (2014), from their study on the effect of public private partnership (PPP) in municipal household solid waste collection in a megacity like Lagos found that estimated waste per capita income generated in Lagos is about 0.95kg per day. PPP performance was seen to be influenced by economic status, affordability, flexibility, capacity, trip rate etc. Waste collection and transportation in municipal have been observed to be costly. Thus requiring real time traceability using modern technology. Anagnostopoulos *et al*. (2015) proposed novel algorithms aiming at providing efficient and scalable solutions to the dynamic waste collection problem through the management of the trade-off between the immediate collection and its cost. Their paper focused on smart cities where a number of collection bins are located in different areas with sensors attached to them, a dynamic study of waste collection architecture was studied which is based on data retrieved by sensors. Comprehensive simulations on top of the data retrieved by a smart cities validate the proposed algorithms on both quantitative and qualitative criteria which are adopted to analyze their strengths and weaknesses.

Gilardino et al. (2017) carried out a research on combining operational research techniques with Life Cycle Assessment to locate collection sites for general and recyclable residues and create an effective collection-route system for compactor trucks to attain a reduction in environmental impacts. For the location of the collection sites a mathematical optimization model was proposed to decide where to locate them, as well as the number of containers required at each site, considering that general and recyclable residues would not be collected at the same site due to the restricted space available. For the creation of collection routes, a heuristic approach based on the Vehicle Routing Problem was constructed, taking into account the available working time of each collection truck to assign them collection routes and minimize the number of compactor trucks. Computed results show that implementing a container collection system reduces the number of compactor trucks required by up to 50% as compared to the current door-to-door collection system. Juyoung, et al. (2013)propose a large neighborhood search based iterative heuristic approach consisting of several algorithms for the problem on roll-on–roll-off waste collection vehicle routing problem involving large containers that accumulate huge amounts of garbage at construction sites and shopping districts. The effectiveness of the proposed method was demonstrated by computational experiments using the benchmark data. The proposed approach generates much better solutions–in terms of the number of tractors required and the total route time- on the benchmark data than the current company practice. An awesome research has been presented as approaches to handling of waste, this approaches includes government partnership with individual, government working alone and use of algorithm to locate landfill centers.

3.5 Municipal Solid Waste Collection Using Capacitated Vehicle Routing Problem

Prodhon and Prins (2014), analyzed the recent literature (72 articles) on the standard location routing problem (LRP) and new extensions such as several distribution echelons, multiple objectives or uncertain data. From their work location and routing decisions are interdependent and studies have shown that the overall system cost may be excessive if they are tackled separately. The (LRP) integrates the two kinds of decisions. Given a set of potential depots with opening costs, a fleet of identical vehicles and a set of customers with known demands, the classical LRP consists of opening a subset of depots, assigning customers to them and determining vehicle routes, to minimize a total cost including the cost of open depots, the fixed costs of vehicles used, and the total cost of the routes. Results of state-of-the-art metaheuristics were also compared with standard sets of instances for the classical LRP, the two-echelon LRP and the truck and trailer problem. Vecchi *et al* (2016) worked on the use of capacitated arc routing problem CARP as a sequential approach for the optimization of truck routes for solid waste collection. In

implementation, the method involves grouping of arcs based on an adapted model of the p-median problem, formulated as a problem of Binary Integer Linear Programming (BILP), development of a model for the solution to the CARP, formulated as a Mixed Integer Linear Programming (MILP) problem and carrying out the application of an adapted algorithm of Hierholzer. Their results led to a reduction in the distances traveled by trucks, which could promote money savings for the public coffers. Aremu (2013), formulated a travelling salesman problem for in-town tour optimization of municipal solid waste collection in Ilorin, Kwara state, Nigeria. In this work, ten prominent routes were optimized using Microsoft excel 2010 solver and the optimization process reduced tour distance by 2.04 – 19.27%, tour time by 0.33 – 22.80% and fuel consumption by 1.78 – 20.54% thus accruing to a cost reduction on diesel between US$0.11 – US$1.65per vehicle per day. However he assumed that the collection vehicle begins and ends the work at the garage and that the collection vehicle moves from garage through waste bin locations (drop points) and back to the garage. Collection of municipal solid waste analysis considers only the route to collection and the capacity of the Truck without showing evidence to its earliest and latest time of visitation of each dumpster.

3.6 Municipal Solid Waste Disposal

Cervantes *et al* (2018), used indicators to evaluate the municipal solid waste over a decade. In the paper40 sets of indicators were documented and analyzed based on their characters, strengths, and weaknesses. The analysis contained a variety of characteristics, such as the type of indicators (qualitative, quantitative or both) and the level at which they are applicable (municipal, regional, national, international or various levels), among others. Finally, list of 377 different indicators was obtained, with 49.3% of them focusing on technical aspects of waste management. From the analysis, the main qualities that an indicator set must accomplish were identified to allow their possible standardization; that is, it must be useful at different geographical and economic levels, include indicators of different types, follow a clear methodology, and cover all aspects of possible interest.

Nwosu and Pepple (2016) determined the most suitable site(s) for waste disposal in Ile-Ife, Osun State. The research was carried out using Geographic Information System (GIS) which allows users to view, understand, query, interpret and visualize spatial and non-spatial data in many ways that reveals relationships, patterns and trends in the form of maps, reports and charts. The Criteria for site selection included physical characteristics, socioeconomic, and land-use factors (EPA, 2006). Sener,*et al*(2010)investigate the possibility of selecting landfill site using the Geographic Information System (GIS).The Analytical Hierarchy Process (AHP) and the remote sensing methods for the Senirkent–Uluborlu Basin were integrated into the procedure. The basin is located in the Egirdir Lake catchment area, which is one of the most important fresh water In Turkey where waste management must be regulated. Ten different criteria (Lithology, Surface Water, Aquifer, Groundwater Depth, Land Use, Lineaments, Aspect, Elevation, Slope and distance to Roads) were examined in relation to landfill site selection. Each criterion was identified and weighted using AHP. The results indicate that 96.3% of the area in the Basin was unsuitable; 1.6%, moderately suitable; and 2.1% most suitable. Finally, suitable regions in the Basin were determined for solid waste landfill disposal. Relevant checking measures were explored in the field. Muttiah, *et al* (1996), discuss the use of Markov-chain-based simulated annealing algorithm as a search engine to locating potential waste disposal sites in the Indian Pine watershed of Indiana, using geographical information system on administrative scores that have been regulated by the Indiana Solid Waste Management Board. Results show that simulated annealing achieved an order of magnitude reduction in execution time over that of an exhaustive search method, and gives a policy maker the option of selecting the final site based on social factors that are not considered in the numerical model. Mensah et al. (2016) use heuristic approach to locate landfill site in Sekondi – Takoradi metropolis Ghana. In the presentation, the need to find the optimal location of a landfill site in the Sekondi – Takoradi metropolis was seen as an integer programming model and the solution presented as an ant colony solution based meta-heuristic. Disposal of waste can be determined with geographic information system, use of indicators and Markov chain annealing. Ozor, *et al* (2017) further describe how solid waste management in Enugu metropolis of Nigeria can be implemented. The authors noted the paucity of landfill site in the metropolis (only one at the time) and suggested creation of additional nine land fill sites, according to ten hypothetical zones of the area. The location of the proposed landfill site and solid waste collection centers were formulated as an assignment problem and solved with the Hungarian approach.

3.7 Municipal solid waste collection using vehicle routing problem with time windows

Optimal solutions are needed with regards to variants that are being met in real life situation of waste management for realistic cost reduction. Kim *et al* (2006) consider a real life waste collection vehicle routing problem with time windows (VRPTW) in North America while considering multiple disposal trips and lunch breaks. Solomon's

algorithm was extended to develop a capacitated clustering–based waste collection algorithm with the aim of minimizing number of vehicles and total travelling time. Unlike the normal vehicle route planning with time windows, their own covers disposal operation and driver's lunch break and is also modeled using a clustering–based waste collection VRPTW algorithm and simulated annealing (SA) meta-heuristic using the CROSS exchange local search method. Two main constraints were considered in the research; vehicle capacity and route capacity and a lunch break. Result showed the solution showcased better route compactness than solution from extended insertion algorithm. Buhrkal *et al* (2012)present waste collection vehicle routing problem with time windows with the objective of finding the optimal route for travel cost minimization for trucks such that all bins will be emptied and waste disposed while still meeting the time window specification. According to them, waste collection vehicle routing problem with times windows (WCVRPTW) is different from the known VRPTW in the sense that in the former, trucks must empty their loads at the disposal sites, must be empty when returning to the depot and multiple trips are allowed. Adaptive large neighborhood search (ALNS) Meta - heuristic was used to solve the set problem and an average improvement of 9% was observed. The data used was obtained from literature as well as Danish garbage collecting company. Rousseau and Gendreau (2002) develop models based on constraint–based operators for solving vehicle routing problem with time windows. Though most methods for optimization have been based on mathematical programming or metaheuristics, constraint programming which came from artificial intelligence seem to offer more flexibility especially for real world problems. Thus, in the work, feasibility of using constraint programming combined with variable neighbourhood descent (VND) to get a solution for VRPTW was tested. The 56 Solomon problem was used as benchmark while introducing the concept of naive ejection chain (NEC) in the algorithm. The results show that NEC which was designed to optimize vehicle distance provided a solution using less number of vehicles. No case study was mentioned in this paper.

Faccio *et al.* (2011) worked on development of a multi objective model with real time traceability. Their work was aimed at reducing investment cost, operational cost, and unnecessary stops by collecting real time data using modern devices. Result showed that use of modern traceability technology allows for the real time replenishment level of each bin and real time vehicle position of each vehicle. Financially, the benefit of using the model was observed to be less than the cost of implementing it. Syberfeldt *et al.* (2015) optimize a real world travelling salesman problem using evolutionary algorithm by adding a repair function to it. Accordingly, optimization of waste collection in Sweden was implemented. The problem involves about 17,000 garbage bins served by three bin Lorries which was seen as a travelling salesman problem to be solved using simulation-based optimization and an evolutionary algorithm. A repair function was added to the evolutionary algorithm to make it easier for shorter routes to be found. The algorithm was tested using order crossover and heuristic cross over with result showing that order crossover is better than heuristic cross over. However, this was observed to be due to the introduction of repair function. Otti (2011) develop a flexible model for minimizing cost of solid waste management in Anambra state. Studies carried out in the state have shown that indiscriminate dumping of refuse is an everyday phenomenon. Thus using linear programming and considering cost of maintenance of the vehicles used, equipment purchase and money spent on personal and sundry matters. The research, though, suggest feasible solution workable for a country like Nigeria where access to financial resources is scarce, but did not take any time window effects into consideration.

4. Discussion

From the foregoing, it can be seen that various works on waste management, solid waste collection and control techniques have been suggested by past researchers under different facades. Most of the presentations delve into various constraints like number of vehicle, distance from homes and dumpsters, distance of dumpsters to landfill site, optimization of existing methodologies and so on. Some of the approaches used have also been found to be borrowing from separate field, for example, the introduction of repair function, applicable in maintenance management. The emphasis have been mostly on advanced countries that have almost exited infrastructural development phase, like provision of good network of roads, which is required for solid waste evacuation. The application of optimal strategies is therefore apt in such regions. The review has also revealed that majority of waste management methodologies suggested in developing countries, expectedly dwell on traditional vehicle routing problems with preset and inflexible times, though the Ant colony algorithm has been suggested in Ghana. To further relax the dynamics of the suggested models, this research note that provision of models and solid waste management and control strategies with time windows can also be investigated for developing countries. The approach can begin at Municipalities and taken to the National level and comparison made with the existing techniques. This work

suggest that such studies can be conducted in Nigeria, where a lot of alternative techniques appear to have turned out in recent past.

Conclusion

Nevertheless, in all the works reviewed, routing and planning of waste management system in Nigeria have been more of a traditional vehicle routing problem without times windows. As such efficiencies that are the product of inclusion of times windows in vehicle routing problem have not been evident. This knowledge gap can improve the effectiveness of Solid Waste Management if closed. Currently, most vehicles (compactors for solid waste disposal) operate on routine schedules, which results in excessive dumpster overflows in some cases. The other extreme of having dumpsters premature for evacuation is also evident in other places. The summary, observation and recommendation of this research is that a robust solid waste management and disposal model that can take the differences in "maturity for disposal time" of solid waste collection cans or dumpsters into account should be explored. The proposed study should also consider consistency with the traveling salesman approach, in other to ensure optimal traveling distances, which can translate to effective cost.

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