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Solid Waste Collection Optimization: A literature Review

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Abstract: **The urban population saw an increase of 80 million in 2019. The accelerated movement of people towards urban centres along with annual increasing per capita waste generation calls for an urgent need to address the rising solid waste generation. Contemporary pandemic of Covid-19 puts the demand all time high for revival and optimizing solid waste management system. For optimizing solid waste management, solid waste collection is the most important aspect of process as it includes majority of financial inputs. This article aims to provide literature review regarding different methodologies and criteria for solid waste collection optimization. The article also examines trends and areas of future research along with unexplored and budding domains. This would help reader identifying his interest area besides getting a comprehensive understanding of research trends. The study could also be used by waste management firms to analyze, compare different methods, their performance and their suitability under different environment conditions.**

Keywords**: solid waste collection optimization, waste management, literature review, solid waste**

I. INTRODUCTION

As per World Bank, the world urban population grew by 1.8 % in 2019 to 4.29 billion. This growth rate is further high in developing countries such as India where annual rise is between 3-3.5% in urban population. Waste generation per capita is also increasing with time. For instance, waste generation per capita in India increases around 1.3- 1.5 times per annum. Thus this calls for an urgent need for optimizing and managing solid waste collection. Further with contemporary challenge of Covid-19, leading to exponential increase in biomedical waste supplemented with evergreen problems of unavailability of sufficient land, lack of adequate funds, informal recycling system and treatment process calls for an urgency to look into the issue on a priority basis. Efficient waste collection could also reduce problems, if not solve, relating to landslides at landfill , leachate contamination of groundwater, release of noxious gases in atmosphere and other related environment hazard.

Solid waste collection is a part of solid waste management. Solid waste collection is removal of solid waste from premises of primary generating source to treatment or disposal site. Waste also includes curbside collection of recyclable materials that are technically not waste. On analyzing different articles it has been found that definition of waste has changed to a great deal! Now it is not looked as a leftover but as a potential resource for recyclables such as plastic, glass etc. The current use of waste even emphasize on electricity and energy generation at different waste processing facilities. Thus the perspective of waste management has changed to a great deal and holds enormous potential and scope for optimization and making profits. It's very essential to optimize waste management cycle. Under waste management, it has been found that around 80% of all costs incurred in waste management process is associated with collection process (Clark and Gillean (1975) and Or and Curi (1993)) . Thus collection process under solid waste management has immense scope for optimization and to bring in the desired results in terms of financial as well as non financial parameters. Non financial parameters can be in terms of environmental outputs, worker's safety, satisfaction, better health outcomes etc. Thus this paper aims to review available literature on solid waste collection with special focus on optimizing transport cost of waste from collection to disposal sites.

Few decades back, solid waste collection was carried out without analyzing waste generation rate. The rising population and urbanization calls for a need to adopt more scientific and calculative approach for waste collection since there are limited resources such as land for waste disposal. Further the global scenario of climate change post Paris conference of 2015, ask nations to cap their carbon dioxide emission rates to prevent global rise in temperature above 2°C (compared to pre-industrial levels) by the end of century. This treaty is legally binding and as huge quantity of waste is incinerated, which could be compensated via optimizing truck routes (Macrorouting), policy regulation such as compulsory segregation at source or disposing recyclables into green bags could help to better waste collection and processing, thus reducing pollutants emitting via incineration. Hence the paper talks of work on optimizing solid waste collection under different classification.

On finding related resources for literature review regarding works on solid waste collection optimization, the resources are meagre. However no paper could be found of which focuses exclusively on literature review of optimization in solid waste collection, though few papers were found which focussed on optimizing solid waste management and dealt with solid waste collection as a part of. An attempt has been made to provide a comprehensive resource for the reader regarding trends and development in research done in solid waste collection optimization. This would help reader to understand the current state and research gaps and relevant problems in this field. It could also help the reader to identify his relevant area and field of interest as different areas follow different approaches. The approaches discussed vary from traditional approaches of mathematics to latest trends by use of cyber physical systems, Internet of things etc.

As goes with rising need, the number of publication on solid waste management has increased steadily. Most of the papers mentioned can be found on online search engines and databases such as Google, Google Scholar, Baidu, Researchgate etc. The various journals which has published the articles are maths journals (Advances in Mathematics) , science journals (Internal journal of Innovative Research and Development) , engineering journals (Hindawi journals of engineering, Transportation science, Engineering Optimization, Procedia Engineering) Environmental Journals (Waste Management, Environmental Modelling & Assessment), Operation Research (Computers and operation Research, American Journal of Operation Research) , different conferences (Proceedings on 21st conference on modelling and simulation), books etc. . The first paper studied was published by Finnie (1973). The latest paper studied has been published by Al-Rafaie et al (2020) which emphasize on solid cost collection optimization via efficient clustering of garbage containers or bins. Much available literature is after 2010 and majorly deals with vehicle routing. Papers making use of GIS software has also seen a rising trend. ArcGIS is most commonly used software for this purpose.

The above graph shows classification of papers on the basis of research area. Maximum number of publications dealt with optimization via operation research, statistics, mathematics etc. The next major domain is transportation science. GIS & Computing includes GIS software, Google Earth, Google Maps, Decision Support System etc. The papers which focus on environmental parameter such as reducing green house gases were 8 in number. Few papers also dealt with psychology. The first paper studied by Finnie (1973) can be dealt under psychological approach. Nascent technology include articles dealing with IoT, RFID, sensors etc.

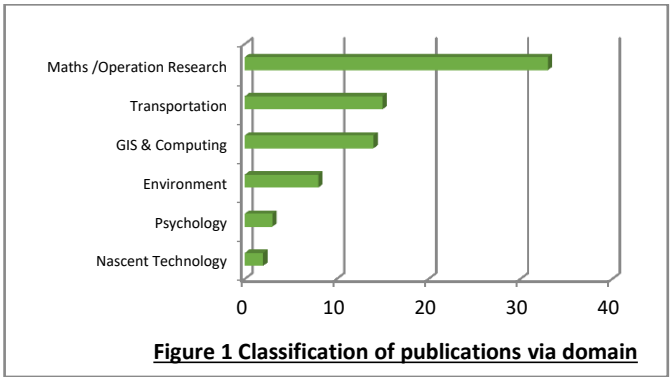

Figure 1 Classification of publications via domain

The various publications have been grouped under different heads to help reader identify his area of interest. The paper has been studied under different perspective which are listed as follows-

Scope of Solid Waste

Solid waste has often different definitions and these maybe even contrasting at times. Initial work on solid waste management, regarded solid waste as simply garbage (Beltrami and Bodin, 1974). This understanding prevailed for a long time and majorly perceived solid waste as household / kitchen waste. As per Angelidaki et al (2011, p.343), solid waste can be defined as organic material with solid content of 10-40% of total solids, which is not fluid. However the constituents are often debatable. As per Solid waste management rules, 2016, "solid waste means and includes solid or semi- solid domestic waste sanitary waste, commercial waste, institutional waste, catering and market waste and other non-residential waste , street sweepings, silt removed or collected from surface drains, horticulture waste, agriculture and dairy waste, treated bio- medical waste excluding industrial waste, bio medical waste and e-waste, battery waste, radio-active waste generated in the area under local authorities and other entities." As per Resource Conservancy and Recovery act (popularly known as RCRA), solid waste is defined as "any garbage, refuse, sludge from a wastewater treatment plant, water supply treatment plant or air pollution control facility and other discarded material, including solid, liquid, semisolid or contained gaseous material, resulting from industrial, commercial, mining and agricultural operations and from community activities. " However usually after examining number of papers, semi solid waste such as sludge and night soil are considered to be a part of liquid waste management system. Municipal solid waste is defined to include refuse from households, non hazardous solid waste from industrial, commercial, and institutional

establishments (including hospitals), market yard waste, and street sweepings. This paper provides reviews for papers related to hazardous waste as well as municipal solid waste.

Solid waste collection optimization has been studied under various classifications -

Classification based on use of GIS Software

As vehicle routing problem has relatively more publications in waste collection optimization, vehicle routing is increasingly being carried with the help of GIS software. Many publications using ArcGis to find the best route as per demand of parameters have been studied. Lopez et al (2008) used ArcGis to design routes for Leganes (Spain). The routes use bin to bin (BTB) collection of paper and cardboard waste from new locations and small businesses. Beside this, the number of containers needed for commercial and non-commercial areas was also calculated. Paper and cardboard were emphasized due to their large proportion in daily waste generation. The service became more frequent and it led to reduction of waste in bin. While Karadimas et al (2008) found efficient routing for trucks in Athens (Greece) to collect waste items of large sizes. Their study resulted in identifying shortest route resulting in minimum cost. Itnal and Prakash (2008) aims to minimize route distance and time for collection of community solid waste in Bangalore city (India). They are able to achieve a distance reduction of 12.95 % and 12.92% saving in operational cost via GIS. Apaydin and Gonullu (2008) worked on non financial parameters and found the most optimized routes for least emission reduction from trucks during collection of solid waste. It also resulted in reducing operational cost by reducing travel time besides reducing exhaust gas emissions. A study carried out by Zsigraiova and Carvalho (2009) in Cape Verde (Africa) aimed to optimize collection process by reducing time of travel and fuel consumption. They come up with a route having 29% distance minimization and 16% fuel saving , Zamorano et al (2009) developed an optimal model for municipal solid waste collection for Churriana de la Vega (Spain) . They reduced length and time for solid waste collection routes via GIS. Another study was carried out by Malakahmad et al (2014) in Ipoh, Malaysia .The methodology used was a combination of territorial analysis, GIS analysis and service design. ArcGis was used to optimize waste collection by reducing collection time, cost and air pollution emission. For this purpose, ArcGis came up with appropriate distance between collection point and optimal collection duration for different routes considered. The best route was selected on the above parameters resulting in reduction of collection time by 2332 second and distance by 22 %. This would also result in pollution reduction as per study. Bhambulkar (2011) uses ArcGIS network analyst for best routing identification in municipal solid waste collection by considering environmental and social implications.

Classification based on Single or Multiple Objectives

Classifying publications on the basis of objective can help reader to get acquainted with research trends in alignment with his goals. Many research papers were analyzed. Research can be classified under-

Optimization studies with single objective- Among the single objective, minimization of cost is most dominant. For instance, solid waste collection optimization via vehicle routing is most common area which tends to reduce waste collection cost by shortening route length. The other common single objectives dealt are truck allocation. Texeira et al (2004) aim to find optimum vehicles routes for recyclable collection. The areas under study are Coimbra and Aveiro in Portugal. A total distance reduction of 29% was obtained which is quite significant.

Optimization studies with multiple objectives – Many studies had multiple objectives to carry out optimizations. The research under multiple objectives has steadily increased and attempts have been made to simulate real life conditions. Various mathematical models have been used to carry out optimization under such scenario. Sahoo et al (2005) aims to carry out multi objective optimization via minimizing number of vehicles, travel time, maximizing visual attractiveness and balancing workload among vehicles. Banyai et al (2019) proposes a mathematical model for optimal assignment of waste sources to garbage trucks, scheduling of the waste collection through routing of each garbage truck to minimize the total operation cost, increase reliability while comprehensive environmental indicators that have great impact on public health are to be taken into consideration. They consider use of cyber physical system for collection of waste via smart bins using Internet of Things (IoT) and smart devices technology. Binary Bat algorithm is used for performance validation with different benchmark functions.

Classification based on Domain of Study

Mathematical Programming/Models- Many mathematical models have worked on clustering to optimize solid waste collection. An optimization based heuristic algorithm was developed by Koskosidis et al (1992). Cluster-first, route-second was used for vehicle routing and scheduling. They focussed on minimizing transportation cost. Otoo, Amponsah and Sebil (2014) used heuristics to develop a feasible solution to extended capacitated arc routing problem. A 40% reduction in vehicle distance travelled per week was the outcome for the study carried out at Ghana.

Solution methods for optimizations can be divided into many sub types based on methods. The most basic and initial efforts were found out among papers in field of linear programming. The various sub fields are linear programming, mixed integer programming, Non linear programming. Heuristics have been most employed to find optimum solution. Heurisitics can be studied under methods of Tabu search, Genetic algorithm, Ant colony optimizations, simulated annealing, construction, clustering and partitioning heuristics. Other methods came across are simulation, branch and bound solution methods.

The basic principle governing mathematical modelling is to maximize or minimize an objective function by choosing values of integer or real variables.

Linear programming has been used by to find optimal route via cost minimization and at same time minimizing probability of accident in a hazardous context. While Simonetto and Borenstein (2006) hold a view that flip side of such model is that it could not be solved within a reasonable computation time as it has a lot of variables and constraints. Thus they came up with heuristic and linear programming formulation. Krikke et al (2007) have used linear programming in recyclable waste context. They developed a linear model such that all models with high priority are finished at minimum cost. The most common objective function used for linear programming is cost minimization by bringing about relevant optimizations.

Then comes the most prominent class of mixed integer programming. By mixed integer programming, mixed implies that only some variables have been placed under constraints and not all. Pati et al (2008) used mixed integer goal programming (MIGP) or multi period integer programming to analyze relationship between multiple objectives of a waste management system. A recycled paper distribution network was analyzed to determine facility location, route, and waste flow in a multi item and multi facility decision making framework. Beamon and Fernandes (2004) used multi period integer programming for joint analysis of investment and operational costs in closed supply chain network including a waste related facility. Another use of mixed integer linear programming was made at Ankara for end-of-life vehicle recovery system to carry out network design by Demirel et al (2016). Mixed integer programming can be used for facility location as well as collection routing problem.

One of the drawbacks of mathematical programming is the boundaries they have, for instance Sniezek and Bodin (2006) could not solve capacitated arc routed problem exceeding 500 acres and 10 vehicles. They solved the model by taking a set of routes from the model and solving them. The new routes replace the old routes and the procedure is repeated. A portion is solved using this process while the remainder is kept fixed.

At this point of time, it is worthwhile to discuss about grey mathematical programming. The basic advantage of this programming is that it can work under variable conditions. For instance when we deal with waste collection, the amount of waste generated vary across different days, seasons. Another example can be taught of variable incinerator capacity so the routes or capacity of collection may vary. Huang (1994) describes a good explanation of grey mathematical programming. Most of the paper on Grey mathematical programming deals with facility location while Huang et al (1998) deals with truck allocation and hence can be used for optimizing collection process as well.

Non linear programming is not much used for collection purpose as it is relatively difficult. Wu et al (2006) uses non linear programming to establish a non linear relationship among different process in waste management such as waste collection, classification, distribution, transportation and disposal. Another work is done by Bedenik and Kravanja (2007) for optimizing collection, recycling and disposal of treatment and disposal of municipal solid waste via mixed integer non linear programming.

Another category under which examined papers can be placed is heuristics. Heuristics can be further sub divided into metaheuristics and construction and partitioning heuristics. Various publications studied under metaheuristic can be divided into local search heuristics, tabu search algorithm, genetic algorithm, ant colony optimitization and stimulated annealing.

Metaheuristic can provide sufficiently good solution to an optimization problem when information is incomplete, imperfect or there is limited computational capacity. The most studied process under it is local search which aims to search for better solution by iteratively exploring the neighbourhood. Bianchessi and Righini (2007) carry out local search algorithm using different types of neighbourhood. They also compare local search and tabu search for vehicle routing problem.

Tabu search is an optimization over local search as it searches nonimproving neighbourhood. Tabu search performed better between 3% to 11% in terms of cost optimization as per Bianchessi and Righini (2007). The heuristics sometimes can also be used in combination. For instance, dynamic programming and variable neighbourhood search was used by Hemmelmayr et al (2013) to solve waste collection problem in which glass, metal , plastics or paper is brought to certain waste collection points by citizens of certain region. Periodic routing with intermediate facilities was considered and a saving of 25% in cost was the outcome.

Genetic algorithm (GA) is next class under metaheuristics. It implies Genetic operators over earlier solutions (which are referred as parents) to create kids (new clients) which inherit certain characteristics of their parents. Most papers consider a deterministic setting. However Chang and Wei (1998) consider uncertainties encountered by adopting a stochastic approach. They considered objective parameters as minimization of distance travelled by collection vehicles as well as minimum distance to drop off stations.

Next division under Metaheuristics is Ant colony optimization (ACO). ACO is inspired by nature and was proposed in 1996. It is based on principle of food searching by ants. Ants while searching food secrete a scented material (pheromone) on traversed path. This pheromone is sensed by other ants and they track the already found food sources. So the paths which having higher concentration of pheromone are shorter in length and have higher probability to be chosen. ACO performs excellently among other nature inspired approaches such as Genetic algorithms, Tabu search and particle swarm optimization (Bansal et al, 2020). Karadimas et al (2005) used ACO to reduce collection time. ACO is also used for solving complex combinatorial optimization problem

like Vehicle routing problem (VRP), Travelling salesman problem (TSP), Job shop scheduling etc. There are certain improved version of ACO such as Hybrid ACOs, ACS (ant colony system) , Max-Min ACS, Multi- ACS etc. Bansal et al (2020) works on further optimizing ACO by hybridizing it with Levy flight optimization.

The last category studied under Metaheuristics is simulated annealing (SA). As per Ahmed et al. (2020, p.209), Simulated annealing is a probabilistic technique for approximating global optimum of a given function. Sahoo et al (2005) use SA to carry out multi objective optimization in terms of minimizing number of vehicles, travel time, maximizing visual attractiveness and balancing workload among vehicles. The other notable work is of Muttiah et al (1996) which intend to make site selection for disposal with the help of GIS based simulated annealing.

The second category under heuristics is Construction and partitioning heuristics. Construction heuristics determine a tour on basis of some construction rules but may not improve the tour. Hence it is often used in combination with different metaheuritics to carry out optimization. Amponsah and Salhi (2005) developed a construction heuristic to solve waste collection problem by taking environmental aspects into consideration. This algorithm is specific to developing countries.

A notable work on construction heuristic is done by Clarke and Wright (1964). Many researchers applied this heuristic in their research publications such as Beltrami and Bodin (1974), Hansmann and Zimmermann (2009) etc. An insertion heuristic is a type of construction heuristic which creates a convex hull and then includes all the nodes which increase the length the least. Sahoo et al (2005) used insertion heuristic of Soloman to carry out multi objective optimization in terms of reducing number of vehicles, travel time and maximizing visual appeal to optimize waste collection.

Partitioning and Routing heuristics are generally used in 2-phase and they can be of two types. Type-1 (cluster first- route second) deals with problems in which customers are clustered in groups (phase 1) and vehicles are assigned, then each cluster is looked for efficient routes (phase 2). Koskosidis et al (1992) extend Type-1 algorithm for vehicle routing and scheduling. Ooto et al (2019) also uses cluster first route second for optimizing waste collection in Ghana. Their study resulted in 40% reduction in vehicle distance per week. Type-2 (Route first-cluster second) deals with travelling salesman problem (TSP) who visit to all customers (phase 1) and then clusters are built up at later stage via partitioning (phase 2). Bodin and Beltrami (1974) mentions that Type-2 heuristic is more suitable when the number of pick up points are more and travelling and collection is required from each house/ multiple points. While type-1 will generate better results, when travelling has many tours and collection points are less.

Branch and bound methods partitions the solution space into disjoint subsets which are represented by nodes of branching tree. As per Naud and Tisseyre (2020, p.208) the tree avoids exploring the whole tree as before creating a new node, it looks for a better solution than the current best solution. The subtree is discarded if better solution is not found. Branch and bound method has been used by De Meulemeester et al (1997) to solve real time routing problem for collection and delivery of skips.

Simulation models are used for optimizing by varying each input and keeping other inputs as constant. Some works on optimizing via simulation are done by Bhatt (1996), Johansson (2006). Salhofer et al. (2017) carry out simulation in Europe to assess if recycling with increasing distance of waste disposal is advantageous. On the basis of their work they recommended kerbside collection, which is economically more efficient, besides showing highest collection rates. Simulation models are found very effective when conditions and waste generations are uncertain. Hybrid algorithm combining metaheuristics with simulation are used for solving problems relating to multiple depots and stochastic parameters (Gruler et al , 2017)

Other solution Methods - These methods use unique methods to optimize waste collection. For instance, Eisenstein and Iyer (1997) use Markov decision process for dynamic scheduling of Garbage collection in Chicago. While Torres and Anton (1999) used continuous approximation for vehicle routing in solid waste management.

Upcoming technologies/software - Under this category publications that rely heavily on computing software, upcoming/budding technologies such as smart devices, Internet of things have been studied. The interest in these areas is gradually increasing due to ease they provide for getting required output at minimal input. The most common software used has been ArcGis. Some publications have also used Google Earth, Google Maps for collection route optimization via vehicle routing and bin locations. GIS software has often been used in combination with different solution methods to get maximum optimization. Arena software and C^{++} has been used for making decision support system and programming respectively to optimize waste collection process.

RFID (Radio Frequency IDentification) has been used for tracking and better solid waste management as per Ustundag and Cevikcan (2008). They have considered single vehicle serving multiple location with a predetermined quantity making multiple trips.

In terms of upcoming / budding technologies, Banyai et al (2019) carry out a study to provide smart solutions for waste collection via Industry 4.0 technologies. They use smart bins with sensor installed to get optimum waste collection and get idea of adequate demand. The bins can be monitored real time via Wi-Fi or delayed monitoring where data is emitted offline through RFID readers. Thus collection can be scheduled depending on the waste level of containers. Therefore, the study aims to establish cyber-physical waste collection system using budding technology of internet of things , smart devices etc.

TABLE-1
Advantages and disadvantages of different Metaheuristics studied

Metaheuristic	Advantages	Disadvantages	References
Local search	- More widely used than other heuristics (such as GA) for vehicle routing problem - Can search enormous space with small amount of resources - Flexible - Easier to understand.	- Other methods have shown better results in comparative studies (such as Tabu search) - Solution found may not be optimal	Smet et al (2016), Bianchessi and Ragini (2005), Baker and Ayechew (2003), Dumitrescu, I., & Stützle, T. (2003)
Tabu search	- Improvement over local search - Efficient for vehicle routing problem - Can solve large scale problem (as compared to exact method) - Can escape local optimums by picking non-improving solutions - Can be used for combinatorial optimization - Simple, adaptable - Excellent Accuracy - Rapid, robust	- Number of iteration can be high - Algorithm may have many tunable parameters. - Complexity and limited flexibility of applying method	Xia et al (2018)
Genetic Algorithm	- Easy to understand - Great potential to deal with multiobjective problem - Used in travelling salesman problem - Can deal with complex problems - Can deal with continuous as well as discontinuous function - Can deal with linear as well as non linear functions.	- Careful selection of mutation, crossover, selection criteria, formulation of fitness function is required else may make the algorithm difficult to converge or results maybe meaningless - Abstract genetic algorithm maybe difficult to implement for spatial multiobjective problems	Yang (2014, p.77)
Ant colony optimization	- Efficient for travelling salesman problem which is commonly used in vehicle routing - Can be used for stochastic conditions - Inherent parallelism - Positive feedback accounts for rapid discovery of good solutions. - Used for combinatorial optimization - When graph changes dynamically, it is better than simulated annealing and genetic algorithm	- Research is experimental rather than theoretical - Probability distribution changes by iteration - Difficulty in theoretical analysis - Time to convergence is uncertain	Selvi and Umarani (2010)
Simulated Annealing	- Can solve complex spatial problems, capacitated vehicle routing problem , TSP etc - More widely used than other heuristics (such as GA for VRP) - Useful for combinatorial optimization - Easy to implement - Robust - versatile and flexible - Runs faster than Genetic Algorithm for TSP	- Solution quality is less when compared to genetic algorithm for TSP	Ottubamowo et al (2012)

TABLE-2
Advantages and disadvantages of branch and bound method and simulation Model

Solution Method	Advantages	Disadvantages	References
Branch and Bound Method	- Used for combinatorial optimization - Used for problems whose difficulty is considered exponential - Other techniques can further increase search speed such as heuristics to improve upper bounds on solution, iterative depth based search etc. - Have been used for TSP, integer programming, non linear programming etc.	- Nodes for large problems can be resource intensive/ time consuming. - Limited to small size networks.	GeeksforGeeks (2018)
Simulation model	- Can be used in Capacitated Vehicle Routing Problem (CVRP)/combinatorial optimizations. - Good for stochastic conditions. - Monte Carlo simulation has been effective in obtaining numerical solutions to complex problems which cannot be effectively solved by analytical approaches - Having a model allows to reduce disruptions in real system - Can provide details and understanding about subsystems and how they interact.	- Use for vehicle routing has been scarce and infrequent; (heuristics and meta heuristics are commonly used). - Often very costly - Maybe very time consuming	Juan et al. (2013), Carson (2005)

Psychological / Cognitive Approaches - Though material present is relatively lesser but this approach can prove very effective. A few researches have been discussed under:

As per Finnie (1973), the probability that a person would litter depends on three parameters. Firstly, age i.e. if he is 18 or older. Secondly, if trash cans are conveniently located and lastly if area is already dirty with litter. He found that younger people are much more likely to litter than older person. Gender was found to be insignificant on the basis of statistical studies. Though study was conducted in 1973, its validity remains high even today as role of younger person and location of trash cans play a major role in urban litter. Many studies on optimization in current times work on bin location.

Meng et al (2019) carry out study to investigate decision making mechanism of residents' in classifying and recycling of urban solid household waste. The study merges theory of planned behavior and Attitude-Behavior-Condition (ABC) theory in a study conducted at China. It was found that their disposal behavior of household solid waste depends on 4 intrinsic and 7 extrinsic factors. Most significant among them are education and publicity, environmental awareness, access to recycling facilities, access to classification facilities and willingness to participate. It was also found that impact of law is not significant as there were no incentives. Other studies, which remain valid across all domains such as role of leadership, can be useful in improving job performance of workers. For instance, Mansoor et al (2019) studies role of transformational leadership on job performance in small and medium enterprises.

Thus such studies can help in optimizing waste collection via adequate location of bins; reducing walking time, collection time and sorting time. Thus vehicles can serve more or larger area if less waste is generated.

Classification on basis of deterministic or stochastic conditions -

Most of the publications work on deterministic model. However real life problems are stochastic in nature as they are uncertain and demands/ conditions fluctuate. For better dealing with stochastic models, Grey programming can be adopted for optimizations. Grey programming does not have a fixed condition but works with an upper and lower bounds. Similarly simulation studies can be of much help as it tries to replicate real life conditions. Further combinatorial optimization can be carried out for getting best results.

Yeomans et al (2003) takes into account uncertain factors for municipal solid waste collection by combining simulation with evolutionary algorithm. Real case data from municipality of Hamilton-Wentworth (Canada) have been taken up to carry out optimization under practical conditions.

While Batta and Chiu (1988) propose a model having both deterministic as well as stochastic problems for optimization. As the leakage of gas coming out of a hazardous substance is a stochastic problem which involves a probabilistic function

while deterministic model aims to minimize the distance travelled through street.

Non linear programming can be further used for stochastic model as real life situations may not have linear relationship. However work under non linear programming is meagre as it is relatively tougher.

Wu et al (2006) use interval non linear programming (INLP) to handle practical life situation. Under INLP, when exponential term p=1, problem becomes interval linear program, while with value of p =2, it becomes interval quadratic program. He uses this approach to design waste management in Ontario, Canada. His model shows uncertain and non linear characteristics of system along with economies of scale.

Classification based on Objective function-

The research can be further categorized on the basis of objective function-

Cost - Most studies have attempted to increase efficiency in terms of financial output. The most common aspect focused is vehicle routing i.e. aiming to reduce cost by reducing fuel consumption via shortened road length for a trip. Further researches have been made under open routing system in which the truck after collecting waste does not return to its depot and instead start collection next day in reverse direction. Li et al (2007) mentions that tabu search, deterministic annealing and large neighborhood search have been applied to Open Vehicle Routing Problem (OVRP) with some success.

Also there are many publications which have clearly mentioned objectives but ultimately can be assessed on the parameter of cost or monetary outcome. For instance, many studies focus on finding optimum route length. Suppose, route length is reduced by 23 kilometers. The cost saved can be calculated by determining monetary value of fuel saved. The same goes with cases with environmental objectives which tend to reduce vehicular pollution by reducing fuel consumption. Other objectives such as finding optimum number of crew members can result in economic efficiency in terms of wages for optimum number of employees. Thus cost reduction remains the most common and sought out parameters for solid waste collection optimization.

Route length- The next most common objective function in publications is minimization of route length. There are multiple methods to reduce route length. Solution methods / Mathematical models as well as software such as ArcGIS or both can be used to reduce route length. Mathematical models can work on different solution methods such as linear programming, mixed integer programming, non linear programming, simulation method, branch and bound methods etc. Publications under Metaheuristics are increasing steadily. The common sub areas under heuristics are Tabu search, Genetic algorithm, Ant colony optimization, Simulated Annealing. Few publications have also dealt with construction and clustering/partitioning heuristics. Many papers use combination of above techniques to carry out maximum Optimizations (combinatorial optimization). For instance, methodology used by Gruler et al (2017) for optimizing waste collection in multi depot urban areas via combining Metaheuristics with simulation method. Further hybrid Algorithm are more apt as they give more optimizations under stochastic parameters where demands may fluctuate and variables may be many.

Environmental Impact- Under this environmental safety is prime concern of the publications, especially when dealing with Hazardous waste collection and transportation. For instance, Batta and Chiu (1988) find out optimal route for hazardous waste taking into account the probability of accidental leakage of hazardous waste. Salhofer et al (2007) mention that cost of solid waste transportation has increased many folds with development of waste management system and aims to determine how the transportation distance of solid waste aim to influence economic benefits of recycling. They ultimately aim to reduce green house gases. Karadimas et al (2007) use ArcGis to identify most optimal route for solid waste disposal taking into account dynamic factors. The most optimal solution has been decided considering environmental and social impact beside the route length and road network.

Total collection time- This is a very important criteria with respect to current time of Covid-19 pandemic. Collection time has to be reduced to contain Covid 19 as it would result in reduction of contact period (especially in backyard collection). Everett et al (1998) came up with route time estimation model for collection of recyclables. Their model is especially applicable to curbside collection. They estimate time to collect such waste and to sort it at truck in different categories. The model considers three variables i.e. waiting time, sorting time and travel time. The model has been able to find collection time within 10% of actual value. Wang (2001) has proposed a computer model for solid waste integrated management in Australia. He used simulation keeping in view deterministic and stochastic parameters to reduce collection time. Traffic factors are an important parameter in optimizing total collection time.

Required Number of truck- Many papers have worked on minimizing number of trucks as primary objective. This can be out of fact due to lack of sufficient vehicles to serve the required population or cost reduction in some scenario. Arribas et al (2009) aim to design a solid waste management system using combinatorial optimization and GIS. The study determines adequate vehicle fleet size. Other studies optimizing on number of trucks are Aringhieri et al (2004), Alagoz and Kocasay (2007), Benjamin and Beasley (2010)

Number of teams/ crew size- Curbside pickup requires smaller crew. Studies have found that smallest possible crew yields maximum efficiency in collection. A 4 crew member does not collect 4 times the 1 crew member. Ronen et al (1983) carry out their waste collection optimization study in Israel. They use heuristics and hence result show that proposed route may save town one out of six collection teams. While Hansmann and Zimmerman (2009), adopts an

integrative approach for planning the routes and crews of vehicles. The publication aims to come up with optimum crew scheduling besides vehicle routing.

Other personal related – These include factors such as balancing workload. For instance, unequal workload for equal pay may lead to dissatisfaction among crew members working in an area with higher workload (Ronen et al 1983). Sahoo et al (2005) mentions that waste generation on a highly populated urban locality may be comparatively high, so to get an adequate idea of workload, weight of refuse bag per kilometer can be considered. Bhat (1996) points out that when there is only single disposal site (as evident in many cities, especially in developing countries), queuing arises and creates dissatisfaction among employees. He analyses how each crew has to wait at disposal site.

Classification based on different types of waste-

This is an important criterion to identify research area. For instance, when we select a locality it could be a residential area comprising of garbage or an institutional building or some industrial area. Further the type of waste can determine its handling and disposal site. For example, whether the waste is recyclable or hazardous? So classification of current literature on the basis of type of waste has been dealt with.

The most common type of waste under different publications is garbage. Garbage is residential waste and is different from commercial waste. Garbage requires waste to be collected along different streets or door to door while industrial waste requires waste to be collected from a location. Hence stopping points and number of bins as well as customers are few for industrial waste. Thus vehicle routing for commercial waste and garbage has to be dealt separately (Bodin et al 2000). Ustundag and Cevikcan (2008) analyze municipal solid waste collection optimization by considering single vehicle with pre determined capacity and multiple trips. They use RFID (Radio Frequency Identification) for optimizing waste collection. Arribas et al (2009) aim to optimize urban solid waste collection process by use of GIS and mathematical modeling via getting feasible collection route and adequate fleet size.

Some research papers also dealt with hazardous material. Batta and Chiu (1997) aims to minimize probability of environmental hazard caused during transport of hazardous waste occurring due to gas leakage. While Alagoz and Kocasoy (2007) deals with management healthcare waste. Such Publications hold empirical value and can be useful at times of Covid-19 where generation of bio medical waste has increased significantly.

Publications on recyclables have also been dealt with. For instance, Bommisetty et al (1998) works on scheduling collection of recyclables at Northern Illinois Campus of a university. Vehicle routing with additional constraints has been modeled and provides a heuristic solution. Bedenik and Kravanja (2007) use mixed integer non linear programming for collection, recycling, treatment and disposal of municipal solid waste. The result showed that optimizations could result in reduction in residents' payment of fees for waste collection by upto 25%. These can be quite useful in alignment with many government's ambitious policies such as San Francisco aiming to turn into a zero waste city by 2020.

Classification on basis of disposal facilities-

Some publications consider single disposal facilities while others consider multiple sites for disposal. Normally, it is found that larger/ metropolitan cities have multiple sites for disposal while small towns/ cities often have single site for waste disposal (specially in developing countries). However, sufficient publications are available under both scenarios. Further multiple sites / new sites can be considered if cities having single site, need a new site due to inadequate current disposal facilities or high population forecast or due to closure of landfill.

Single disposal facility - Batta and Chiu (1988) consider single site for disposing hazardous waste. Bommisetty et al (1998) considers collecting recyclable waste via vehicle routing in large university campus with many buildings. They provide a heuristic solution for single disposal facility. The area under study is Northern Illinois University.

Other work with single disposal facility includes Tung and Pinnoi (1999), Ghose et al (2005), Nuortio et al (2006), Tavares et al (2008) , Hansmann and Zimmermann (2009).

Multiple Disposal facilities- Sufficient publications are available across all time (i.e. after 1973) and adequate attention has been paid to multiple disposal facilities. Various numerical methods can be used for optimum allocation of waste to different disposal sites bringing in maximum economic efficiency. For instance some publications have used linear programming for disposal at multiple facilities for getting optimum results. Marianov and ReVelle (1998) use Linear programming for vehicle routing of hazardous waste to multiple disposal sites. While Simonetto and Borenstein (2007) aims to develop a decision support system using Arena software to determine daily amount of waste to be sent to each sorting facility. Benjamin and Beasley (2012) use Metaheuristic for positioning of disposal facilities. They consider 10 test problems with 19 disposal facilities and 2092 customers.

The number of publications with multiple disposal facilities is much higher than number of publication with single disposal though sufficient material is available for both.

Classification on basis of Post optimization Analysis-

This is fairly important for deterministic settings as parameters may vary such as amount of waste collected fluctuates daily, monthly, seasonally, during festivals etc. The post optimization analysis has been majorly carried out under sensitivity analysis and scenario analysis.

Sensitivity analysis measures changes in uncertainty in results as a result of changes in input. Santos et al (2007) aim to implement a multi-vehicle, multi-route spatial decision support system for efficient waste collection in Coimbra, Portugal. They use GIS and heuristics for optimizing collection. They carry out sensitivity analysis by varying input parameters such as vehicle capacity and total shift time. The analysis states that by having 8 hours shift instead of 7 hour 30 minutes shift, Coimbra could be served by 4 trucks instead of 5 trucks currently deployed. The cost of one vehicle is around €100,000 which could be reduced. Li et al (2008) also use sensitivity analysis by varying upper limits of each recycling facility, in a study to optimize solid waste collection via truck scheduling. The area under study is Porto Alegre in Brazil.

Scenario Analysis gives alternate outcome scenario by analyzing future events. Scenario analysis is a type of projection which shows multiple possible future outcomes. This is done by studying sub problems that is derived from underlying problem. Hence it is not an extrapolation relying on past trends. Therefore any uncertainty can be taken into account and could be a good fit for stochastic situations. McLeod and Cherett (2007) carried out scenario analysis for maximizing optimization for domestic waste collection via improved fleet management. They basically tested two different conditions in which depot were located at waste disposal facility and secondly comparing alternate weekly collection with weekly collection. Alternate weekly collection was modeled to reduce to reduce both time taken and vehicle mileage by about 15% when compared to weekly collection. While relocation of depot led to 5.9% increase in mileage saving of refuse collection vehicles. Banyai et al (2019) also carry out scenario analysis to validate their model and then evaluate its performance to increase cost-efficiency and warrant environmental awareness of waste collection.

Statistical analysis- Few papers have carried out statistical analysis. For instance Hung et al (2001) carry out statistical analysis under different conditions by varying significance level.

Solution quality vs. computation time- This is another type of post optimization analysis. This is carried out usually to test effectiveness of optimization in case of heuristics. The use of this method has seen significant increase compared to other analysis post 2000. Bautista et al (2007) attempt to solve a waste collection problem for the municipality of Sant Boi de Llobregat within Barcelona (Spain). They use two different versions of ant heuristics and compare them. They used C ++ to code the programs. The nearest neighbor heuristic of algorithm 1 is compared to nearest insertion heuristic of algorithm 2. Finally nearest neighbor heuristic was found to give better results. Benjamin and Beasley (2010) use this analysis to compare different heuristics applied to their model. They compare variable neighborhood search, variable neighborhood Tabu search and Tabu search. It was found results though of same order, Variable neighborhood search is most efficient among them.

II. Conclusion

The optimization of solid waste collection can be carried via variety of methods. After examining the papers and recent trends it appears that the future optimization studies would be mostly governed by technologies of computing i.e. software and nascent/ budding technologies such as Industry 4.0 technologies, smart devices, Internet of Things (IoT). Of course, studies utilizing operations research/ mathematical models which provide base for optimization to different software would continue to grow. Also studies utilizing combinatorial optimizations have possibilities of better outcomes. Simulation studies along with grey programming which can simulate real life conditions and can work under stochastic conditions can be the next big thing under different solution methods. The real conditions are subject to many fluctuations, hence real time mapping of demands via mathematical models or real time monitoring via technologies such as sensors, smart bins etc. can lead to most optimum outcomes leading to desired efficiency in collection process. This could lead to economic savings, reducing health and environmental hazards. This could also result in better health and work environment for collection workers.

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