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WASTE COLLECTION VEHICLE ROUTING PROBLEM: LITERATURE REVIEW

ABSTRACT

Waste generation is an issue which has caused wide public concern in modern societies, not only for the quantitative rise of the amount of waste generated, but also for the increasing complexity of some products and components. Waste collection is a highly relevant activity in the reverse logistics system and how to collect waste in an efficient way is an area that needs to be improved. This paper analyzes the major contribution about Waste Collection Vehicle Routing Problem (WCVRP) in literature. Based on a classification of waste collection (residential, commercial and industrial), firstly the key findings for these three types of waste collection are presented. Therefore, according to the model (Node Routing Problems and Arc Routing problems) used to represent WCVRP, different methods and techniques are analyzed in this paper to solve WCVRP. This paper attempts to serve as a roadmap of research literature produced in the field of WCVRP.

KEY WORDS

wastecollection; vehicle routing problem; commercial waste; residential waste; industrial waste;

1. INTRODUCTION

Waste poses a major problem for modern societies as the amount of waste is rising and the complexity of some products and components is increasing. According to Eurostat data, the total waste generation in the European Union (EU) amounted to 2.5 billion tons in 2010, an average of 4,986 kg per EU inhabitant. In 2010, 40% of waste went into landfills, 2% was incinerated, 10% went into backfilling, 4% was energy recovery, 38% was otherwise recycled and recovered, and 6% accounted for other disposal [1]. *Figure 1* shows the increasing volume of waste generation in the EU in contrast with the shortage of final landfill, which has caused serious concern about the waste generation problem all over the world. Figures from 1980 to 2004 are data from Eurostat. Figures from 2005 to 2020 are projections [2].

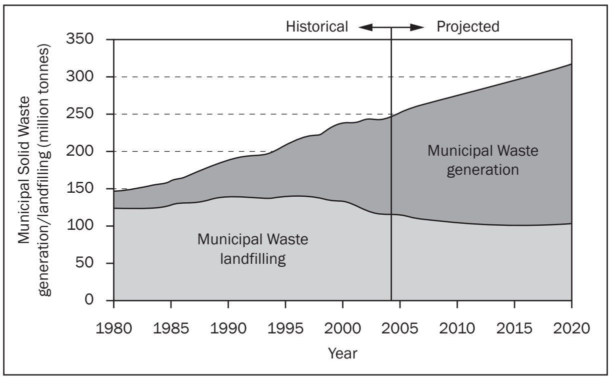

Figure 1 – Projected generation and landfilling of municipal waste in the EU-25, Source: EEA (2007)

Waste collection is a relevant activity in reverse logistics, and vehicle routing problem for this specific activity is an interesting area to be analyzed since it contributes to a more efficient reverse logistics system. There are some different approaches for take-back systems. For instance, individual models or collective systems [3]. Extended Producer Responsibility (EPR) is an environmental policy approach adopted by many EU Directives, where the manufacturer is responsible for the proper disposal of the products they sell. The European Environment Agency proposed collection targets for different municipal solid waste, such as: end-of-life vehicles; waste of electrical and electronic equipment; batteries; and end-of-life tyres. Some authors analyzed different case studies that illustrated the implementation of these Directives and collection targets in different countries. For instance, the impact of emerging environmental regulations in the reverse logistics system for portable batteries in Spain was analyzed by Ponce-Cueto et al. [4]. Mayers et al. studied the possible environmental effects of the WEEE Directive on an example of printer recycling in the United Kingdom [5].

This paper analyzes different solutions and methods for collecting waste. While the objective of a classical Vehicle Routing Problem is to minimize the total route cost, other objectives could be considered and analyzed. Indeed, here are several variations of the Vehicle Routing Problem, for instance with the goal of finding optimal routes for a fleet of vehicles to visit the pick-up and drop-off locations, of those that include capacitation constraints. In addition, other aspects (such as: the model of Node Routing Problems and Arc Routing problems used to represent WCVRP) are also considered and analyzed in this paper. This paper attempts to serve as a roadmap of research literature produced in the field of WCVRP for both academics and practitioners. Finally, further research topics are also identified in order to be studied as future developments.

The remainder of this paper is organized as follows. The methodology for this study is illustrated in Section 2, while Section 3 includes a categorization of the papers reviewed based on three types of waste collection. In Section 4, an overview of research approaches used in different models of WCVRP is provided. Finally, conclusions and future research lines are presented in Section 5.

2. METHODOLOGY

A literature review analysis and key findings identification on WCVRP is conducted in this paper. A total of 65 articles have been reviewed in this research study.

The articles searched focused on academic journals, retrieved from the following databases: Emerald; Elsevier; Wiley; Springer; Ebsco; Scopus; and Metapress. Initially, Web of Science was used to find articles dealing with different aspects of WCVRP.

For the literature search, key words such as "Vehicle Routing Problem", "waste collection", "trash collection", "rubbish collection", "refuse collection", "junk collection" and "garbage collection" were used. The full text of each article was reviewed in order to eliminate those articles that were not really related to WCVRP. As a result of this analysis, 35 articles were selected as relevant for the analysis.

Finally, the reference sections of relevant articles in the topic were scanned for additional citations; this yielded 30 other articles. By these procedures, a total of 42 journals and 65 articles were selected for this research study. *Figure 2* shows the number of papers related to WCVRP that have been published since 1974. It can be noticed that for the last 40 years the academic papers about WCVRP are quite limited. The list of references includes all the articles selected and analyzed in this paper.

3. LITERATURE REVIEW AND WCVRP CLASSIFICATION

Waste collection is an important process of waste management. The Organisation for Economic Co-operation and Development (OECD) in 1997 defines waste collection as follows:

Waste collection is the collection and transport of waste to the place of treatment or discharge by municipal services or similar institutions, or by public or private corporations, specialized enterprises or general government. Collection of municipal waste may be selective, that is to say, carried out for a specific type of product, or undifferentiated, in other words, covering all kinds of waste at the same time (OECD, 1997 [6]).

Waste collection is the part of the process in charge of taking-back wastes (solid waste and recyclables) from the collection point to the disposal facility (it could be a recycling plant, an energy recovery facility or a landfill). Typically, waste collection system (collection and transportation) involves a very high operational cost. Some researchers have been trying to shorten the routing distance (Beltrami and Bodin (1974) [7]; Ronen and Kellerman (1983) [8]; Chang and Wei (2000) [9]; Torres and Antón (1999) [10]; Sniezek et al. (2001) [11]; Angelelli and Speranza (2002) [12]; Viotti et al. (2003) [13]; Bautista and Pereira (2004) [14]; Bianchessi and Righini (2007) [15]; Ghiani et al. (2005) [16]; Ghose et al. (2006) [17]; Karadimas et al. (2007a) [18]; Alagöz and Kocasoy (2008) [19]; Apaydin and Gonullu (2007) [20]; Bautista et al. (2008) [21]; Ombuki-Berman (2007) [22]; Santos et al. (2008) [23]; Ustundag and Cevikcan (2008) [24]; Kim et al. (2009) [25]). Other authors focus on finding the most appropriate location for collection bins and dis-

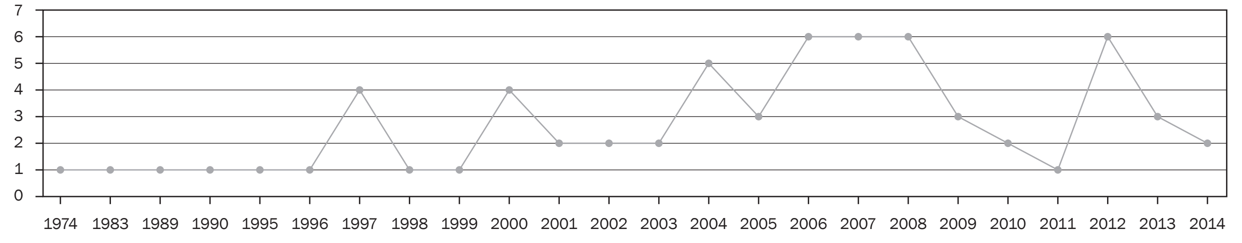

Figure 2 – The number of papers published by years

Table 1 – Type of Waste Collection Vehicle Routing Problems based on Golden et al. [42]

Classification	Type of waste	Type of bin	Location	Type of problem
Residential	Household waste	Bins	Street	Arc routing problem
Commercial	Commercial waste	Large containers	Commercial	Node routing problem
Roll-on-roll-off	Construction wastes	Large trailers or containers	Construction sites	Node routing and bin packing

posal containers (Maniezzo (2004) [26]; Archetti and Speranza (2005) [27]; Sniezek and Bodin (2006) [28]; Karadimas et al. (2007b) [29]; Muttiah et al. (1996) [30]; Cheng et al. (2003) [31]; Huang et al. (1998) [32]; McLeod and Cherrett (2008) [33]; Sumathi et al. (2008) [34]), and other studies focus on minimizing the number of collection vehicles needed for the take-back system (Clark and Gillean (1975) [35]; Aringhieri et al. (2004) [36]; Arribas et al. (2009) [37]).

In the waste collection problem, organizations need to take back wastes from the collection point and send them to the treatment facilities. In this problem, typically many collection points need to be collected in order to be sent to the appropriate facility (typically just one destination). This is a reverse logistics problem, where many points need to be collected with only just one delivery point (vs. deliveries from one point to many destinations in the forward logistics problem).

Some sources of complexity, such as little visibility (it is difficult to know in advance the filling speed of containers), time window constraints, real-time requirements, a mix of public and private firms and actors are involved in the collection process (and sometimes inter-municipal cooperation is also needed), can be identified as sources of complexity when companies tackle the waste collection problem. For instance, instead of heading back to the depot to discharge the collected goods, in a waste collection problem vehicles need to be emptied at a disposal facility in advance, then continue to collect waste from other customers. Thus, multiple trips to the disposal facility occur, as the vehicles have to return to the depot with zero waste. If more than one disposal facility is involved in the reverse logistics system, the waste collection problem will become more complex. For example, in order to minimize the total distance, the right time to empty the vehicles as well as to choose the best disposal facility should be determined. It may not be optimal to only consider vehicles to become full before visiting a disposal facility [38].

In essence, waste collection could be treated as a Vehicle Routing Problem (VRP) [39]. The Vehicle Routing Problem (VRP) introduced for the first time by Dantzig and Ramserl in 1959 [40] focused on forward deliveries (from a depot to "n" customers). The VRP definition is stated in the book "The Vehicle Routing Problem" as:

"M vehicles initially located at a depot are to deliver discrete quantities of goods to n customers. Determining the optimal route used by a group of vehicles when serving a group of users represents a VRP problem" (Caric and Gold, 2008 [41]).

A waste collection vehicle routing problem typically consists of a fleet of vehicles, stops, disposal facilities, a depot, and a number of collection bins or collection points. A vehicle starts and ends at the same depot. The complexity of this problem depends on different characteristics such as different types of vehicles, number of disposal facilities (single or multiple), various types of constraints, etc. [39]; such as time interval or vehicle capacity referred to customer services, revealing the Vehicle Routing Problem with Time Windows (VRPTW) and the Capacitated Vehicle Routing Problem (CVRP), respectively. In the last fifty years numerous real-world problems have demanded widespread formulation that resulted in the VRP with backhauls, stochastic VRP, multiple depot VRP, split delivery VRP, periodic VRP, VRP with pickup and delivering, and many others [41].

Golden et al. (2002) considered three main types of Vehicle Routing problems in the waste industry in the United States: residential, commercial, and industrial (roll-on-roll-off) [42].

Table 1 includes a comparison among these three types of Vehicle Routing problems for the waste industry, according to the type of waste, the type of bin for waste collection, the location of the point of collection and the type of vehicle routing problem considered.

In the following sections the papers analyzed are presented in these three categories of problems.

3.1 Residential waste collection

According to Golden et al. [42] residential collection involves the collection of household refuse along a street network. For this reason, it is solved as an arc routing problem.

Kim et al. (2006) defined the residential waste collection as follows [43]:

The residential waste collection generally involves servicing private homes. The number of homes a residential route may service varies widely from 150 to 1,300 homes every day. The frequency of service per week will vary based on the climate, geography, competition and price of service.

The most relevant papers for household waste collection are included in *Figure 3*.

Household waste is placed in front of the residences in garbage bags or small bins. The collection vehicles will gather all residential waste along the streets that have

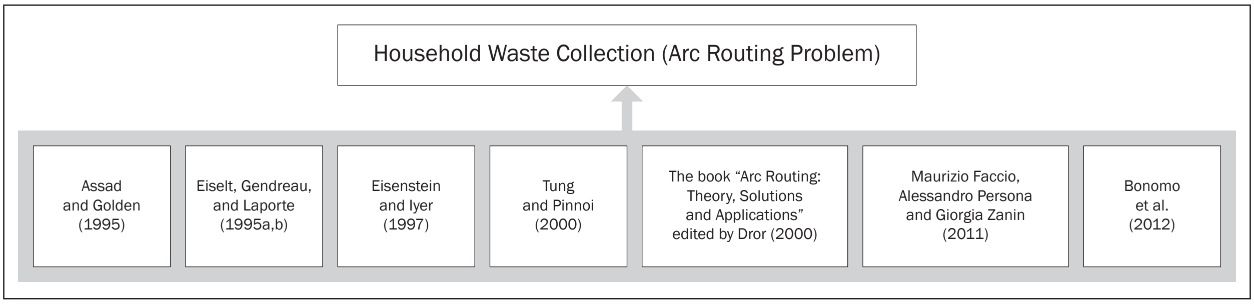

Figure 3 – Relevant papers for Household Waste Collection (Arc Routing Problem)

been assigned to them. Therefore, this problem is often solved by researchers as an arc routing problem where the exact location of every customer is not needed [38]. Naturally, household waste collection is described as an arc routing problem (ARP), as waste normally has to be collected from all the houses in a street.

Assad and Golden [44] in 1995 review the basic methodology about generic arc routing, and describe application areas of arc routing such as sanitation services and postal delivery operations. These areas of application problem solved by arc routing techniques are provided in this book. In the same year, Eiselt et al. [45, 46] write two papers (part I and part II) to review the algorithmic methods which are used to solve arc routing application problem – the postman problem. In the first half of part II of the paper on arc routing problem, the algorithmic results for the Chinese postman problem (CPP) are described; in the second half, the rural postman problem is considered and its relevant contents are stated. Eisenstein and Iyer (1997) [47] use a Markov decision process to provide a dynamic scheduling algorithm. Taking the garbage trucks in Chicago for example, Eisenstein and Iyer provide the flexible routes model to improve the trucks schedule, and the capacity of 12%-16% for a set of five pilot wards is reduced. In 2000, in the book named "Arc Routing: Theory, Solutions and Applications", edited by Dror [48] an exhaustive state-of-the-art for arc routing problems is included, and a number of relevant applications for arc routing theory for real-life problems is presented. Tung and Pinnoi (2000) [49] take urban districts of Hanoi in Vietnam as an example, and modify the Solomon's sequential insertion heuristic combining the phase of Or-opt and 2-opt together to construct a heuristic route procedure. Tung and Pinnoi solve a real world vehicle routing and scheduling problem constrained by multiple time windows and minimum inter-arrival times for each site as well as the limited vehicle capacity and operating hour with improvement in both total cost and the number of vehicles utilized. Faccio et al. [50] in 2011 introduce an innovative vehicle routing model with an application in an Italian city of about 100,000 inhabitants. The results show that the model brings economical and feasible improvement in terms of perishable food, integrating the presented real-time traceability data with the physical conditions of the transported items. In 2012 Bonomo et al. [51] proposed a method that uses operations research techniques to optimize the routes of waste collection vehicles servicing dumpster. They also analyzed the example of a residential waste collection in Buenos Aires. The application of the proposed method by Bonomo et al. saves more than US$200,000 per year with less negative impacts for Buenos Aires.

3.2 Commercial waste collection

According to Golden et al. [42] commercial waste collection involves collection of commercial refuse from large containers at commercial locations. These are considered as node routing problems.

Kim et al. (2006) defined the commercial waste collection as follows [43]:

The commercial waste collection involves servicing customers such as strip malls, restaurants and small office buildings. Each commercial route of WM (Waste Management) may service 60–400 customers, with two or three disposal trips to dump sites each day. Depending upon the customer base, the same driver may visit the same customer multiple times in one week. The weekly service schedule is fairly static, as most customers do not change the frequency of service often.

Figure 4 includes the most relevant papers for commercial waste collection.

In 1996 some researchers started to investigate commercial waste collection vehicle routing problem. Kulcar [52] used an operations research method with systems engineering to study a set of points for the collection routes rather than the arcs making up the streets. Sahoo et al. (2005) [53] proposed a heuristic method using clustering methods and geographic information system (GIS). Their proposed method was applied to an actual waste collection company, which is the leading provider of comprehensive waste management services in North America, and has resulted in significantly reduced operational costs (saving $18 million from March 2003 to the end of 2003). Kim et al. (2006) [43] extended Solomon's insertion algorithm (Solomon, 1987) to develop a route construction algorithm, which mainly focuses on the commercial

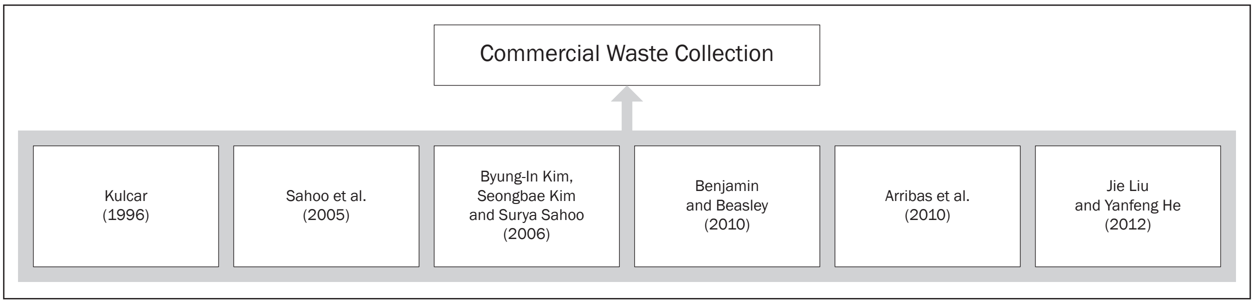

Figure 4 – Relevant papers about Commercial Waste Collection

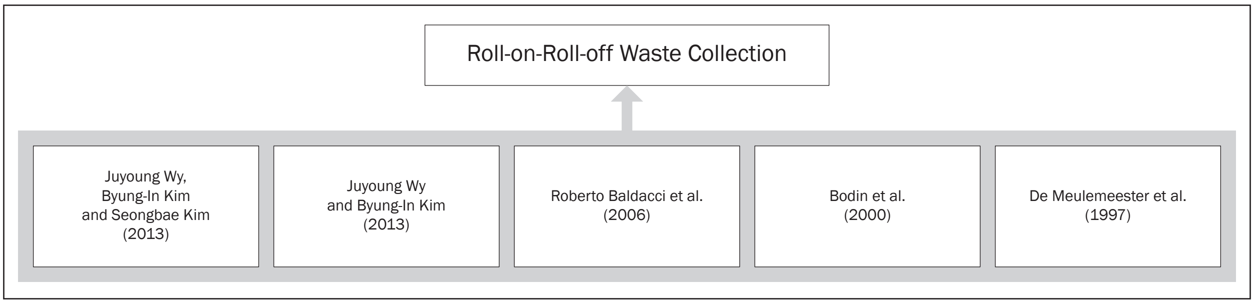

Figure 5 – Relevant papers about Roll-on-Roll-off Waste Collection

waste collection vehicle routing problem with time windows (VRPTW) assuming multiple disposal trips and drivers' lunch breaks. The proposed algorithms have successfully solved the real life waste collection problems at Waste Management, Inc. Benjamin and Beasley (2010) [54] presented meta-heuristic approaches which afford better solutions than previous studies, in order to solve waste collection problem involving multiple disposal facilities. Arribas et al. [37] use integer programming and optimization in GIS environment to design an urban solid waste collection system. A case study about the Municipality of Santiago in Chile is also included. In 2012 Liu and He [55] mainly focus on the daily commercial waste collection problem, and propose a clustering-based multiple ant colony system approach to tackle waste collection vehicle routing problems with time windows and intermediate facilities (WCVRPTW-IF).

3.3 Roll-on-Roll-off waste collection

According to Golden et al. [42] roll-on-roll-off problems involve the pickup, transportation, unloading and drop-off of large trailers (or containers) typically located at construction sites.

Kim et al. (2006) defined the roll-on-roll-off waste collection as follows [43]:

The roll-on-roll-off collection introduces a different routing problem. The differentiator between roll-on-roll-off and commercial is the size of the container. A typical commercial container is eight loose yards, while a roll-on-roll-off container may range from 20 to 40 loose yards and only one container may be serviced at a time. Note that 1 cubic yard is 0.765m^3. While hauling these large containers, it is common for each container to be disposed of and returned to the original customer's location. Driver-experience level, vehicle types, container types, material types and security clearance are all contributing factors when creating industrial routes.

Figure 5 includes the most relevant papers for roll-on-roll-off waste collection.

De Meulemeester et al. (1997) [56] propose a mathematical model combining an exact enumerative algorithm, and they offer two simple heuristics to solve a complex routing problem associated with the collection and delivery of skips. The model proposed by De Meulemeester et al. is efficient to solve this problem by computational results on the case of a skip rental firm in Belgium. In 2000, Bodin et al. [57] define the Roll-on–Roll-off Vehicle Routing Problem (RRVRP), then they use a mathematical programming formulation of the RRVRP with four different heuristic algorithms to solve this problem, and computational results are discussed. Finally, Bodin et al. give some recommendations for further research. Baldacci et al. (2006) [58] describe an exact method based on a bounding procedure. The exact method solves a time-constrained vehicle routing problem on a multi-graph (TVPR-MG), which is modelled by multiple inventory locations roll-on–roll-off vehicle routing problem (M-RRVRP). Compared with procedure of solving M-RPVRP proposed by Fukasawa et al. (2006) [59], Baldacci et al. proposed procedureis at least 10 times faster according to computational results. Wy and Kim (2013) [60] propose a hybrid meta-heuristic method to solve the roll-on–roll-off vehicle routing problem. The proposed approach is effective by computational results using benchmark data. In the same year, Wy et al. [61] present a large neighbourhood search-based iterative heuristic approach consisting of several algorithms to solve roll-on–roll-off waste collection vehicle routing problem with time windows.

4. LITERATURE REVIEW SORTED BY MODELS OF WCVRP WITH RELEVANT METHODS AND TECHNIQUES

Around forty years ago waste collection in the United States was implemented without considering optimizations, and the construction of the routes was left to the drivers. With the expected increase of urban population, the importance of an efficient collection system has been increasing. Optimally, there should be a method that tries to maximize the general acceptance of a solution. However, as this is hard to realize, different methods have been developed that focus on different goals like costs, number of collection vehicles, route length, and so on.

Essentially, the waste collection is a Vehicle Routing Problem (VRP). This means that a solution has to be sought after servicing a crowd of customers with a set of vehicles. In general, different methods can be applied to solve the vehicle routing problem: namely, classical heuristics and meta-heuristics [39].

Papers analyzed in this article have been categorized based on two different models used to represent WCVRP: Node Routing Problems, and Arc Routing problems. In addition, the relevant method and techniques used to solve this problem have been also analyzed. *Table 2* shows this classification (sorted by chronological criteria) which is displayed in the Appendix.

WCVRP problems can be divided into Node Routing Problems and Arc Routing problems. Node Routing Problems have demand on the nodes (or vertices) of a graph. An example of a Node Routing Problem might be a salesman who must travel to each town in a country. In the Arc Routing Problems the demand occurs in each of the arcs (or edges) of the graph. An example of an Arc Routing Problem might be a postman who must visit each house along each street in a town [90]. *Table 3* shows more details about the differences between Node Routing Problems and Arc Routing problems.

Given a set of control points with associated scores besides the start and end points, the orienteering problem (OP) deals with finding a path from start point to end point in order to maximize the total score subject to a given distance budget, denoted by DMAX.

Table 3 – Differences between Node Routing Problems and Arc Routing problems

Characteristics / Types	Node Routing Problems	Arc Routing Problems
Objectives	distribution/collection of goods (point to point)	distribution/collection of goods or materials along the arcs (edges) of a road network
Main components	• Vehicles • Depots • Drivers • Road Network	• Vehicles • Depots • Drivers • Road Network
Solutions	A set of routes performed by a fleet of vehicles such that: • each route starts and ends at vehicles' depots • the customers' requirements are satisfied • the operational constraints are fulfilled • the global transportation cost is minimized	A set of routes performed a fleet of vehicles such that: • each route starts and ends at vehicles' depots • the requests for service associated with arcs or edges are satisfied • the operational constraints are fulfilled • the global transportation cost is minimized
Types	• Traveling Salesman Problem (TSP) • Traveling Salesman Problem with Backhauls (TSPB) • Traveling Salesman Problem with Time Windows (TSPTW) • Multiple Traveling Salesman Problem (MTSP) • Capacitated Vehicle Routing Problem (CVRP) • Distance Constrained Vehicle Routing Problem (DCVRP) • Vehicle Routing Problem with Backhauls (VRPB) • Vehicle Routing Problem with Time Windows (VRPTW) • Vehicle Routing Problem with Pickup and Delivery (VRPPD)	All arcs (edges) must be served: • the Chinese Postman Problem (CPP) Only a subset of arcs (edges) must be served: • the Rural Chinese Postman Problem (RCPP) • the Windy Chinese Postman Problem • the Stacker Crane Problem

It should be mentioned that the OP is equivalent to the Traveling Salesman Problem (TSP) when the time is relaxed and sufficient to cover all points [91]. As we know, the Traveling Salesman Problem is a subset selection version of Node Routing Problem, so the Orienteering Problem (OP) is also included as a Node Routing Problem.

Figure 6 shows a summary of different approximate algorithms used to solve different types of WCVRP.

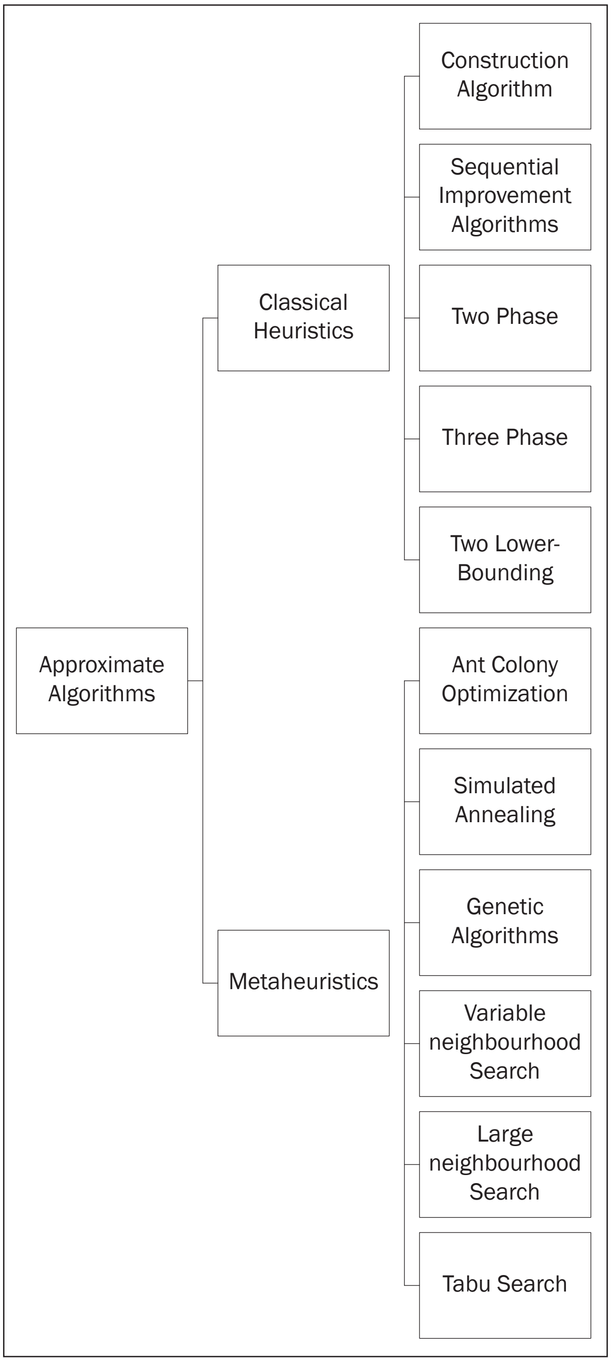

Figure 6 – Algorithms used to solve WCVRP

A brief description of each method shown in *Figure 6* is provided below.

Classical Heuristics

A construction algorithm is an algorithm that decides a tour line according to some construction rules. Every time the heuristic chooses the closest node to the present node as the next customer to visit. It is a way to find close-to-optimal solutions [39].

Two-phase methods can be divided into two types: cluster first-route second and route first-cluster second. Generally, if there are several tours with many customers on each route, clustering these customers into groups and then partitioning the tour will normally generate better results. If many tours have to be created, with several customers on each tour, it is more effective to partition tours first [7].

Meta-heuristics

Glover and Kochenberger [92] define Meta-heuristics as: *Solution methods that orchestrate an interaction between local improvement procedures and higher level strategies to create a process capable of escaping from local optima and performing a robust search of a solution space.*

The metaheuristics that have been studied in the context of waste collection include local search heuristics, tabu search algorithms, genetic algorithms, simulated annealing and ant colony optimization [39].

Tabu search heuristics explores regions in the unexplored search space using a standard local search procedure.

Genetic algorithms try to find potential solutions by mimicking natural evolution. The algorithm starts from a population of candidate solutions. By applying genetic operators, new solutions are created that inherit certain characteristics of their parents solutions. Finally, select the potential solutions among these candidate solutions [39].

Ant colony optimization simulates the behaviour of ants in their search for food. When ants search for food, they produce a pheromone trail which is used by other ants to determine the short path. Eventually, the shortest path is established as the ants who return to the colony by this road will refresh the pheromone trail sooner than the ants who opted for a longer path. The same pheromone logic can be applied to solve waste collection routing problems [39].

For the research work of metaheuristics, Gendreau et al. [93] provide a good source of references of metaheuristics for solving VRP and its extensions.

5. DISCUSSION

Since the end of the nineties, more and more researchers have noticed the importance of WCVRP, and the research contributions on this topic have increased. This paper has attempted to provide a roadmap about WCVRP literature with its limitations as well as some implications.

5.1 Limitations

This paper focuses on solid wastes (organic and recyclables) collection. Other special wastes that also require to be collected in a selective way, such as lube oil wastes, lamp wastes, or battery wastes were out of scope of this paper and in consequence were not analyzed in this research study. The study could be extended to other wastes as well in the future.

Regarding the literature review analyzed, this research study focuses only on scientific papers retrieved from academic databases (such as web of knowledge, Scopus, Ebsco, and so on). Other alternative sources (such as newspapers, magazines, technical reports) were not included in this paper.

5.2 Implications

In reality, waste collection vehicle routing problem is generally more difficult to solve than a classic vehicle routing problem. On one hand, more constraints must be taken into consideration. On the other hand, lots of collection points need to be collected on the same route. Typically, different actors are involved in the process, and some authorizations would be needed for those companies that want to collect wastes. In conclusion, the level of complexity is higher. According to the literature reviewed in this paper, it can be observed that instead of optimization method, heuristic algorithms (such as Tabu search; Variable Neighbourhood Search; and Variable Neighbourhood Tabu Search) are more used to solve this problem. These heuristics methods provide good solutions (within reasonable computation time), although the method could not afford a guarantee of optimality.

VRP is an NP (non-deterministic polynomial) hard combinational optimization problem that can be properly solved only for small instances of waste collection. Although the heuristic approach does not guarantee optimality, it yields good results in practice, as heuristic solution solves WCVRP more quickly, providing a good solution instead of an optimal solution. In the last twenty years the meta-heuristics has appeared as the most promising orientation of research for the VRP family of problems [41]. Compared with classical heuristics, meta-heuristics carry out a more thorough search of the solution space, allowing inferior and sometimes infeasible moves, in addition to re-combining solutions to create new ones. As a result, meta-heuristics is capable of consistently producing high quality solutions, in spite of its greater computation time than early heuristics [94, 95].

There are two WCVRP benchmark problems that are commonly used to test algorithms. One is a real life waste collection benchmark problem, such as the one provided by Kim et al. (2006). It consists of ten test problems, involving up to 2,092 customers and 19 waste disposal facilities [43].The second set of benchmark problems is a MDVRPI (multi-depot vehicle routing problem with inter-depot routes) benchmark set generated by Crevier et al. (2007). It consists of ten test problems, involving up to 288 customers and seven depots [38]. Once any algorithms to solve WCVRP are proposed, these two benchmark problems are available for researchers to test these proposed methods.

Very few studies attempt to include the objective of reducing pollution in the waste collecting process. To our best knowledge, most papers focus on reducing operational costs and time when proposing some methods to solve WCVRP.

6. CONCLUSION

Based on this literature review paper, current research on WCVRP focuses more on improving the efficiency of collection practices by minimization of distance, logistic costs and time. Some researchers are trying to reduce the cost by improving the routing of waste collection vehicles, other researchers are finding the most suitable location of disposal facilities and the location of collection waste bins as well as minimizing the number of vehicles used.

Some proposals for future studies are those that focus on examined opportunities to improve the efficiency of the collection system; such as modifying companies delivery schedules; optimizing the fleet of trucks; incorporating information related to traffic conditions into the WCVRP models in order to avoid generating traffic congestions. Data driven systems and new technologies are going to help and contribute in this way, since real data could be tracking and taking into account for making schedules.

From the literature review analyzed, it can also be concluded that there is a scarcity of papers that try to combine economic and environmental objectives. Environmental concern in modern societies is an important issue, especially in urban areas where waste generation is increasing with population growth. As a future development, the economic and environmental objectives should be combined when trying to solve WCVRP.

The minimization of CO_2 emission, for instance, will become increasingly important in the light of growing environmental regulations. The literature review with particular aspects, models of WCVRP with relevant method and techniques, makes it clear to understand that diverse methods are used to solve various models of WCVRP. This information can be applied as considerations when choosing from a number of methods to design routes with the purpose of minimizing CO_2. The environmental aspects of WCVRP indicate that activities concerning the transport of waste stuffs are also an important part of the Green Logistics agenda, especially in urban areas where population is growing [96].

Finally, this study facilitates better understanding of the state of the art of WCVRP. Based on the review, classification and analysis of the scientific articles, future research lines have been identified that may hopefully stimulate in researchers and practitioners further interest in the topic.

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PROBLEMA DE PROGRAMACIÓN DE RUTAS EN LA RECOGIDA DE RESIDUOS: REVISIÓN DE LA LITERATURA

RESUMEN

La generación de residuos es un problema relevante y está siendo causa de preocupación en las sociedades modernas, no sólo por el aumento en la cantidad de residuos generados, sino también por el incremento en la complejidad de algunos de estos productos y sus componentes. La recogida de residuos es una de las actividades más relevantes en los sistemas de logística inversa y cómo realizar estas recogidas de forma eficiente es un área en el que aún existe un amplio margen de mejora. En este artículo se revisan y analizan las principales contribuciones realizadas en la literatura científica sobre el problema de programación de rutas para la recogida de residuos. El análisis se centra en residuos sólidos urbanos, más concretamente se emplea la siguiente clasificación de recogida de residuos: residencial, comercial e industrial. En primer lugar, se presentan las principales aportaciones para cada uno de estos tipos de residuos recogidos. Además, y de acuerdo con el tipo de modelo empleado (problemas de rutas basados en nodos o en arcos) para representar los WCVRP, diferentes métodos y técnicas son analizados en este artículo para resolver el problema de WCVRP. Este artículo trata de ser una referencia en la literatura a la hora de abordar el problema de WCVRP, ya que presenta una estructura que clasifica y revisa las diferentes técnicas empleadas para resolver este problema. A partir de ahí, se proponen líneas posibles de continuación de esta investigación.

PALABRAS CLAVE

recogida de residuos; programación de rutas; residuos comerciales; residuos sólidos urbanos; residuos industriales;

REFERENCES

[1] Blumenthal K, Issn LB, Union E, States EUM. Waste indicators on generation and landfilling measuring sustainable development 2004-2010. 2013;(June 2012):1–12.

[2] Mazzanti M, Zoboli R. Municipal Waste Kuznets Curves: Evidence on Socio-Economic Drivers and Policy Effectiveness from the EU. Environmental and Resource Economics. 2009 Mar 20;44(2):203–30.

[3] Atasu A, Wassenhove LN. An Operations Perspective on Product Take-Back Legislation for E-Waste: Theory, Practice, and Research Needs. Production and Operations Management. 2011 May 7;21(3):407–22.

[4] Ponce-cueto E, González-manteca JA. Impact of Emerging Environmental Regulations on the Reverse Logistics System for Portable Batteries in Spain. In: Golinska P, Romano CA, editors. Environmental Issues in Supply Chain Management. Berlin, Heidelberg: Springer Berlin Heidelberg; 2012. p. 155–70.

[5] Mayers CK, France CM, Cowell SJ. Extended Producer Responsibility for Waste Electronics: An Example of Printer Recycling in the United Kingdom. Journal of Industrial Ecology. 2005 Jul 8;9(3):169–89.

[6] OECD. OECD Glossary of Environment Statistics, Studies in Methods. 1997;

[7] Beltrami EJ, Bodin LD. Networks and vehicle routing for municipal waste collection. Networks. Wiley Subscription Services, Inc., A Wiley Company; 1974;4(1):65–94.

[8] Ronen R, Kellerman A, Lapidot M. Improvement of a solid waste collection system: the case of Givatayim, Israel. Applied Geography. 1983 Apr;3(2):133–44.

[9] Chang N-B, Wei YL. Siting recycling drop-off stations in urban area by genetic algorithm-based fuzzy multiobjective nonlinear integer programming modeling. Fuzzy Sets and Systems. 2000 Aug;114(1):133–49.

[10] Torres OAC, Antón FR. A Continuous Approximation Model for Vehicle Routing in Solid Waste Management Systems. Investigación Operativa. 1999;8:109–53.

[11] Sniezek J, Bodin L, Levy L, Ball M. Capacitated Arc Routing Problems with Vehicle-Site Dependencies: The Philadelphia Experience. In: Toth P, Vigo D, editors. The Vehicle Routing Problem: Discrete mathematics and its applications. Philadelphia; 2001. p. 247–54.

[12] Angelelli E, Speranza MG. The application of a vehicle routing model to a waste-collection problem: two case studies. In: Klose A, Speranza MG, Van Wassenhove LN, editors. Quantitative Approaches to Distribution Logistics and Supply Chain Management. Berlin, Heidelberg: Springer Berlin Heidelberg; 2002. p. 269–86.

[13] Viotti P, Polettini A, Pomi R, Innocenti C. Genetic algorithms as a promising tool for optimisation of the MSW collection routes. Waste Management & Research. 2003 Aug 1;21(4):292–8.

[14] Bautista J, Pereira J. Ant algorithms for urban waste collection routing. Ant Colony Optimization and Swarm Intelligence, Proceedings. 2004;3172:302–9.

[15] Bianchessi N, Righini G. Heuristic algorithms for the vehicle routing problem with simultaneous pick-up and delivery. Computers & Operations Research. 2007 Feb;34(2):578–94.

[16] Ghiani G, Guerriero F, Improta G, Musmanno R. Waste collection in Southern Italy: solution of a real-life arc routing problem. International Transactions in Operational Research. 2005 Mar;12(2):135–44.

[17] Ghose MK, Dikshit a K, Sharma SK. A GIS based transportation model for solid waste disposal--a case study on Asansol municipality. Waste management (New York, NY). 2006 Jan;26(11):1287–93.

[18] Karadimas N V., Kolokathi M, Defteraiou G, Loumos V. Ant Colony System vs ArcGIS Network Analyst: The Case of Municipal Solid Waste Collection. 5th WSEAS International Conference on Environment, Ecosystems and Development. 2007;128–34.

[19] Alagöz AZ, Kocasoy G. Improvement and modification of the routing system for the health-care waste collection and transportation in Istanbul. Waste management (New York, NY). 2008 Jan;28(8):1461–71.

[20] Apaydin O, Gonullu MT. Route optimization for solid waste collection: Trabzon (Turkey) case study. GlobalNEST. 2007;9(1):6–11.

[21] Bautista J, Fernández E, Pereira J. Solving an urban waste collection problem using ants heuristics. Computers & Operations Research. 2008 Sep;35(9):3020–33.

[22] Ombuki-berman BM, Runka A, Hanshar F. Waste collection vehicle routing problem with time windows using multi-objective genetic algorithms windows using multi-objective genetic algorithms. International Association of Science and Technology for Development Proceedings of the Third IASTED International Conference on Comutational Intelligence. 2007;91–7.

[23] Santos L, Coutinho-Rodrigues J, Current JR. Implementing a multi-vehicle multi-route spatial decision support system for efficient trash collection in Portugal. Transportation Research Part A: Policy and Practice. 2008 Jul;42(6):922–34.

[24] Ustundag A, Cevikcan E. Vehicle route optimization for RFID integrated waste collection system. International Journal of Information Technology & Decision Making. World Scientific Publishing Company; 2008 Dec 20;07(04):611–25.

[25] Kim H, Yang J, Lee K-D. Vehicle routing in reverse logistics for recycling end-of-life consumer electronic goods in South Korea. Transportation Research Part D: Transport and Environment. 2009 Jul;14(5):291–9.

[26] Maniezzo V. Algorithms for large directed CARP instances: urban solid waste collection operational support. UBLCS Technical Report University of Bologna. Bologna; 2004 p. 29.

[27] Archetti C, Speranza MG. Collection of waste with single load trucks: A real case. In: Fleischmann B, Klose A, editors. Distribution Logistics. Berlin, Heidelberg: Springer Berlin Heidelberg; 2005. p. 105–19.

[28] Sniezek J, Bodin L. Using mixed integer programming for solving the capacitated arc routing problem with vehicle/site dependencies with an application to the routing of residential sanitation collection vehicles. Annals of Operations Research. 2006 May 24;144(1):33–58.

[29] Karadimas N, Kolokathi M, Defteraiou G, Loumos V. Municipal Waste Collection of Large Items optimized with arc GIS network analyst. Proceedings 21st European Conference on Modelling and Simulation. 2007;4–9.

[30] Muttiah RS, Engel BA, Jones DD. Waste disposal site selection using GIS-based simulated annealing. Computers & Geosciences. 1996 Nov;22(9):1013–7.

[31] Cheng S, Chan CW, Huang GH. An integrated multi-criteria decision analysis and inexact mixed integer linear programming approach for solid waste management. Engineering Applications of Artificial Intelligence. 2003 Aug;16(5-6):543–54.

[32] Huang GH, Baetz BW, Patry GG. Trash-Flow Allocation: Planning under uncertainty. Interfaces. 1998;28(6):36–55.

[33] McLeod F, Cherrett T. Quantifying the transport impacts of domestic waste collection strategies. Waste management (New York, NY). 2008 Nov;28(11):2271–8.

[34] Sumathi VR, Natesan U, Sarkar C. GIS-based approach for optimized siting of municipal solid waste landfill. Waste management (New York, NY). 2008 Nov;28(11):2146–60.

[35] Clark RM, Gillean JI. Analysis of Solid Waste Management Operations in Cleveland, Ohio: A Case Study. Interfaces. 1975 Nov;6(1-part-2):32–42.

[36] Aringhieri R, Bruglieri M, Malucelli F, Nonato M. A particular Vehicle Routing Problem arising in the collection and disposal of special waste. Presented at Tristan 2004. Guadeloupe, French West Indies; 2004.

[37] Arribas CA, Blazquez CA, Lamas A. Urban solid waste collection system using mathematical modelling and tools of geographic information systems. Waste management & research : the journal of the International Solid Wastes and Public Cleansing Association, ISWA. 2010 Apr;28(4):355–63.

[38] Benjamin A. Metaheuristics for the waste collection vehicle routing problem with time windows[PhD thesis]. Brunel University; 2011. p. 1–196.

[39] Beliën J, Boeck L De, Ackere J Van. Municipal solid waste collection and management problems: a literature review. Transportation Science. 2012;48(1):78–102.

[40] Dantzig GB, Ramser JH. The Truck Dispatching Problem Stable. Management Science. 1959;6(1):80–91.

[41] Caric T, Gold H. The Vehicle Routing Problem. Toth P, Vigo D, editors. Society for Industrial and Applied Mathematics; 2008.

[42] Golden B, Assad A, Wasil E. Routing vehicles in the real world: applications in the solid waste, beverage, food, dairy, and newspaper industries. In: Toth P, Vigo D, editors. The vehicle routing problem. SIAM; 2002. p. 245–86.

[43] Kim B-I, Kim S, Sahoo S. Waste collection vehicle routing problem with time windows. Computers & Operations Research. 2006 Dec;33(12):3624–42.

[44] Assad A, Golden B. Arc routing methods and applications. Handbooks in operations research and management science. 5 Elsevier. 1995. p. 375–483.

[45] Eiselt H, Gendreau M, Laporte G. Arc routing problems, part I: The Chinese postman problem. Operations Research. 1995;43(2):231–42.

[46] Eiselt AHA, Gendreau M, Laporte G. ARC ROUTING PROBLEMS , PART II : THE RURAL POSTMAN PROBLEM. 1994;43(3):399–414.

[47] Eisenstein D, Iyer A. Garbage collection in Chicago: a dynamic scheduling model. Management Science. 1997;43(7):922–33.

[48] Dror M. Arc routing: theory, solutions, and applications. Springer; 2000.

[49] Tung DV, Pinnoi A. Vehicle routing–scheduling for waste collection in Hanoi. European Journal of Operational Research. 2000 Sep;125(3):449–68.

[50] Faccio M, Persona A, Zanin G. Waste collection multi objective model with real time traceability data. Waste management (New York, NY). Elsevier Ltd; 2011 Dec;31(12):2391–405.

[51] Bonomo F, Durán G, Larumbe F, Marenco J. A method for optimizing waste collection using mathematical programming: a Buenos Aires case study. Waste management & research : the journal of the International Solid Wastes and Public Cleansing Association, ISWA. 2012 Mar;30(3):311–24.

[52] Kulcar T. Optimizing solid waste collection in Brussels. European Journal of Operational Research. 1996 Apr;90(1):71–7.

[53] Sahoo S, Kim S, Kim B, Kraas B, Jr AP. Routing optimization for waste management. Interfaces. 2005;35(1):24–36.

[54] Benjamin A, Beasley J. Metaheuristics for the waste collection vehicle routing problem with time windows, driver rest period and multiple disposal facilities. Computers & Operations Research. 2010;37(12):2270–80.

[55] Liu J, He Y. A Clustering-Based Multiple Ant Colony System for the Waste Collection Vehicle Routing Problems. 2012 Fifth International Symposium on Computational Intelligence and Design. Ieee; 2012. p. 182–5.

[56] Meulemeester L De, Laporte G. Optimal sequencing of skip collections and deliveries. Journal of the operational Research Society. 1997;48(1):57–64.

[57] Bodin L, Mingozzi A, Baldacci R, Ball M. The Rollon–Rolloff Vehicle Routing Problem. Transportation Science. 2000 Aug;34(3):271–88.

[58] Baldacci R, Bodin L, Mingozzi A. The multiple disposal facilities and multiple inventory locations rollon–rolloff vehicle routing problem. Computers & Operations Research. 2006 Sep;33(9):2667–702.

[59] Fukasawa R, Longo H, Lysgaard J, Reis MP de AM, Uchoa E, F.Werneck R. Robust branch-and-cut-and-price for the capacitated vehicle routing problem. Mathematical Programming. 2006;106(3):491–511.

[60] Wy J, Kim B-I. A hybrid metaheuristic approach for the rollon–rolloff vehicle routing problem. Computers & Operations Research. Elsevier; 2013 Aug;40(8):1947–52.

[61] Wy J, Kim B-I, Kim S. The rollon–rolloff waste collection vehicle routing problem with time windows. European Journal of Operational Research. Elsevier B.V.; 2013 Feb;224(3):466–76.

[62] Bommisetty D, Dessouky M, Jacobs L. Scheduling collection of recyclable material at Northern Illinois University campus using a two-phase algorithm. Computers & industrial engineering. 1998;35(98):435–8.

[63] Shih L, Chang H. A routing and scheduling system for infectious waste collection. Environmental Modeling & Assessment. 2001;6:261–9.

[64] Baptista S, Oliveira R, Zúquete E. A period vehicle routing case study. European Journal of Operational Research. 2002;139:220–9.

[65] Teixeira J, Antunes AP, de Sousa JP. Recyclable waste collection planning––a case study. European Journal of Operational Research. 2004 Nov;158(3):543–54.

[66] Karadimas N, Kouzas G. Urban solid waste collection and routing: The ant colony strategic approach. International Journal of Simulation. 2005;6(12):45–53.

[67] Nuortio T, Kytojoki J, Niska H, Braysy O. Improved route planning and scheduling of waste collection and transport. Expert Systems with Applications. 2006 Feb;30(2):223–32.

[68] Schultmann F, Zumkeller M, Rentz O. Modeling reverse logistic tasks within closed-loop supply chains: An example from the automotive industry. European Journal of Operational Research. 2006 Jun;171(3):1033–50.

[69] Simonetto E de O, Borenstein D. A decision support system for the operational planning of solid waste collection. Waste management (New York, NY). 2007 Jan;27(10):1286–97.

[70] Krikke H, le Blanc I, van Krieken M, Fleuren H. Low-frequency collection of materials disassembled from end-of-life vehicles. International Journal of Production Economics. 2008 Feb;111(2):209–28.

[71] Aguiar M. Optimization techniques for the mixed urban rural solid waste collection problem. 2010[PhD thesis]. p. 1–90.

[72] Buhrkal K, Larsen A, Ropke S. The Waste Collection Vehicle Routing Problem with Time Windows in a City Logistics Context. Procedia - Social and Behavioral Sciences. 2012;39:241–54.

[73] Carrasco-Gallego R, Ponce-Cueto E, Dekker R. Closed-loop supply chains of reusable articles: a typology grounded on case studies. International Journal of Production Research. 2012 Oct;50(19):5582–96.

[74] Otoo D. Capacitated arc routing problem: collection of solid waste at Kwadaso estate, Kumasi [PhD thesis]. 2012. p. 1–95.

[75] Ferreira J, Quintas A, Oliveira J. Solving the Team Orienteering Problem: Developing a Solution Tool Using a Genetic Algorithm Approach. Soft Computing in Industrial Applications. 2012. p. 1–10.

[76] Markov I, Varone S, Bierlaire M. Vehicle Routing for a Complex Waste Collection Problem. 14th Swiss Transport Research Conference [Internet]. 2014 [cited 2014 Nov 27]. p. 1–25. Available from: http://www.strc.ch/conferences/2014/Markov_EtAl.pdf

[77] Mourão MC, Almeida MT. Lower-bounding and heuristic methods for a refuse collection vehicle routing problem. European Journal of Operational Research. 2000 Mar;121(2):420–34.

[78] Minciardi R, Paolucci M, Trasforini E. A new procedure to plan routing and scheduling of vehicles for solid waste collection at a metropolitan scale. Odysseys, Palermo, Italy. 2003;

[79] Amponsah SK, Salhi S. The investigation of a class of capacitated arc routing problems: the collection of garbage in developing countries. Waste management (New York, NY). 2004 Jan;24(7):711–21.

[80] Koushki PA, Al-Duaij U, Al-Ghimlas W. Collection and transportation cost of household solid waste in Kuwait. Waste management (New York, NY). 2004 Jan;24(9):957–64.

[81] Ismail Z, Loh SL. Ant Colony Optimization for Solving Solid Waste Collection Scheduling Problems. Journal of Mathematics and Statistics. 2009 Mar 1;5(3):199–205.

[82] Bodin L, Fagin G, Welebny R, Greenberg J. The design of a computerized sanitation vehicle routing and scheduling system for the town of oyster bay, new york. Computers & Operations Research. 1989 Jan;16(1):45–54.
[83] Ong HL, Goh TN, Poh KL, Lim CC. A computerised vehicle routing system for refuse collection. Advances in Engineering Software (1978). 1990 Apr;12(2):54–8.
[84] Chang N, Lu H, Wei Y. GIS technology for vehicle routing and scheduling in solid waste collection systems. Journal of environmental engineering. 1997;123(9):901–10.
[85] Smith Korfmacher K. Solid Waste Collection Systems in Developing Urban Areas of South Africa: an Overview and Case Study. Waste Management & Research. 1997 Oct;15(5):477–94.
[86] Ismail Z bin H, Nurhadi I, Zainuddin ZM. Development of heuristic methods based on genetic algorithm (GA) for solving vehicle routing problem. 2008 p. 1–166.
[87] Hansmann RS, Zimmermann UT. Integrated Vehicle Routing and Crew Scheduling (IVRCS) in Waste Management Part I. Dagstuhl Seminar Proceedings 09261 Models and Algorithms for Optimization in Logistics. 2009. p. 1–8.
[88] O'Connor DL. Solid Waste Collection Vehicle Route Optimization for the City of Redlands, California[PhD thesis]. 2013. p. 1–77.
[89] Fooladi S. Waste collection vehicle routing problem considering similarity pattern of trash can and garbage unloading. International Journal of Modern Management and Foresight. 2014;1(7):245–54.
[90] Benavent E, Campos V, Corberán A, Mota E. The capacitated arc routing problem: lower bounds. Networks. 1992;22(7):669–90.
[91] Tasgetiren MF. A Genetic Algorithm with an Adaptive Penalty Function for the Orienteering Problem. 4(2):1–26.
[92] Glover F, Kochenberger GA. Handbook of Metaheuristics. Internatio. Springer; 2003.
[93] Gendreau M, Potvin J-Y, Bräumlaysy O, Hasle G, Løkketangen A. Metaheuristics for the Vehicle Routing Problem and Its Extensions: A Categorized Bibliography. In: Golden B, Raghavan S, Wasil E, editors. The Vehicle Routing Problem: Latest Advances and New Challenges. Boston, MA: Springer US; 2008. p. 143–69.
[94] Cordeau J-F, Gendreau M, Laporte G, Potvin J-Y, Semet F. A guide to vehicle routing heuristics. Journal of the Operational Research Society. 2002 May;53(5):512–22.
[95] Lin C, Choy KL, Ho GTS, Chung SH, Lam HY. Survey of Green Vehicle Routing Problem: Past and future trends. Expert Systems with Applications. 2014 Mar;41(4):1118–38.
[96] Sbihi A, Eglese RW. Combinatorial optimization and Green Logistics. 4OR: A Quarterly Journal of Operations Research, Springer Verlag (Germany). 2007 Jun 1;5(2):99–116.
[97] Eksioglu B, Vural AV, Reisman A. The vehicle routing problem: A taxonomic review. Computers & Industrial Engineering. Elsevier Ltd; 2009;57(4):1472–83.

APPENDIX

Table 2 – Models of WCVRP with methods and techniques used to solve the problem

Types of Models	Authors	Main Contributions	Methods to solve WCVRP
Node Routing Problems	Kulcar (1996) [52]	Optimize solid waste collection in Brussels.	Computer system
	De Meulemeester et al. (1997) [57]	Solve a complex routing problem associated with the collection and delivery of skips.	Two simple heuristics
	Eisenstein and Iyer (1997)[47]	Investigate the scheduling of garbage trucks in Chicago.	Markov Decision Process
	Bommisetty et al. (1998) [62]	Address the recyclable materials activities in a large university campus.	Heuristic Two-phase Solution Method
	Bodin et al. (2000) [57]	Define the Roll-on–Roll-off Vehicle Routing Problem (RRVRP).	Four different heuristic algorithms
	Tung and Pinnoi (2000) [49]	Consider the problem of collecting waste in Hanoi, Vietnam.	Improvement heuristics
	Shih and Chang (2001) [63]	Optimize routing and scheduling for the collection of infectious medical waste from a set of hospitals.	Two-phase approach
	Angelelli and Speranza (2002) [12]	Analyze two case studies about WCVRP in Val Trompia (Italy) and Antwerp (Belgium), respectively.	Tabu search algorithm
	Baptista, Oliveira, and Zúquete (2002) [64]	A case study on collection of recycling paper in Portugal is presented.	Heuristic approach
	Teixeira et al. (2004)[65]	Develop real-life vehicle routes for the collection of different types of urban recyclable waste in Portugal.	Heuristic Techniques
	Karadimas et al. (2005) [66]	Identify the most cost-effective alternative scenario for waste collection and transport.	Ant Colony Optimization (ACO) and GIS
	Sahoo et al. (2005) [53]	Reduce operational costs for a waste collection company in North America.	A heuristic method
	Baldacci et.al (2006) [58]	Solve a time constrained vehicle routing problem on a multi-graph (TVPR-MG)	An exact method based on a bounding procedure.
	Ghose et al. (2006) [17]	Design plans for the Asansol Municipality Corporation (AMC) of West Bengal State (India).	A GIS optimal routing model
	Nuortio et al. (2006)[67]	Optimize vehicle routes and schedules for collecting municipal solid waste.	Heuristic Solution
	Kim et al. (2006) [43]	Solve a real life waste collection vehicle routing problem with time windows (VRPTW) assuming multiple disposal trips and drivers' lunch breaks.	Route Construction Algorithm
	Schultmann et al. (2006) [68]	Reverse logistics modeling for end-of-life vehicle (ELV) in Germany is done by vehicle routing planning.	Tabu Search
	Apaydin and Gonullu (2007) [20]	Optimized routes contribute a benefit by 24% in total cost.	The Route View ProTM software
	Simonetto and Borenstein (2007) [69]	The solid waste collection is modelled as a typical multi-depot VRP with a heterogeneous flee.	Heuristic methods
	Ombuki-Berman (2007) [22]	Solve a waste collection vehicle routing problem with time windows (VRPTW) using benchmark data from et al. [38].	Genetic algorithm
	Alagöz and Kocasoy (2008) [19]	Develop a health-care waste collection and transportation system for the city of Istanbul, Turkey.	Software programs called MapInfo and Road net
	Krikke et al. (2008) [70]	Optimize route planning for low-frequency collection of materials disassembled from end-of-life vehicles and results show savings up to 19% for Auto Recycling Nederland.	Information technology and 'look ahead' planning methodology based
	Kim et al. (2009) [25]	Find a vehicle routing approach for the transport of recycled electronic goods in South Korea.	A Tabu search
	Aguiar (2010) [71]	Solve the Periodic Vehicle Routing Problem (PVRP); A real-world solid waste collection system of a municipality in northern Portugal is used as a case study.	Hierarchical approaches
	Benjamin and Beasley (2010) [54]	Solve waste collection problem involving multiple disposal facilities.	Variable neighbourhood and Tabu search
	Buhrkal et al. (2012) [72]	Solve Waste Collection Vehicle Routing Problem with Time Window for Danish garbage collection company.	Large neighbourhood search algorithm
	Carrasco-Gallego et al. (2012) [73]	Describe types of reusable article networks: star systems vs. multi-depot systems.	Strategies
	Liu and He (2012) [55]	Tackle waste collection vehicle routing problems with time windows and intermediate facilities (WCVRPTW-IF).	Ant colony system
	Otoo (2012) [74]	Find the minimum tour lines for collection of solid waste at Kwadaso estate, Kumasi.	Ant Colony Optimization (ACO)
	Ferreira et al. (2012) [75]	Treated WCVRP as Team Orienteering Problem (TOP), and use a software application.	Genetic Algorithm
	Wy and Kim (2013) [60]	Solve the roll-on–roll-off vehicle routing problem.	A hybrid meta-heuristic method
	Wy et al. (2013) [61]	Solve roll-on–roll-off waste collection vehicle routing problem with time windows.	A large neighbourhood search
	Markov et al. (2014) [76]	Model WCVRP as a mixed binary linear program and the case study about a French waste collection company is presented.	A local search heuristics

Table 2 (continued) – Models of WCVRP with methods and techniques used to solve the problem

Types of Models	Authors	Main Contributions	Methods to solve WCVRP
Arc Routing Problems	Beltrami and Bodin (1974) [7]	Solve the problem of collecting municipal wastes in New York.	A simple heuristics
	Ronen and Kellerman (1983) [8]	Reduce the total collecting distance of residential waste by 18.7% in Givatayim, Israel.	Heuristics model
	Assad and Golden (1995) [44]	Describe applications areas of arc routing such as sanitation services and postal delivery operations.	Lower bounding techniques
	Torres and Antón (1999) [10]	Partial results are applied to real case "Students City" and give some guidelines.	A continuous approximation approach
	Chang and Wei (2000) [9]	The case study based on one of the administrative districts in the city of Kaohsiung in Taiwan.	A genetic algorithm
	Mourão and Almeida (2000) [77]	Relative gap between the two methods which are used to solve WCVRP is discussed.	Two lower-bounding Methods and Three-phase Heuristics
	Sniezek et al. (2001) [11]	Describe Capacitated Arc Routing Problem with Vehicle-Site Dependencies (CARP-VSD) and its application in Philadelphia.	Vehicle Decomposition Algorithm (VDA)
	Minciardi et al. (2003) [78]	Present a case study on large-scale solid waste collection in Genoa, Italy.	Heuristics Approach
	Amponsah and Salhi (2004) [79]	Specifically design for collecting garbage in developing countries.	Constructive look-ahead Heuristic
	Bautista and Pereira (2004) [14]	Design collection routes for urban wastes.	Ant Algorithm
	Koushki et al. (2004) [80]	Present several indicators to evaluate the efficiency of municipal solid waste collection in Kuwait.	Comparative Analysis and Indicators
	Ghiani et al. (2005) [16]	Conduct a study on solid waste collection for the Health Department of the Municipality of Castrovillari, a town located in Southern Italy.	Heuristics
	Sniezek and Bodin (2006) [28]	Solve Arc Routing Problem with Vehicle/Site Dependencies (CARP-VSD) and describe its application to the routing of residential sanitation vehicles.	The Initial Fleet Mix Generator (IFM), the Mathematical Programming Procedure (MPP), and the Measure of Goodness
	Ismail and Loh (2009)[81]	Solve solid waste collection problem at Southern Waste Management environment company in Johor Bahru, Malaysia.	Ant Colony Optimization and Simulated Annealing
	Faccio et. al (2011) [50]	Introduce an innovative vehicle routing model with an application in an Italian city of about 100,000 inhabitants.	Traceability technology
	Bonomo et. al (2012) [51]	Optimize routes of waste collection for Buenos Aires.	Mathematical programming
Node Routing Problems and Arc Routing Problems	Bodin et al. (1989) [82]	Design computerized system for the routing of solid waste collection vehicles, and present the application in the Town of Oyster Bay, New York.	Computerized system
	Ong et al. (1990) [83]	Optimize the refuse collection in Singapore by first cluster second approach.	Heuristic Route
	Chang et al. (1997)[84]	Present a case study on routing and scheduling of solid waste collection trucks in Taiwan.	Mixed-integer Programming Model with GIS
	Smith (1997)[85]	Arrange solid waste collection. A case study on urban areas of South Africa is presented.	Strategies
	Viotti et al. (2003) [13]	Reduce vehicle maintenance expenditures and improve traffic conditions in urban areas by optimal routes design.	A genetic algorithm and an adhoc algorithm
	Maniezzo (2004) [26]	Solve a capacitated arc routing problem on large directed graphs (DCARP) using various meta-heuristics to real-world applications and compare results.	Meta-heuristics
	Bianchessi and Righini (2007) [15]	Optimally integrate goods distribution and waste collection.	Heuristic algorithms
	Karadimas et al. (2007a) [18]	Two methods are discussed for identification of optimal routes in the case of Municipal Solid Waste (MSW) collection.	ArcGIS Network Analyst and Ant Colony System (ACS) algorithm
	Karadimas et al. (2007b) [29]	Identify best routes applied in municipal waste collection of large items in Athens.	ArcGIS Network Analyst Algorithm
	Bautista et al. (2008) [21]	Solve an urban waste collection problem in the municipality of Sant Boi de Llobregat, Barcelona (Spain).	Ant colonies heuristics
	Ismail et al. (2008) [86]	Solve VRP with Stochastic Demands (VRPSD) and describe the application of picking up garbage in a solid waste collection company.	Meta-heuristic algorithms
	Santos et al. (2008) [23]	Test one system for trash collection in Coimbra, Portugal.	Spatial decision support system (SDSS)
	Ustundag and Cevikcan (2008) [24]	Via Radio Frequency IDentification (RFID) develop a vehicle routing model for waste collection.	Dash Optimization XPress Solver
	Hansmann and Zimmerman (2009) [87]	Focus on the route generation with two waste management companies.	Three-phase optimization approach
	O'Connor(2013) [88]	Determine optimal routes for solid waste collection in the city of Redlands, California.	Esri's ArcGIS Network Analyst software
	Fooladi1 and Fazlollahtabar (2014) [89]	Propose a mathematical model to reduce the cost of waste collection and transporting for recycling process.	LINGO 0.9 software