Description of the publications classification and the models used to solve of the vehicle routing problem with pickup and delivery

Pedro Pablo Ballesteros Silva[*]
Antonio Hernando Escobar Zuluaga[**]

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Abstract

This review paper presents the description of the state of the art of the vehicle routing problem with pickups and deliveries, VRPPD, product obtained from the literature review of most of the models reported in the international technical literature and used for many years by specialized researchers in the field. This classification considers the different solution methods, the treatment of the problem in time and future trends in its formulation, and proposal of new methods of solution, such as the metaheuristics caused by the complexity of the problem. Finally, several elements are left to discuss about existing and available tools for solving this problem.

Key words: complexity of the problem, mathematical programming, methods of solution, modeling tools, vehicle routing problem with delivery and pickups, future trends and treatment of the problem.

[*] Industrial Engineer. M. Sc in Research of Operations and Statistics with emphasis on Production. Leading Researcher of the Logistics Group on Supply Chain Strategy. Associate Professor, Coordinator of the Specialization in Business Logistics, Faculty of Technology, Universidad Tecnológica de Pereira. Pereira, Colombia. E-mail: ppbs@utp.edu.co

[**] Electrical Engineer and M.Sc., in Electrical Engineering, Universidad Tecnológica de Pereira, Colombia. Ph.D. In Electrical Engineering, Universidade Estadual Paulista UNESP. SP, Brazil. Associate Professor, Faculty of Technology, Electrical Technology Program, Universidad Tecnológica de Pereira. Pereira, Colombia. E-mail: Aescobar@utp.edu.co

Descripción de la clasificación de publicaciones y los modelos utilizados en la solución del problema de enrutamiento vehicular con entregas y recogidas

Resumen

Esta revisión presenta la descripción del estado de arte del problema de enrutamiento vehicular con entregas y recogidas (VRPPD), producto obtenido de la revisión de literatura de la mayoría de modelos reportados en la literatura técnica internacional y utilizados por muchos años por investigadores especializados en el campo. Esta clasificación considera los diferentes métodos de solución, el tratamiento del problema en el tiempo y las futuras tendencias en cuanto a su formulación y propuesta de nuevos métodos de solución, como la metaheurística causada por la complejidad del problema. Finalmente, se dejan para discusión diferentes elementos sobre herramientas existentes y disponibles para la solución de este problema.

Palabras clave: Complejidad del problema; programación matemática; métodos de solución; herramientas de modelado; problema de enrutamiento vehicular con entregas y recogidas; futuras tendencias y tratamiento del problema.

INTRODUCTION

In recent years, particularly from 2002 onwards, research on vehicle routing problem [1] has increased significantly. In addition, there has been a substantial intellectual production in the different versions of the problem. Technical literature has published important documents and works including new models, solution methods and the application of new optimization algorithms that use more efficient computers to obtain good results in relatively short computation times. Paper [2] shows this is a difficult problem of combinatorial optimization of the NP type. This means that the solution cannot be found in polynomial time.

In this paper, an updated review of the literature concerning the most prominent of vehicle routing problem with deliveries and pick-ups is presented, considering the different solution methods, as well as future trends in the development and use of metaheuristics, following the complexity of the problem.

Content analysis of these publications provides a holistic view that includes knowledge of the various models used by researchers to solve the problem, the set of possibilities from simple situations to complex problems that are currently the subject of important research, with a corresponding interpretation of their results, and an identification of the different routes of vehicles that provide a service to several clients in the most appropriate way possible, in the development and implementation of processes related to the supply and distribution. The objective of the problem is to find a set of good solutions obtained by applying heuristics or metaheuristics, conditioned by a variety of constraints related to the number of vehicles, capacity, destination sites and demand, delivery time and pickup, length of route, use of multiple depots, mixed fleet of vehicles, among others. If the problem is very complex and has sufficient technological and computing resources, it is possible to obtain the optimal solution.

Because of space limitations, many of the reviewed papers on the subject are just quoted, including some Master and Ph.D. thesis work. However, the decision to exclude some material was taken because of its length to be documented in this paper. Of the total papers in the database the most 112 relevant were classified under the following criteria: year of publication, authors, country of origin of the research group or University to which the authors belong, and the methodology or the proposed solution algorithm. This information is the basis for building a historical review and state of the art of the problem.

Authors like Berblegia et al. [3] make a proposal for a general classification scheme of delivery and pickup problems with their characteristics. The classification has three groups. The first group consists of the graph “many to many problems”, where any

vertex can be used as source or destination. Its structure is similar to the vehicle routing problem with simultaneous pickup and delivery-VRPSPD. The second group includes the problems of "one-to-many to one." It means that all delivery demands are initially located at the depot and all pickup demands are delivered at the depot. An application of this case is the delivery of full bottles and the collection of empty ones in a bottling industry. Its equivalent is the mixed vehicle routing problem with pickup and delivery (MVRP). Here it appears that clients request only one of the two services. The third group consists of the routing problems one-to-one, where each product is considered a request that comes from a source and has a defined destination. This problem is identical to the traveling salesman with mixed deliveries and pickups.

The scenarios in which this problem can be analyzed by Berbeglia et al. [4] are: Static environment: where all the input data of the problem is known before the construction or route design. In this scenario, the planning horizon is limited and functions in a dynamic environment, where some input data is known or updated during the period in which operations perform delivery and pickup of products or goods. The planning horizon in this scenario is unlimited. Most delivery and pickup problems have focused on the static scenario and few authors have worked the dynamics of the problem.

Variations of the classic VRP consider the problem with a mix of nodes that require delivery only, pickup only or both delivery and pickup [5]. In the VRP with simultaneous pickup and delivery, all vehicles or conveyances returning to a depot (source) and all clients (nodes) will be visited only once. The design of the route seeks to be the path of minimum cost or minimum distance, and the vehicle load must not exceed its capacity along the route.

The objective of the VRP with deliveries and selective pickups that includes time windows (VPRDSPTW) is to minimize the difference between routing costs and revenues associated with the pickups. In this scenario, there are five variants of the problem [6]: VRP with mixed delivery and pickup; VRP with pickup and delivery with backhaul; VRP with pickup and delivery with individual visits; VRP with pickup and delivery with multiple visits and routes mixture; and VRP with pickup and delivery with backhauls allowed.

On the other hand, some authors consider the factor of time window [7] within the routing problem with simultaneous delivery and pick-up, and developed a mathematical model from a genetic algorithm penalizing delays [8]. Others, such as the exact method, among other techniques, apply the branch and price, with the comparison of instances of up to 100 clients. The VRP with partial delivery and pickup with multiple visits (mixed route) includes the integer programming solution with competitive decision

algorithm (CDA) [9]. In 2014, [10] developed a local search algorithm based on the variable neighborhood search (VNS) method to improve the performance of the heuristic. An adaptive local search algorithm for the vehicle routing problem with simultaneous and mixed pick-ups and deliveries was presented in 2015 [11]. The vehicle routing problem with simultaneous pick-ups and deliveries with two-dimensional loading constraints is introduced and solved in 2016 [12].

The paper is organized as follows: Introduction, methodology, brief description of the theoretical framework, future trends, conclusions and bibliography review.

1. THEORETICAL FRAMEWORK

This document deals with the VRP with deliveries and pickups, including one of the early researches about the problem with VPRSPD which arises in the year 1989 [13]. Following, a taxonomy of the problem is presented, considering the formulation of mathematical models and the solution methods employed:

1.1. Classification due to solution method

A sample of 98 papers was classified by their solution method into the following categories: exact methods (24 papers), heuristics (29 papers), metaheuristics (35 papers) and hybrid (exact method, heuristics and metaheuristics) (10 papers) :

1.1.1. Exact methods

The following methods were found: branch and cut algorithm (5 papers) [14-18]; branch and price algorithm (2 papers) [19, 20]; branch and bound algorithm (1 paper), [21] dynamic programming (5 papers) [22-26]; mixed integer linear programming (5 papers) [27-31]; experiments (1 paper) [32]; column generation scheme (4 papers) [33-36]; classical theory of programming and graph theory (1 paper) [37].

Aspects of these methods are described below:

Branch and cut algorithm: it was first applied in 1997 by Ruland and Rodin and consists of a fleet of vehicles serving a set of customers. It is a restricted version of the multiple traveling salesman problem and the optimal solution for 2,392 cities (destinations) served from a single deposit. In 2011, the same algorithm was applied with restrictions that ensure that the capacity is not exceeded in the middle of the route, incorporating an approximate separation. The test was done in 87 cases between 50 and 200 customers, improving the lower bounds and showing new optimal solutions [16]. Then, [17] in the same year, present a work related with the search of locations and the design of routes of the vehicles, so that the delivery and pick up are carried out in

the same vehicle, reducing the total cost. The application was made for 88 clients and 8 depots, obtaining optimal solution in a reasonable time. In 2013, this problem was treated as a special case of the pickup and delivery problem with time windows in two parts, evaluating the method on the generated instances and real-world, considering 193 transport requests. The optimum is achieved with a maximum of 87 clients in a computation time of one hour [18].

Branch and price algorithm: in 2010, this method was applied using time windows and a set of homogeneous vehicles [19]. The optimal solution was obtained for instances that contain a deposit and up to 100 clients. Concurrently, the problem "A population-based metaheuristic for the pickup and delivery problem with time windows and LIFO loading" was resolved for three exact branch-price-and-cut algorithms [20].

Dynamic programming: a stochastic and dynamic model for the vehicle routing problem with deliveries and pickups was proposed and developed by [22] in 1999, considering vehicles with unit capacity and variable capacity, seeking to reduce the waiting time in the system demands. In 2009 [23] developed a model similar to the schedule with setup times in the sequence and timing of release times, with the novelty to combine or separate delivery and pickup operations.

In 2011, [25] proposed solutions for multiproduct dynamic programming with pickups and capacitated deliveries. Non-optimal solutions were found. By 2013 [26] worked dynamic programming algorithm, considering the problem in a horizon of finite and infinite time with a predefined customer sequence for both delivery and collection. The objective was to find the optimal path of least cost.

Mixed integer linear programming: Here, the problem is studied using special graphics as trees, polynomial algorithms in cycles and store graphics. Satisfying requests for pickup and delivery of customers within the constraints of vehicle capacity is studied when depots are considered exogenous and endogenous [27]. A new mixed integer linear programming (MILP) approach is presented under uncertainty by taking greenhouse emissions into consideration [28]. A variant of the many-to-many location-routing problem, where hub facilities have to be located and customers with either pickup or delivery demands have to be combined in vehicle routes is seen in [29]. A single vehicle routing problem with pickups and deliveries, continuous random demands and customers served according to a particular order are treated in [30]. In 2016, [31] proposed two mixed integer linear programming (MILP) models for solving the green vehicle routing problems with pickups and deliveries in a semiconductor supply chain (G-VPRPD-SSC). Design of experiments: in 2009 [32] do an experiment associated to split

load in the delivery and pickup that is affected by the average size, number of sources relating to the destinations, grouping of depots and customer locations.

Column generation scheme: this method was applied in 1999, when the problem of delivery and pickup of goods with time windows, looked for the shortest route on a scenario of multiple warehouses and different types of vehicles [33]. By 2009, the problem of incorporating the generation time in the care of deliveries and pickups to customers was considered, with restrictions in allocation drivers and vehicles to customer requests [34]. By 2013, [36] increase the scope of the problem, by working residential and commercial networks, applying this scheme, which is significantly reduced when the two networks are combined fully or partially.

Classical theory of programming and graph theory: In 2009, using this procedure, [37] designed an algorithm programming and delivering tasks in hospitals, making efforts to accelerate health care, and reduce waiting time and patient costs.

1.1.2. Heuristics

It is known that the heuristic solutions are procedures which usually show good quality through a restricted search space research.

Today, heuristic methods are an alternative to mathematical optimization models. Heuristics is associated with invention or creation, and it is used to describe the techniques which, instead of using a classical optimization approach, apply a step by step construction process, evaluating and selecting different options with or without help from the user, to perform local searches under the guidance of the rules and / or logical or empirical sensibilities.

The heuristics found in the revised data bases explored papers dealing with a classification into two construction methods and phases given by [38] in 2011:

- *Construction methods:* are based on the traveling salesman problem, 1994, [39]; transfer opportunity in 1996 [40]; dynamic routing, 1996 [41]; split routes, 1998 [42]; single and multiple depot, 2005 [43]; search shortest path, 2006, [44]; approach for a vehicle routing problem on a tree-shaped network with a single depot, with free delivery and pick up on request, 2006 [45]; time windows and waiting time, 2006 [46], 2011 [47]; Nearest neighbor search, 2006, [48]; Variable nearest neighbor search, 2012 [49]; hybrid approach to adaptive predictive control (HAPC), 2008 [50]; problem solving of routing single vehicle deliveries and pickups, 2007 [51]; selective pickup and delivery, 2008 [52]; route search with stowage planning in three dimensions, 2008 [53]; TSPPD with first-in, first-out loading (TSPPDF) 2009 [54]; grouping, 2009 [55]; parallel heuristics, 2010 [56]; Variable local search (VNS),

2011 [57]; heuristic approach 2012 [58]; algorithm NPFDS, 2013 [59]; political dynamics of the nearest neighbor (DNN), 2013 [60]; fleet size and the vehicle routing problem mixed, 2013 [61]; Scanning, 2013 [62]; split for simultaneous deliveries and pickup, 2009 [63], 2010 [64]; pheromones, 2009 [65]; hybrid heuristics, 2010 [66].

- *Methods phase's multiphase constructive heuristics:* these are group nodes with proximity criterion, using the shrink algorithm with generalized vehicle allocation, genetic algorithm with application in the last search, 2007 [67].

1.1.3. Metaheuristics

They are defined as methods or approximate iterative procedures of general purpose, designed as superior strategies to guide the heuristics methods in the achievement of feasible solutions, appropriately combining the different concepts to explore with intensification or diversification the search space in the domains where the problems are complex. It is usually applied to solve complex problems NP or NP complete problems associated with combinatorial optimization.

In table 1 you can see the different metaheuristics that were found in the bibliography review.

Table 1. Taxonomy metaheuristics solution methods

Metaheuristics		
Tabu search [69 -72]	Reactive tabu search [68]	Local search and tabu search [73,74]
Simulated annealing [90]	Improved simulated annealing [72]	Hybrid metaheuristics [76-77, 95, 101]
Metaheuristic for routing [78]	Ant colony [79, 81-82]	Evolutionary procedure based on adaptive memory [80]
Differential evolutionary algorithm [83]	Local search [84]	Genetic algorithm [85-90]
Coevolution algorithm [91]	Theory of fuzzy credibility [92]	Memetic algorithm [94]
Hybrid genetic algorithm [96-97].	Swarm optimization [98,100]	Evolutionary algorithm [99]
Iterative local search [112]		

Source: authors

1.1.4. Hybrid (heuristics and metaheuristics, exact and heuristic or metaheuristics)

Eleven hybrid methods found in the papers consulted, combining metaheuristics and exact methods heuristics to obtain better solutions to the problem are presented in table 2.

Table 2. Taxonomy methods, hybrid methods.

Hybrid (heuristics and metaheuristics, exact and heuristic or metaheuristics)		
Cheapest insertion procedure and tabu search [102]	Exact integer programming formulation and heuristic constructive [103]	Local search and exact algorithms and heuristic [104]
Hybrid algorithm and a packing procedure [105]	Algorithms GENVNS+TS+CL+PR [106]	Simulated annealing + particle swarm optimization pso + genetic algorithm + artificial immune system [107]
Simulated annealing + variable search local+ probabilistic tabu search [107]	Genetic algorithm and tabu [108]	Mixed integer program +, adaptive neighborhood search and insertion heuristic [109]
Ant colony system based on heuristic algorithm [110]	Mixed algorithm PSO_ACS [111]	

Source: authors

1.2. Depending on the formulation of mathematical models

The vehicle routing problem with deliveries and pickups was studied first in 1989 by H. Min, who proposed a three-phase heuristic [13]. It has been observed that the interest of researchers in this problem has been increasing after year 2006. For the literature review, it was found that from 1981 to 2005, 15 papers were written and in the 2006-2016 period, the intellectual production reached 97 papers in the selected sample. Both the general formulation for the vehicle routing problem VPRS and the case of the vehicle routing problem with deliveries and pickups, are still regarded as a combinatorial optimization problem and most versions are considered an NP-problem.

A summary of the relevant variants this problem has presented in 1981-2016 are presented in table 3.

Table 3. Taxonomy formulating mathematical models for vehicle routing problem with deliveries and pickups

Relationship of the formulation of mathematical models for the vehicle routing problem with deliveries and pickups		
With multiple vehicles and simultaneous deliveries and pickups [13]	With deliveries and pickups using time windows [33]	Traveling salesman with deliveries and pickups [39]
With deliveries and pickups using multi-criteria [40]	Pickup and delivery systems [41]	With single and multiple vehicles, simultaneous deliveries and pickups [42]
With multiple vehicles, split pickup [44]	With delivery and pickup, applying the tree method [45]	With deliveries and pickups using time windows and waiting times [46]
With one vehicle, with deliveries and selective pickups [52]	With multiple vehicles for break bulk deliveries and collections [32]	With one vehicle, deliveries and pickups with predefined customer sequence [24]
With one vehicle, deliveries and collections based on customer satisfaction [72]	With vehicles with pickups and deliveries, continuous random demands and predefined customer order [30]	With break bulk pickup for delivery by applying time windows [61]
With flexible delivery and pickups, applying time windows [92]	With deliveries and pickups, applying transport routes [18]	With simultaneous deliveries and pickups, with uncertain demand and travel times [86]

Source: authors

2. FUTURE TRENDS

With respect to the formulation of the problem, according to recent research carried out in 2013, it is considered that the scenario is an infinite horizon with multiple vehicles and multiple customers [14], which cover 2,392 cities, the optimal solution was found, ensuring service level of 100% in deliveries and pickups. Here, it doesn`t matter whether the vehicle can interrupt his journey to return to depot, return the picked-up products listed and make new deliveries replenishment, retaking the remaining routes, working in dynamic environments. If this is the solution method, it shows a marked tendency to use metaheuristics, precisely because of the complexity of the problem.

On the other hand, the intent to consolidate or create many research lines that may be aimed at developing effective local search strategies associated with local searches to reduce the computational effort while maintaining a good level of quality in the solutions, while using algorithms that are able to solve large problems where it is possible to design new variants of the problem, remains. Also, the algorithms applied in

this problem can be used in other cases of combinatorial optimization and scheduling of single and multiple machines or grouping problems, in the research of alternative hybridization between heuristic approaches and exact forms. Finally, it is important to consider the incorporation of environmental variables such as reducing the impact of greenhouse emissions, fuel consumption and costs of emission of carbon, trying to address the problem of routing at its green version and clean scenarios [28, 31, 69].

3. METHODOLOGY

A detailed review of a sample of more than 100 papers of the VRP with pickup and delivery (VPRPD), published in the last two decades in international databases was made, taking into account the methods of solution with new optimization algorithms.

4. CONCLUSIONS

- It was noted in this paper that most of the methods used in solving the different variations of the problem correspond to metaheuristics, because of the growing complexity of the problem over time, followed by the heuristics; then come exact methods and finally, mixed methods.
- It was possible to show that the scope of the vehicle routing problem is very wide in all real economic sectors in both manufacturing and services, either discrete or continuous events, which makes the application of solution techniques become more interesting.
- In this bibliography review it was noted that there are important contributions of the authors to solve the problem. A strong and growing research is advancing worldwide in combinatorial optimization, as well as in the area of operations research. We found that some researchers designed their own algorithms.
- When comparing the resulting instances, it was noted that although there is an attempt to improve results, in the case of the exact methods, the runtime of the algorithm that solves the problem is crucial to decide which method gives the best solution.
- The references submitted, without being complete, are prime examples for the authors and the general public to address this exciting area of research.

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