

Algorithms applied to the problem of Routing of Vehicles with Capacity Restriction (CVRP): bibliometric analysis of the solutions

Algoritmos aplicados al problema del enrutamiento de vehículos con restricción de capacidad (CVRP): análisis bibliométrico de las soluciones

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Abstract

Solution methods for the Capacitated Vehicle Routing Problem (CVRP) are identified as a bibliometric analysis using quantitative and qualitative statistical techniques based on the impact and visibility criteria of the published documents. The results obtained from this research conclude with the selection of memetic algorithms and select a local search heuristic presentation that displays the closest to optimum.

Keywords: Capacitated Vehicle Routing Problem (CVRP), bibliometric analysis, algorithms

Resumen

Los métodos de solución para el problema de enrutamiento de vehículos capacitados (CVRP) se identifican como un análisis bibliométrico utilizando técnicas estadísticas cuantitativas y cualitativas basadas en los criterios de impacto y visibilidad de los documentos publicados. Los resultados obtenidos de esta investigación concluyen con la selección de algoritmos meméticos y seleccionan una presentación heurística de búsqueda local que muestra el más cercano al óptimo.

Palabras clave: Problema de enrutamiento de vehículos capacitados (CVRP), análisis bibliométrico, algoritmos

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1. Introduction

One logistic distribution problem is delivery merchandise at the right place and on the estimated time, to achieve this is necessary to plan the most efficient route, which means reduce resources consumption, like time, and then, it will be a lower cost system. Developing a route with different delivery points further complicate the activity, these led to research on the issue and its possible solutions, authors such as Dantzig and Ramser (1959) defined the problem as a Vehicle Routing Problem (VRP), which considered it as a classic optimization problem represented in mathematical language and solve with a computer tools. One of the most important VRP branches that have been the main objective of analysis in the literature over the last years has been called the Capacitated Vehicle Routing Problem (CVRP).

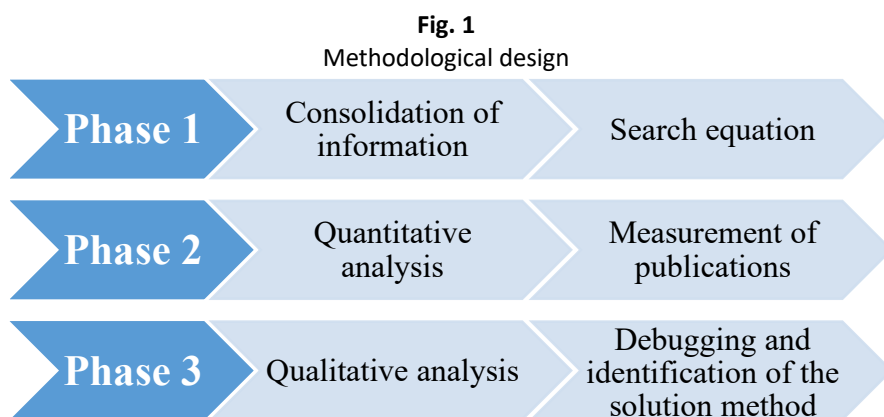
The CVRP is one of the variants of the VRP, which takes into account a similar vehicle fleet capacity. This problem seeks to find the optimal route, either in costs, distance or time, among others. Each vehicle is loaded with a certain quantity of a product without exceeding its capacity, to guarantee that each one of them leaves the warehouse and returns to it, enforcing a milk route strategy.

The increased interest in the scientific literature related to the CVRP allows for a bibliometric analysis, in which scientific publications are investigated by statistical techniques. These results in a quantification of the information Zhang et al., – (2015), which makes it possible to evaluate the state of research, trends and opportunities to deepen on the topic Fu et al., -(2010).

This paper carries out such a bibliometric analysis of the publications related to the CVRP from 1983 to the first quarter of 2018. Until now, this analysis has not been carried out on the theme. The following characteristics were considered: types of documents published, the number of documents, citations per year, the countries in which the documents and the most cited authors were published. In this way, it was possible to identify the documents examined in-depth, establish which method of solution is most used and delivered the best results for the CVRP, determine the algorithms and programming language they used, as well as the particularities of the computer equipment and the CVRP instances tested.

2. Methods

To do a bibliometric analysis using quantitative statistical techniques, to evaluate scientific production and determine research trends Zhong et al., (2016), it is necessary to develop a database that has wide information to evaluate. According to Archambault & Vingola (2004), the databases most used for bibliometric analysis are those developed by Thomson ISI (2014). One of them is Web of Science (WOS), which was chosen in this paper as information source because of accessibility and easy handling.



Source: Authors

In Figure 1 establishes the three phases that were considered necessary for the execution of the bibliometric analysis. In the first one, the search equation was applied, which was tested in WOS and obtained 163 related papers. The equation is displayed below:

$$TI= ((capacitated\ vehicle\ routing\ problem\ OR\ CVRP)\ AND\ (((solution\ OR\ heuristics)\ OR\ metaheuristics)\ OR\ algorithm)\ OR\ mathematical\ model))$$

In the second phase, the quantitative analysis was done. Three software programs were used to classify, count and characterize the information: 1) Bibexcel, which enables the analysis of the information obtained from WOS; 2) Power BI, to represent the results in graphs, and 3) VOSVIEWER, to represent the analysis of networks, which relates certain terms.

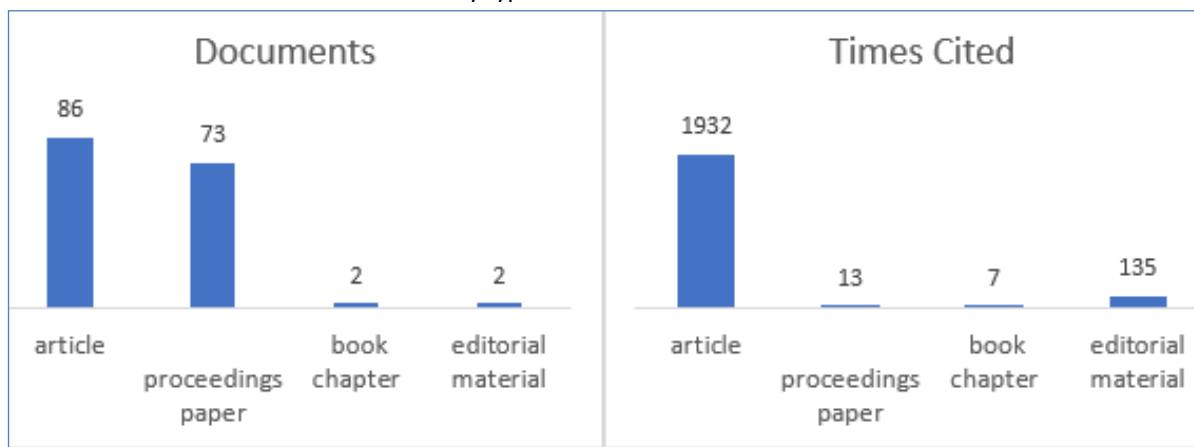
In the last phase, the information was filtered according to the visibility and impact indicator, that is, the number of citations, or h-index. This way, it was possible to stand out documents for deeper analysis to identify the solution method, the programming language, the characteristics of the computer equipment, the evaluated instances of CVRP, and the results were finally identified with the most widely used mathematical method.

3. Results

3.1. Quantitative analysis

The number of documents published since 1983 to 2018, located in the WOS database, was 163. According to the type of document, they were classified as articles (86), proceedings papers (73), book chapters (2), and editorial material (2). Of these scientific documents, the articles in journals were most-cited, with 92.6%. On the other hand, papers in memoirs did not contain information as valuable as those found in journal articles or opinion papers according to Fig. 2.

Fig. 2
Distribution by type of document since 1983 to 2018



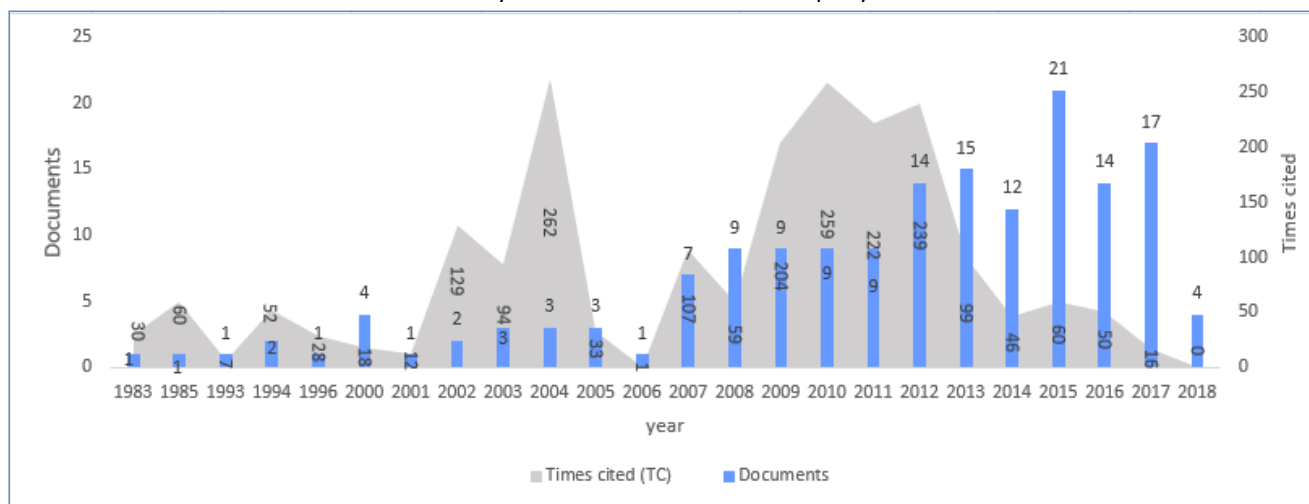
Source: Authors

The first publication of this topic was in 1983. From 2007 it has been a significant increase in research activity and is during this stage that concepts and theoretical bases of CVRP were established. From 2012 a sustained increase in publications can be seen, with a peak in 2015. The information analysis included the first quarter of 2018, with only 4 publications according to Fig. 3.

Regarding the number of citations, they were not correlated with the number of publications. Fig. 3 shows that there were periods of significant growth, specifically between 2001-2004 and 2006-2012, the period between 2004 and 2006 was an opposite trend. The year with the highest number of references was 2004, with 262, but

that same year, only three documents were published. The most-cited publication “A new branch-and-cut algorithm for the capacitated vehicle routing problem” also came from that year, as seen in Table 1. The highest citations per year are generated by few specific articles in the same year. For example, the next more cited paper was published in 2011 and garnered 58.1% of the total number of citations that year, followed by a document published in 2002, which garnered 82.9% of citations over the publication year.

Fig. 3
Quantity of documents and citations per year.



Source: Authors

Table 1

Most-cited documents and their year of publication

Title	Document Times	
	Type	Cited Year
A new branch-and-cut algorithm for the capacitated vehicle routing problem	Article	162 2004
An artificial bee colony algorithm for the capacitated vehicle routing problem	Article	129 2011
An integer L-shaped algorithm for the capacitated vehicle routing problem with stochastic demands	Article	107 2002

Source: Authors

According to the classification made with WOS, it shows the different fields of research in CVRP have been carried out in Table 2 (it must be taken into account that a document can have more than two fields of application). There are 17 documents dealing with industrial engineering, with a contribution of 11.4%, and 12 that specialize in transportation, that is, 7.3%.

Table 3, shows the top 12 countries (out of 41 countries in the research), the highest number of citations, the number of articles and the h-index. It should be highlighted Denmark, which has the highest number of citations since 2007 to 2014, with 436 citations in 6 articles and the h-index of 6 for this country, the author with the most citations is Lysgaard, with 277 citations. Besides, China has great participation with 43 articles and h-index of 8 and 323 citations, followed by Canada with 11 articles, h-index of 8 and 418 citations, which makes us think that their contribution is more significant; also are included United Kingdom (UK) and Italy with several citations higher than China, these being 327 and 303, respectively, 6 articles and h index of 5.

Table 2
Application fields

Web of Science Categories	Record Count	%	Web of Science Categories	Record Count	%
Operations research management science	62	37,8	Automation control systems	6	3,7
Computer science artificial intelligence	38	23,2	Engineering civil	6	3,7
Computer science theory methods	33	20,1	Transportation	5	3
Engineering electrical electronic	30	18,3	Engineering environmental	4	2,4
Computer science interdisciplinary applications	25	15,2	Materials science multidisciplinary	4	2,4
Management	19	11,6	Computer science cybernetics	3	1,8
Mathematics applied	18	11,0	Computer science hardware architecture	3	1,8
Engineering industrial	17	11,4	Engineering manufacturing	3	1,8
Computer science information systems	13	7,9	Engineering mechanical	3	1,8
Computer science software engineering	12	7,3	Mathematical computational biology	3	1,8
Engineering multidisciplinary	11	6,7	Physics applied	3	1,8
Mathematics interdisciplinary applications	8	4,9	Construction building technology	2	1,2
Transportation science technology	7	4,3			

Source: Authors

Table 3

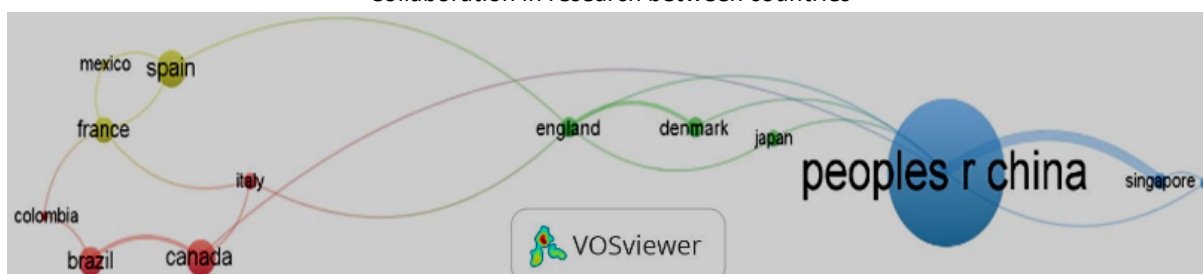
Documents, citations and h-index by country

Country	All articles	h-index	All citations	Country	All articles	h-index	All citations
China	43	8	323	Thailand	7	2	84
Canada	11	8	418	Denmark	6	6	436
Spain	11	5	101	UK	6	5	327
Taiwan	9	5	124	Turkey	6	4	99
Brazil	9	4	94	Italy	6	5	303
France	8	4	126	Japan	5	4	74

Source: Authors

Fig. 4 shows the cooperation of countries in publications. In this regard, the densest network is formed by China, Canada, England, Denmark, Japan, Singapore, and Australia, which means that there is a high degree of cooperation between them in the development of scientific production of the CVRP. China assumed publications leadership are in collaboration with other countries. The leadership assumed by China, to increase knowledge, it has been developed in collaboration with researchers in other countries like England, Canada, and Spain. Those countries have been stronger in this matter.

Fig. 4
Collaboration in research between countries



Source: Authors

Next, we present the top of the authors with the highest number of citations and additional information, such as the h-index and the number of articles generated. It can be seen that the author with the most citations is Lysgaard, with 277, followed by Laporte, with 273. The latter author has a better h-index and a greater number of publications. Laporte was, in fact, the first author who published a document on the topic in 1983. Being Canadian, he also comes from one of the most prominent countries according to the ranking in Table 3.

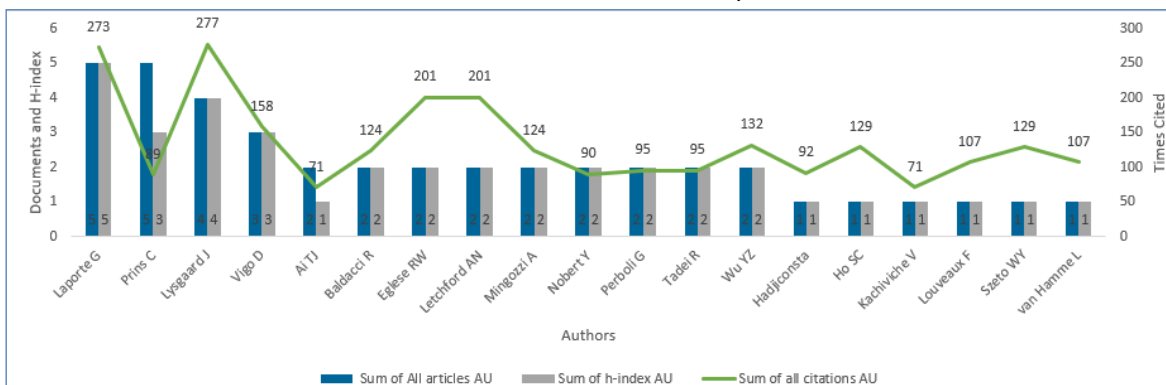
Table 4
Ranking of authors by citation

Authors	All citations	All articles	h-index	Authors	All citations	All articles	h-index
Lysgaard J	277	4	4	Szeto WY	129	1	1
Laporte G	273	5	5	Baldacci R	124	2	2
Eglese RW	201	2	2	Mingozzi A	124	2	2
Letchford AN	201	2	2	Louveaux F	107	1	1
Vigo D	158	3	3	van Hamme	107	1	1
Wu YZ	132	2	2	Perboli G	95	2	2
Ho SC	129	1	1	Tadei R	95	2	2

Source: Authors

Table. 4 and Fig. 5 shows the authors organized by several publications, and the criterion of more than 70 citations is chosen, as a result of which 19 authors were obtained. The one with the highest number of publications is Chun Yu Ren, with 6 documents; followed by Gilbert Laporte and Christian Prinscon, with 5 publications each. Chun Yu Ren is not shown in Fig. 6, because his number of citations and h-index are 0. Laporte and Prins had an h-index of 5 and 3, and citations of 273 and 89, respectively. The most-cited author was Jens Lysgaard and his h-index is 4. Two authors, Sin C. Ho, and Wai Yuen Szeto published only one article but received 129 citations, which resulted in a very high publication to citation ratio.

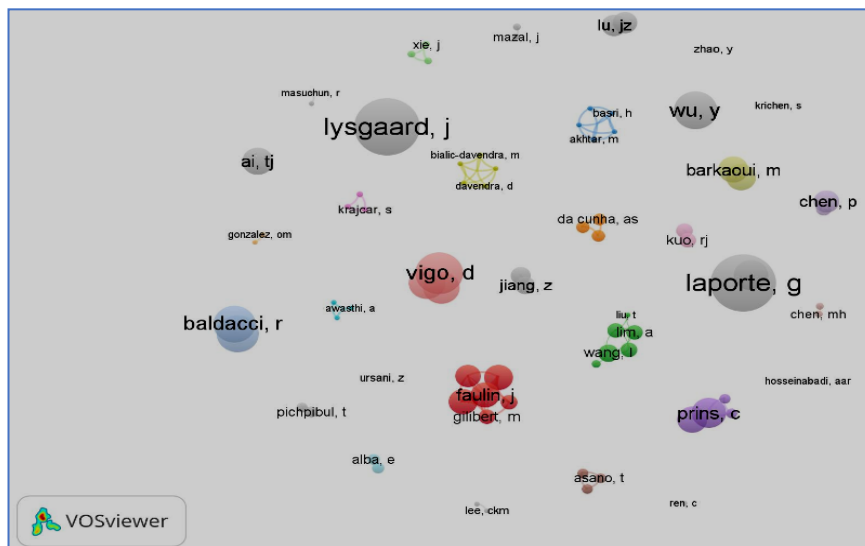
Fig. 5
Documents, h-index and citations by author



Source: Authors

Fig. 6 shows the different collaboration groups in publications. The clusters, or groupings, are differentiated by the color and size of the circles. Based on the number of citations, the clusters with the highest participation of authors and biggest impact according to color are: 1) red, consisting of Barrios (B), Faulin (J), Juan (AA) and Ruiz (R), with the article *The SR-GCWS hybrid algorithm for solving the capacitated vehicle routing problem*; 2) pink, by Perboli, Tadei, and Vigo, with the document *The Two-Echelon Capacitated Vehicle Routing Problem: Models and Math-Based Heuristics*; 3) purple, by Calvo, Ngueveu and Prins, with *An effective memetic algorithm for the cumulative capacitated vehicle routing problem*, and 4) green, by Lim, Liu, Luo, and Qin, with *A branch-and-cut algorithm for the two- echelons capacitated vehicle routing problem with grouping constraints*.

Fig. 6
Collaboration between authors



Source: Authors

3.2. Qualitative analysis

After carrying out the quantitative analysis, we proceed to refine the information, in order to identify the publications to be investigated and identify the method of solution, the programming language, the characteristics of the computer equipment and the results. Here we relied on the visibility and impact indicators from 1983 to 2018, that is, the number of citations, the h-index and the periods that are described in the analysis of Fig. 2.

The first step is to take into account the authors with the highest citations and the highest h-indices according to Table 4, establishing the number of publications by each one and choosing the one with the highest citations. This generated 30 articles; however, when reviewing the documents selected by authorship, it can be shown that important data about countries as with the highest citations, the highest h-indices and the number of publications according to Table 3, universities and journals according to Table 5.

This inquiry generated a list of 15 articles from the period 1983-2011. For the period 2012-2017, the most cited article was chosen for each year. During 2018, the selection criteria were based on the most important citation index by author, because the documents have no citations yet. A list of 21 documents were thus obtained, which were downloaded for later review. The article “An exact algorithm for the asymmetrical capacitated vehicle-routing problem” (1986) was discarded in the review, since it was difficult to download; that left a final list of 20 publications, organized according to the year of publication and according to information such as title, authors, year of publication, city, type of document, institution, journal and total citations according to Table 5.

To begin, the title and summary were reviewed to locate the algorithm proposed in the document and classify them according to six different types of solution methods, as seen in Fig. 7. The algorithm with the highest participation in the documents is the exact algorithm, with 9 articles and a percentage of 45%, followed by the hybrid algorithm, with 35%, and 7 documents.

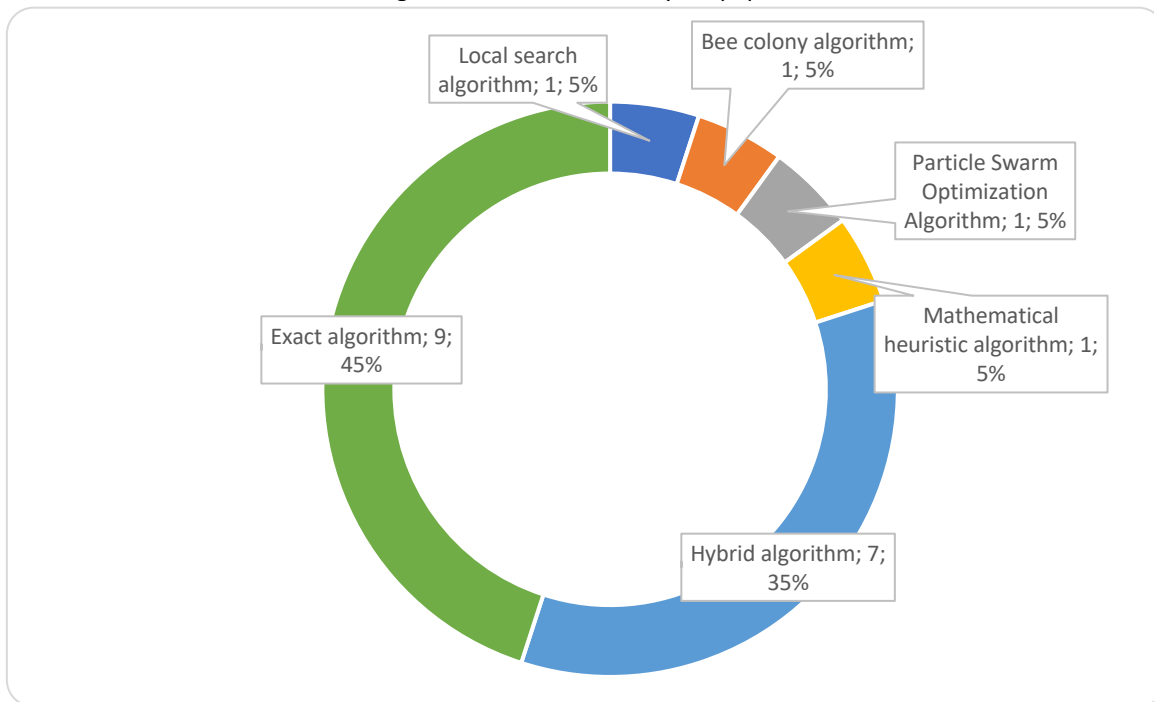
Since algorithms are executed computationally, it is necessary to identify the programming language and the characteristics of the computer equipment. Fig. 8 shows the programming languages used in the documents selected for review and the percentage of participation. C++ compiler was the most common since it was used 50% of the publications, followed by C, with 20% and 4 documents. Java was used in the 2018 publication, which comprised 10% of the publications.

Table 5
Selected documents and relevant information

N°	Title	Author	Year	Country	Document Type	Organization	Sources	Times Cited
1	A branch and bound algorithm for the capacitated vehicle-routing problem	Laporte G, Nobert Y	1983	Canada	Article	Tsing Hua Univ	Mathematical programming	30
2	An integer L-shaped algorithm for the capacitated vehicle routing problem with stochastic demands	Laporte G, Louveaux F, van Hamme L	2002	Belgium Canada	Article	Curtin Univ Technol	Operations research	107
3	A new branch-and-cut algorithm for the capacitated vehicle routing problem	Eglese RW, Letchford AN, Lysgaard J	2004	Denmark UK	Article	Bogazici Univ Galatasaray Univ	Operations research	162
4	An exact algorithm for the capacitated vehicle routing problem based on a two-commodity network flow formulation	Baldacci R, Haqiqi Constantinou E, Mingozzi A	2004	Italy UK	Article	Univ Tecn Federico Santa Maria	Transportation science	92
5	A branch-and-cut algorithm for the capacitated open vehicle routing problem	Eglese RW, Letchford AN, Lysgaard J	2007	Denmark UK	Article	Liaoning Univ Sci & Technol	Computers & operations research	39
6	Applying hybrid meta-heuristics for capacitated vehicle routing problem	Lee CY, Lee ZJ, Lin SW, Ying KC	2009	Taiwan	Article	Univ Zagreb	Networks	43
7	Edge Assembly-Based Memetic Algorithm for the Capacitated Vehicle Routing Problem	Braysy O, Nagata Y	2009	Finland Japan	Article	Zhejiang Univ Tech	Journal of the operational research society	43
8	Particle swarm optimization and two solution representations for solving the capacitated vehicle routing problem	Ai TJ Kachitvichyanukul V	2009	Thailand	Article	Univ Zagreb	Or spektrum	71
9	An effective memetic algorithm for the cumulative capacitated vehicle routing problem	Calvo RW, Nogueveu SU, Prins C	2010	France	Article	Univ Nacl Patagonia Austral	Expert systems with applications	68
10	The SR-GCWS hybrid algorithm for solving the capacitated vehicle routing problem	Barios B, Caballe S, Faulin J, Juan AA, Ruiz R	2010	Spain	Article	City Univ Hong Kong Shanghai Jiao Tong Univ	Applied soft computing	40
11	A new Hybrid Electromagnetism-like Algorithm for capacitated vehicle routing problems	Emel E, Yurtkuran A	2010	Turkey	Article	Univ Paris 13 Univ Technol Troyes	Expert systems with applications	58
12	An artificial bee colony algorithm for the capacitated vehicle routing problem	Ho SC, Szeto WY, Wu YZ	2011	Denmark China	Article	Panyapiwat Inst Technol Tatung Univ	Networks	129
13	The Two-Echelon Capacitated Vehicle Routing Problem: Models and Math-Based Heuristics	Perboli G, Tadei R, Vigo D	2011	Canada Italy	Article	Csiro Unsw Adfa	Computers & industrial engineering	78
14	An adaptive large neighborhood search heuristic for the cumulative capacitated vehicle routing problem	Laporte G, Ribeiro GM	2012	Brazil Canada	Article	HEC Montreal Natl Univ Def Technol	Computers & operations research	64
15	An Exact Algorithm for the Two-Echelon Capacitated Vehicle Routing Problem	Baldacci R, Clavo RW, Mingozzi A, Roberti R	2013	France Italy	Article	Univ Fed Minas Gerais	Operations research	32
16	A branch-and-cut-and-price algorithm for the cumulative capacitated vehicle routing problem	Lysgaard J, Wohlk S	2014	Denmark	Article	Aarhus Univ	European journal of operational research	21
17	A novel membrane algorithm for capacitated vehicle routing problem	He JJ, Niu YY, Wang S, Xiao JH	2015	China	Article	Huazhong Univ Sci & Technol Nankai Univ Peking Univ	Soft computing	14
18	Mathematical formulations and exact algorithm for the multitrip cumulative capacitated single-vehicle routing problem	Afsar HM, Prins C, Rivera JC	2016	Colombia France	Article	Univ EAFIT Univ Technol Troyes	European journal of operational research	10
19	Solving the battery swap station location-routing problem with capacitated electric vehicles using an AVNS algorithm for vehicle-routing problems with intermediate stops	Goeke D, Hof J, Schneider M	2017	Germany	Article	Rhein Westfal TH Aachen TU Kaiserslautern	Transportation research part b-methodological	9
20	A branch-and-cut algorithm for the two-echelon capacitated vehicle routing problem with grouping constraints	Lim A, Liu T, Luo ZX, Qin H	2018	China Singapore	Article	Dongguan Univ Technol Huazhong Univ Sci & Technol Nanjing Univ Natl Univ Singapore	European journal of operational research	0

Source: Authors

Fig. 7
Algorithms found into analyzed papers

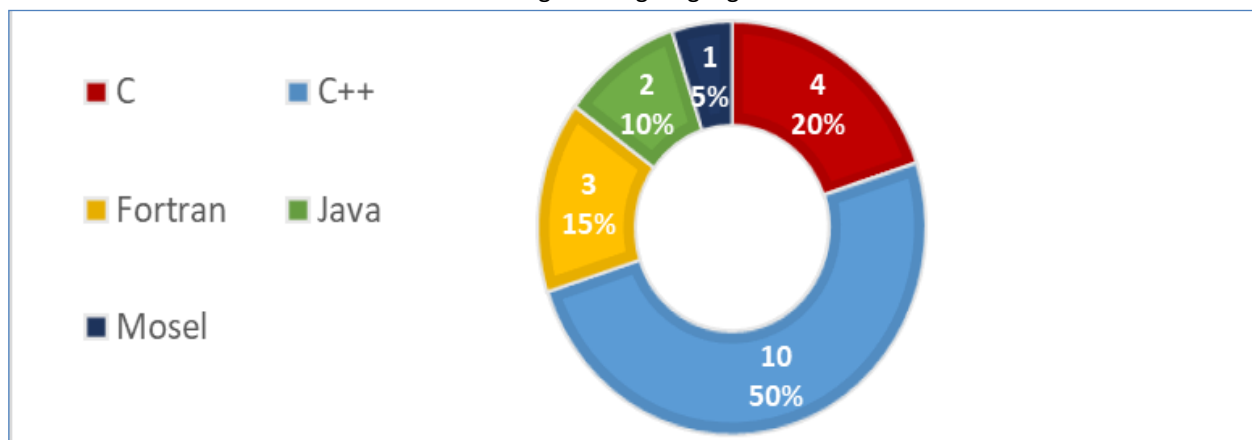


Source: Authors

According to Deitel & Deitel (2003), C ++ is composed of C language and Simula. This was to improve structured programming and include technology object-oriented programming. Another advantage of this development is that it can be applied in particular areas and generate code that can be reused. In conclusion, Deitel & Deitel report that one of the advantages of C ++ and Java is: “Object-oriented programming tends to produce software that is more understandable, better organized and easier to maintain, modify and correct” Deitel & Deitel (2003).

According to Table 6 shows the selected compiler in each research, it must choose the characteristics that the equipment on which the code is to be executed must comply.

Fig. 8
Programming languages



Source: Authors.

As can be seen in Table 6, the Intel processor is the most used, because Intel has a high market share, and, together with AMD, is one of the companies with the highest sales among the manufacturers of processors and

microprocessors according to Maycotte (2016). The Intel R&D team is interested in offering products with better characteristics (electricity use, refrigeration, compatibility, among others) and to market updates of their products more frequently than its competitors. Additionally, Intel leads the niche market in desktop computers and its products are low cost.

According to Table 6, another important feature to evaluate is the computer's RAM since the greater the amount of memory, the faster the execution of the program becomes. As we have mentioned, the articles studied have been analyzed from 1983 to 2018, for this same reason, the oldest items were made with computers with much smaller RAM than the types of memory on computers in recent years. Logically, over time the memory capacity of computers has evolved from 256 MB to 16 GB.

Table 6
Characteristics of the computer equipment and programming languages

N°	Title	Programming language	Hardware
1	A branch and bound algorithm for the capacitated vehicle-routing problem	Fortran	University of Montreal CYBER 173 computer
2	An integer L-shaped algorithm for the capacitated vehicle routing problem with stochastic demands	C ++	Not mentioned
3	A new branch-and-cut algorithm for the capacitated vehicle routing problem	C ++	Computer equipped with an Intel Celeron 700 MHz processor and 256 MB of RAM, running on Microsoft Windows 98.
4	An exact algorithm for the capacitated vehicle routing problem based on a two-commodity network flow formulation	Fortran	IBM computer equipped with a 933 MHz pentium III processor.
5	A branch-and-cut algorithm for the capacitated open vehicle routing problem	C ++	Computer equipped with an Intel Pentium M 1,6 GHz processor and 512 MB of RAM, running on Microsoft Windows XP.
6	Applying hybrid meta-heuristics for capacitated vehicle routing problem	C	Computer equipped with an Intel Pentium IV 2,8 GHz processor and 1024 MB of RAM.
7	Edge Assembly-Based Memetic Algorithm for the Capacitated Vehicle Routing Problem	C ++	Single-processor 3.2 GHz Xeon computer with 1 GB of RAM.
8	Particle swarm optimization and two solution representations for solving the capacitated vehicle routing problem	C	Computer equipped with an Intel Pentium IV 3,4 GHz processor and 1 GB of RAM.
9	An effective memetic algorithm for the cumulative capacitated vehicle routing problem	C	Computer equipped with an Intel Pentium D 3,4 GHz processor and 1 GB of RAM, running on Microsoft Windows XP.
10	The SR-GCWS hybrid algorithm for solving the capacitated vehicle routing problem	Java	Computer equipped with an Intel Core 2 Duo 2.4 GHz processor and 2 GB of RAM.
11	A new Hybrid Electromagnetism-like Algorithm for capacitated vehicle routing problems	C ++	Computer equipped with an Intel Core 2 Duo 2 GHz processor and 2 GB of RAM.
12	An artificial bee colony algorithm for the capacitated vehicle routing problem	C ++	Computer equipped with 1,73 GHz processor.
13	The Two-Echelon Capacitated Vehicle Routing Problem: Models and Math-Based Heuristics	Mosel	Computer equipped with an Intel Pentium 3 GHz processor and 1 GB of RAM

N°	Title	Programming language	Hardware
14	An adaptive large neighborhood search heuristic for the cumulative capacitated vehicle routing problem	C ++	Computer equipped with an Intel Pentium Core 2 Duo 2 GHz processor and 3 GB of RAM running on Microsoft Windows.
15	An Exact Algorithm for the Two-Echelon Capacitated Vehicle Routing Problem	Fortran	IBM Intel Xeon X7350 server computer (2.93 GHz-16 GB of RAM).
16	A branch-and-cut-and-price algorithm for the cumulative capacitated vehicle routing problem	C ++	Computer equipped with an Intel Pentium Core 2 Duo (P8700) 2,53 GHz processor and 1,86 GB of RAM running on Microsoft Windows XP.
17	A novel membrane algorithm for capacitated vehicle routing problem	C	Computer equipped with an AMD 3500+ 2.21 GHz processor and 1 GB of RAM running on Microsoft Windows XP.
18	Mathematical formulations and exact algorithm for the multitrip cumulative capacitated single-vehicle routing problem	C ++	Computer equipped with an Intel Core i5 2,5 GHz processor and 4 GB of RAM running on Microsoft Windows 7 Professional.
19	Solving the battery swap station location-routing problem with capacitated electric vehicles using an AVNS algorithm for vehicle-routing problems with intermediate stops	C ++	Computer equipped with an Intel Core i7 2,8 GHz processor and 8 GB of RAM running on Microsoft Windows 7 Professional.
20	A branch-and-cut algorithm for the two-echelon capacitated vehicle routing problem with grouping constraints	Java	Dell computer equipped with an Intel Core i7-4790 3,6 GHz processor and 16 GB of RAM running on Microsoft Windows 7.

Source: Authors.

In the selected documents, it is reported in CVRP instances of literature can be found on websites such as:

- <http://www.branchandcut.org>
- <http://people.brunel.ac.uk/~mastjib/jeb/info.html>
- <http://mscmga.ms.ic.ac.uk/jeb/orlib/vrpinfo.html>
- http://www.or.deis.unibo.it/research_pages/OR_instances/OR_instances.html
- <http://neo.lcc.uma.es/vrp/vrp-instance>

Among the authors who proposed CVRP instances for the trained routing problem, stand out Christofides, Feliu, Crainic, Hemmelmayr, Nguèveu, Golden, Salehipour, Oppen, Lokketangen, Lysgaard, Fukasawa, Naddef, Rinaldi, Augerat, Mingozzi, Toth, Taillard, and Chen. In case any problem had no tested CVRP instances fulfilling the principle of optimality, or if it wanted to perform more tests, the proposed solution is compared with similar algorithms. Among the analyzed publications were those by Perboli, Tadei and Vigo, Jepsen, Spoorendonk and Ropke, Clarke and Wright, Fisher and Jaikumar and Christofides, and algorithms such as CMTE, GRASP VDN, and CPLEX.

According to the kind of algorithms used in the selected publications represented according to Fig. 7. It can be seen as a kind of algorithm exact algorithm, bee colony algorithm, local search algorithm, particle swarm optimization algorithm, hybrid algorithm, and mathematical heuristic algorithm among others.

Most of the documents using exact algorithms show that such algorithms can only solve small and medium objectives, that is, they can optimally solve very limited problems of CVRP, and, therefore, it can be inferred that it cannot be applied to real routing problems.

The next type of algorithms presented in Fig. 7 are hybridization and in this respect, it was found that hybrid algorithms are part of the metaheuristic technique, which allows combining local algorithms with global algorithms, for the approximation and optimization of solutions that heuristics cannot solve efficiently. In general, genetic and biological theories are used to simulate the problems to be treated.

In all possible combinations, the local algorithm most used is local search, and was present in four of the seven articles belonging to this type. Among the global algorithms, the following was found: simulated annealing, EAX crossover, Clarke and Wright heuristics, electromagnetism and ant colony, each one appearing only once.

According to Table 7, there were articles mentioned using memetic algorithms, independently of the coincidences presented. These articles are 1) "Edge Assembly-Based Memetic Algorithm for the Capacitated Vehicle Routing Problem", which unifies EAX crossover with local search, and 2) "An effective memetic algorithm for the cumulative capacitated vehicle routing problem", which uses evaluations not trivial of cost variations in the local search.

Within the publications analyzed in Table 7, the number of vertices or clients that were evaluated was taken into account. Five of the seven publications have clients amount equal to, or greater than 420; that is, the problem uses large CVRP instances to verify its performance of the algorithm. The article "An effective memetic algorithm for the cumulative capacitated vehicle routing problem" used up to 500 clients for its execution.

With the described procedure, we proceeded to discard the publications with 420 clients, which left two publications with 480 clients and one with 500 clients. The computational times of the two with 480 clients were compared, and one of them was discarded, due to its results according to Table 8.

Table 7
Comparison of the number of clients selected in the documents

Problem	Applying hybrid meta-heuristics for capacitated vehicle routing problem	Edge Assembly-Based Memetic Algorithm for the Capacitated Vehicle Routing Problem
50	524.61	524.61
75	835.26	835.26
500	826.14	826.14
150	1038.71	1028.51
199	1311.70	1293.93
120	1045.50	1042.11
100	819.56	819.56

Source: Authors.

Table 8
Comparison of the number of clients selected in the documents

Title	Year	Number Customer	Time
Edge Assembly-Based Memetic Algorithm for the Capacitated Vehicle Routing Problem	2009	480	1622.8
Solving the battery swap station location-routing problem with capacitated electric vehicles using an AVNS algorithm for vehicle-routing problems with intermediate stops	2017	480	1693.3

Source: Authors

The mentioned refinement processes resulted in two final publications, but they do not present similarities in any instance, and, therefore, cannot be compared. These publications are shown according to Table 9.

Table 9
Articles with hybrid algorithms without comparison

N°	Title	Author	Year
1	Edge Assembly-Based Memetic Algorithm for the Capacitated Vehicle Routing Problem	Braysy O Nagata Y	2009
2	An effective memetic algorithm for the cumulative capacitated vehicle routing problem	Calvo RW Ngueveu SU Princs CU	2010

Source: Authors

According to Table 8, it can be seen that the two algorithms presented are memetic, therefore, this solution could be done with the best computational times in minutes. Memetic algorithms emerge at the same time as metaheuristic ones. Its objective is to combine different heuristic methods, including population-based search (evolutionary algorithms) and local optimization (gradient tracking techniques), and seeking to improve the solutions obtained by these techniques according to Moscato & Cotta (2003).

The development of this research culminates with the inference that hybrid algorithms are algorithms used to implement solutions close to the optimum, looking for an approximation to the application in real problems. For this, the memetic algorithm must be taken into account, including the local search algorithm, which is in fact, the most used.

4. Conclusions

The measurement of the literature developed on CVRP identified in this article evidences largely the use of exact algorithms and hybrid algorithms in this field of this research. This is also the future trend regarding the use of algorithm types in this topic of research. Likewise, China is identified as one of the countries with the highest number of publications over time, followed by Canada with an h index of eight in both cases.

On the other hand, according to the Web of Science Categories on CVRP, evidence of use was identified in 81% of the participation in categories such as Operations Research Management Science, Artificial Intelligence of Computer Sciences and Methods of Theory of Computing in the same order. This is also the future trend regarding the use of categories in this field of research.

The bibliometric analysis determined the outstanding authors according to the total number of citations as shown in Table 4. These are Lysgaard, with a total of 277, and Laporte, with 273. Analysis of the networks shows that co-authorship is not dynamic and that the most relevant clusters within are made up of 6 authors.

The main journals that publish articles related to this topic within engineering disciplines (more exactly, industrial engineering) are: Expert Systems with Applications, Computers & Industrial Engineering and Operations Research Letters, and they are also the ones with the greatest impact, because they are located in the first quartile (Q.1).

The exact algorithms present optimal results when evaluated in small and medium CVRP instances, but they tend to take a long time in the process of solving problems with more data. This means that they are used to a greater extent with non-practical or non-real cases. It could be inferred that they are employed in order to create new CVRP instances of the problem.

Branch and Cut, Lagrangian relaxation/column generation, and a hybrid approach called Branch and Cut and Price stands out at using exact algorithms for the CVRP problem, optimally solving instances of the literature of up to 135 clients. However, many CVRP problems with 75 clients cannot be solved with the exact best solution methods, leading to the development of different heuristic, metaheuristic and hybrid algorithms to solve problems in real cases that consider a greater number of clients and where quality is evaluated of the solution reached with respect to a lower limit and the calculation time required to obtain the solution.

The hybridizations used for the CVRP solution are characterized by using a local and global algorithm, in such a way that the combination of these methods generates optimal results and, according to the evaluated instance. The computational times are reasonable, and thus it can be used in real cases, for example, the collection of waste, the transport of milk, couriers and school transport.

It is suggested to perform the coding in C++ or Java, since they include object-based technology in structured programming, allowing sequential codes that are easily understood and possibly modified. Additionally, these languages can be used in computers with Intel processors and microprocessors, which offer good performance in the execution of the algorithm.

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