AUSUD
BANDIRMA ONYEDİ EYLÜL ÜNİVERSİTESİ
JITSA

Research Article

A bibliometric analysis of publications related to dynamic vehicle routing problems

Mustafa DEMİRBİLEK*
Department of Industrial Engineering, Faculty of Engineering and Natural Sciences, Gaziantep Islam Science and Technology University, Gaziantep, Turkey
*Correspondence: mustafa.demirbilek@gibtu.edu.tr
DOI: 10.51513/jitsa.1230420

Abstract: Dynamic Vehicle Routing Problems (DVRP) have been highly studied by researchers and decision-makers for the last couple of decades with the effect of developments in GPS and mobile digital tools. Particularly, the digital transformation in logistic and supply chain activities under Industry 4.0 paradigm provides a more suitable environment for DVRP applications. In this study, we conduct a bibliometric analysis related to studies in the DVRP area to understand relationships among publications in terms of countries, institutions, citations, journals, authors, etc., and to show related information and possible trends to the current and prospective researchers and decision-makers. A total of 831 articled retrieved from the Scopus database are examined for the analysis. As a result, the highest number of studies are published by researchers in China while the most impactful studies in terms of citations are carried out by researchers affiliated with US institutions. DVRPs have been frequently studied in Industrial/System Engineering and Management Schools whereas journals in transportation science and operations research/industrial engineering have mostly published DVRP studies. From the application side, ride-sharing, ride-hailing, and crowdsourced delivery appear as new trends for DVRPs in terms of co-occurrence analysis. On the other hand, heuristic and metaheuristic solution approaches frequently co-occur with DVRPs.

Keywords: Dynamic Vehicle Routing Problem, Bibliometric Analysis, Industry 4.0

Dinamik araç rotalama problemleriyle ilgili çalışmaların bibliyometrik analizi

Özet: Son birkaç on yılda, küresel konumlama sistemleri ve mobil dijital araçlardaki gelişmelerin etkisiyle, Dinamik Araç Rotalama Problemi (DARP), araştırmacılar ve karar vericiler tarafından önemli oranda çalışmaya başlanmıştır. Özellikle tedarik zinciri yönetimi ve lojistik alanlarındaki Endüstri 4.0 paradigmasının getirdiği dijital dönüşüm DARP uygulamaları için daha uygun bir ortam sağlamıştır. Bu çalışmada, ülke, enstitü, dergi, yazar, atıf gibi kriterlere bakarak bu alanda yazılan makaleler arasındaki ilişkileri anlamak ve bu konuyla ilgili araştırmacılara ve karar vericilere bilgi vermek adına bibliyometrik analiz yapılmıştır. Bu kapsamda Scopus veri tabanından bulunan 831 adet makale incelenmiştir. Sonuç olarak bu alanda en fazla makalenin Çin'de yayınlandığı, diğer taraftan atıf bazında en etkili makalelerin Birleşik Devletler' de çalışan araştırmacılar tarafından yapıldığı ortaya çıkmıştır. DARP çalışmalarının en fazla üniversitelerin endüstri/sistem mühendisliği ve yönetim bölümleri tarafından gerçekleştirildiği, diğer taraftan ulaşım bilimleri ve yöneylem araştırmaları/endüstri mühendisliği alanlarında çıkan dergilerde yayınlandığı görülmüştür. Uygulama tarafında, paylaşımlı biniş, çevrimiçi kısa süreli özel araç kiralama gibi konuların DARP alanında yeni eğilimler olduğu görülmüştür. Diğer yönden, sezgisel ve metasezgisel metotların DARP çalışmalarında sıklıkla kullanıldığı tespit edilmiştir.

Anahtar Kelimeler: Dinamik araç rotalama problemi, bibliyometrik analiz, endüstri 4.0

ORCID: 0000-0002-1520-2882
Received 06.01.2023; accepted 06.07.2023
Peer review under responsibility of Bandirma Onyedi Eylul University.
Licence CC BY NC 4.0

1. Introduction

Vehicle Routing Problem (VRP) first appeared in the literature with the study of Dantzig and Ramster (1959), entitled "The Truck Dispatching Problem". They attempted to minimize the number of tankers carrying fuel from a central depot to several stations in a region. Many studies considering different variants of VRP such as time windows, stochastic service and travel times, the capacity of vehicles, simultaneous pickup, and delivery, etc. as well as different solution strategies such as integer, mixed integer linear, stochastic programming, genetic algorithms, simulated annealing, tabu search, ant colony optimization, etc. have been carried out since then (Demirbilek, 2021b; Laporte, 2009; Koç and Laporte, 2018). Not only different variants and solution methodologies have been proposed, but also VRPs have been applied in a variety of areas such as homecare (Demirbilek et al., 2021; Fikar and Hirsch, 2017), ambulance management (Talarico et al., 2015; Tlili et al., 2017), patrol management (Dewinter et al., 2020), courier (Chang and Yen, 2012; Ulmer et al., 2017), waste collection (Han and Ponce-Cueto, 2015), etc.

One of the most important extensions of VRP is the Dynamic VRP (DVRP). Before going deeper into DVRP, one must understand what the Static, Deterministic, and Stochastic VRP are:

Static: The problem does not consider any dynamic changes, such as new customer requests or vehicle breakdowns, during the planning and execution of routes. The problem assumes that all the necessary information is available upfront.

Deterministic: The problem assumes that all parameters, including travel times, distances, customer demands, and vehicle capacities, are known with certainty and do not involve any randomness or uncertainty.

Stochastic: The problem incorporates uncertainty in various parameters, such as travel times, customer demands, or vehicle capacities. These parameters are assumed to be random variables with probability distributions, and their specific values are not known with certainty in advance.

It is assumed that all related data such as customer requests, locations, demands, etc. are known before the execution of optimization begins in the Static VRP (Demirbilek, 2021a). However, some data are most likely revealed when the current schedules are already being executed in real-life problems. This is where the dynamism issue is taken into consideration. In the Dynamic VRP, routes of vehicles should be flexible enough in such a way that they can answer new customers, demands, or changings in previous demands. Dynamic problems can sometimes involve deterministic elements, while other times they can involve stochastic elements. Therefore, some problems are classified as Dynamic and Deterministic VRPs while some are called as Dynamic and Stochastic Problems. Stochastic elements deal with uncertainty in VRP while dynamic elements involve time-dependent changes in the problem parameters. Stochastic conditions arise from various factors such as unpredictable travel times, customer demand fluctuations, or vehicle breakdowns. On the other hand, dynamic conditions can be new customer requests, cancellations, or real-time updates on traffic conditions. Dynamic problems consist of some Studies in DVRPs started in the late 70s not too later than the first VRP studies. Studies of Wilson and Colvin (1977) and Psaraftis (1980) can be shown as examples of the first DVRP studies. DVRPs did not attract many researchers` attention due to the absence or insufficiency of necessary technologies such as global positioning systems (GPS), PCs, mobile phones, business models, etc. (Ojeda Rios et al., 2021). However, DVRP studies have been increasing since the beginning of the new millennia thanks to not only outstanding development in the technology of GPS, mobile phones/PCs, management of business models such as ERP and CRP, data collection methods and process algorithms, but also new application areas raised from changings in demand of customers including same day delivery (Voccia et al., 2019), ride-sharing (Agatz et al., 2012), ride-hailing (Feng et al., 2020), and crowdsourced delivery (Arslan et al., 2019). Particularly, fast developments in Industry 4.0 requiring mobility and real-time integration make DVRP and solutions methods more important day by day (Abdirad et al., 2020). Therefore, studies in DVRP have significantly increased recently. Before 2000, while only two review studies were conducted (Dial, 1995; Gendreau and Potvin, 1998), many review studies have been observed after 2000 (Ghiani et al., 2003; Larsen et al., 2002; Larsen et al.,

2008; Ichoua et al., 2007; Ojeda Rios et al., 2021; Pillac et al., 2013a; Rios et al., 2021; Ritzinger et al., 2016; Toth et al., 2015). These review studies categorized existing DVRP studies based on the evolution and quality of information, solution methods, objectives, constraints, and accepting/rejecting options.

Bibliometric analysis studies provide researchers to review a substantial amount of knowledge in a specific area in a relatively short time. These studies show relationships between authors, citations, institutions, and countries as well as recent trends in a specific topic. Bibliometric analysis studies have been conducted in many areas such as a journal evaluation (Martínez-López et al., 2018), economics (Bonilla et al., 2015), tsunami research (Chiu and Ho, 2007), occupational health and safety (Demirbilek and Özulukale Demirbilek, 2022), knowledge management (Gaviria-Marin and Baier-Fuentes, 2019), and etc. for long years. Although good review studies already exist as mentioned above, we cannot find a bibliometric analysis study for DVRPs. To be able to fill this gap, we present the bibliometric analysis of DVRPs to demonstrate researchers and interested readers in the area to the most influential authors, institutions, and countries involved in DVRP studies, the most cited publications and journals, and the most recent trends in the field. In this study, we used the VOSviewer software developed by van Eck and Waltman (Van Eck and Waltman, 2010) to carry out the bibliometric analysis and mapping. VOSviewer software provides different mapping types such as label, density, cluster-density and scatter and they help readers to easily interpret relationships between examined factors. Distance-based maps supported by VOSviewer software show the strength of relationships among nodes. Smaller distances indicate strong relations whereas longer distances demonstrate weak relationships among nodes.

2. Methodology

2.1. Data Source

Examined publications in this study were retrieved from the Scopus database in November 2021. The search inquiry covered “dynamic routing AND vehicle”, “online routing AND vehicle”, “dynamic traveling”, “dynamic vehicle routing”, “vehicle routing AND real-time”, “real-time AND traveling salesman”, “real-time AND traveling salesperson”, “online traveling”. The keywords were searched in titles, abstracts, and keywords of the publications. According to the search, a total of 1793 documents were accessed. The distribution of documents is shown in Figure 1. Note that we only consider 831 articles in this study. The citation and bibliographical information, abstract and keywords, funding details, and other related data were imported as a CSV file.

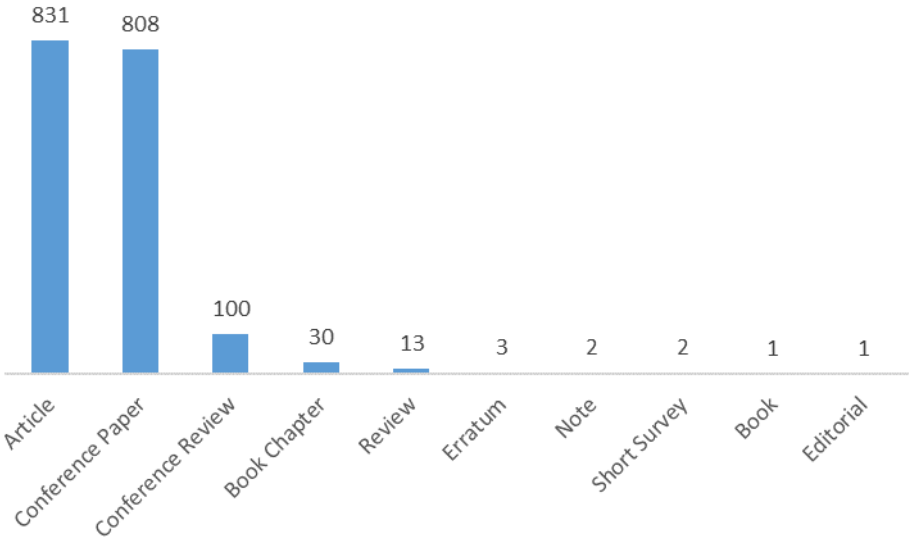

Figure 1. The distribution of documents

2.2. Bibliometric Analysis and VOSviewer Software

Bibliometric analysis is a quantitative approach to the study of scholarly publications that involves analyzing patterns of publication, citation, and authorship. The term "bibliometrics" is derived from the Greek words "biblio," meaning book, and "metrics," meaning measurement. The goal of bibliometric analysis is to use statistical and mathematical methods to uncover patterns in the production, dissemination, and impact of scholarly literature.

Bibliometric analysis can be used to study a wide range of scholarly outputs, including journal articles, books, conference proceedings, patents, and even social media posts. By analysing bibliographic data, researchers can identify patterns of research activity, influential authors and publications, and emerging areas of research (Bornmann and Leydesdorff, 2014).

There are several commonly used bibliometric indicators, including citation counts, h-index, and journal impact factor. Citation counts measure the number of times a particular publication has been cited by other scholars. The h-index is a measure of an author's productivity and impact, calculated based on the number of papers they have published and the number of citations they have received. The journal impact factor is a measure of a journal's influence, calculated based on the number of citations its articles have received in a given period (Van Eck and Waltman, 2017).

Bibliometric analysis can be used for a variety of purposes, such as evaluating the impact of research programs, identifying potential collaborators or competitors, or monitoring trends in research activity over time. It is a valuable tool for researchers, administrators, and funding agencies seeking to understand the landscape of scholarly communication and to make informed decisions about research funding, collaboration, and dissemination (Kumar and Rathi, 2019).

VOSviewer is a free software program for constructing and visualizing bibliometric networks. It is widely used for conducting bibliometric analysis, which involves the statistical analysis of publications to identify patterns of research activity, influential authors, and key research topics (Van Eck and Waltman, 2017). VOSviewer works by analysing bibliographic data in various formats, including bibliographic databases such as Web of Science, Scopus, and PubMed. The program uses co-citation and co-authorship analysis to identify the relationships between publications, authors, and institutions. Co-citation analysis involves identifying two or more publications that are cited together in a third publication, indicating a relationship between the cited publications. Co-authorship analysis involves identifying two or more authors who have collaborated on a publication, indicating a relationship between the authors (Waltman et al., 2010). Once the bibliographic data is analysed, VOSviewer creates a visualization of the bibliometric network. The visualization can be customized to display different aspects of the network, such as the number of publications, the number of citations, or the number of authors. The program also provides tools for clustering and mapping the network, making it easier to identify research clusters and patterns (Chen, 2017).

One of the strengths of VOSviewer is its ability to handle large amounts of bibliographic data. The program can analyse tens of thousands of publications and hundreds of thousands of citations, making it suitable for large-scale bibliometric studies. Additionally, VOSviewer is user-friendly and provides a range of visualization options, making it accessible to researchers without extensive programming experience.

3. Results and Discussions

3.1. Yearly Distribution and Growth Trend

Reviewing the number of studies published on year basis provides a good estimation for future trends in a specific area. The number of studies published since 1977 is shown in Figure 2. Only 15 studies were published until 1990 while the number of publications was around 40 between 1990 and 2000. As we discussed previously, developments in internet and GPS technologies increased and they started to be used by individuals and companies more commonly in the 90s. This might explain why 40 studies were published in only ten years while there were only 15 studies in the previous 23 years. There was a significant incline in the number of studies after 2000. The average number of studies published year basis between 2001 and 2006 was 12. The number of DVRP studies published each year has been more

than 30 since 2007 except in 2011, only 21 studies were carried out. The number of publications related to DVRP has skyrocketed in the past two years. Seventy-eight studies were conducted in 2020 while 92 studies have been published till November 2021. These numbers are much higher than the ten-year average number of 55. As we discussed earlier, Industry 4.0 has been significantly affecting manufacturing systems and related logistics and supply chain activities. Particularly, interconnected activities, real-time event handling, and decision-making have gained importance with Industry 4.0 together. Furthermore, online shopping has remarkably increased during the COVID-19 pandemic. Dynamic requests of customers and simultaneous pick-up and delivery activities are also important issues to handle. Since DVRP covers the aforementioned issues, it is quite reasonable that the number of DVRP studies has raised significantly compared to previous years.

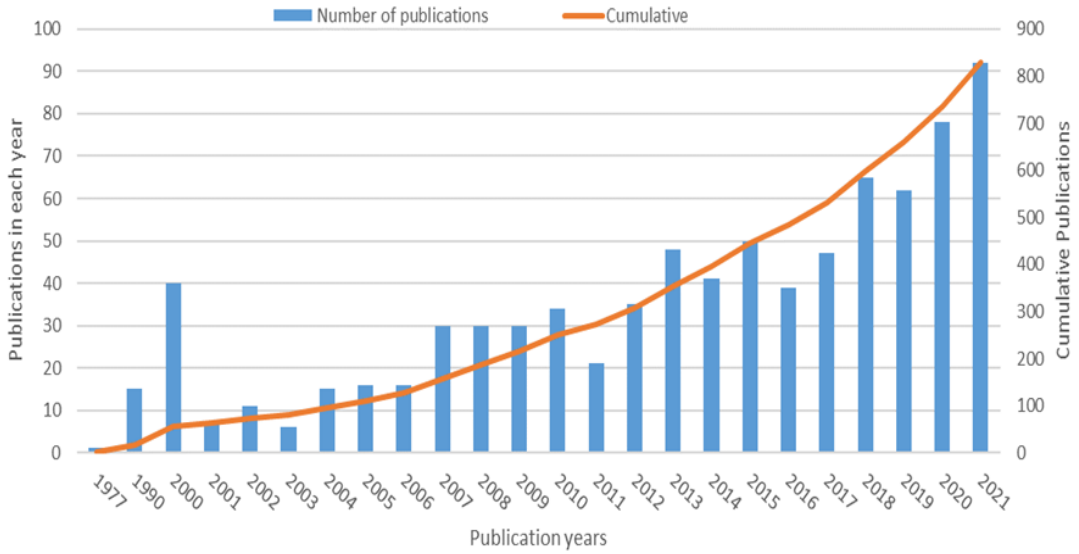

Figure 2. The number of articles published since 1977

3.2. Distribution of Publications on a Country Basis

A total of 831 studies were carried out from 64 countries while the origin country of 29 publications was not identified. The highest number of studies were conducted in China (20.2% of all studies) while the US was ranked the second with 206 out of 831 studies. Germany and Canada were ranked third and fourth with 53 and 52 publications respectively in the DVRP area. Compared to the first two countries (approximately 40% of all studies carried out), only 10% of all publications were from these two countries. Following mentioned countries, the UK came with 35 studies while India and Italy shared the 6th rank with 34 publications. Subsequently, six countries published studies in the range of 20 and 29, in the following eleven countries, the number of published articles was in the range of 10 and 19, lastly, the number of countries that published between four and ten studies was 13. The remaining 26 countries contributed DVRP areas with 44 publications, 4.1% of all studies. The total number of studies contributed by each country was 1085. As we mentioned previously, the total number of published studies was 831. It meant that researchers from different countries collaborated to conduct and publish some DVRP studies. Approximately 60% of all studies were published in countries ranked in the first ten based on their nominal GDPs. This indicates that economically more developed countries have paid more attention to the DVRP area. It is not surprising that US and China have a significant number of studies on DVRP compared to the other countries when we consider giant US and China-based e-commerce and retail companies, such as Amazon and Alibaba, and related logistics and supply chain activities.

Although China had the greatest number of studies compared to the others, the total number of and average citations were relatively low. A total of 219 studies were cited 2808 times and the average citations per document were 12.8. On the other hand, a total of 206 studies conducted in the second-ranked US in Table 1 were cited 8333 times and the average citations per document were 40.5. Notably, Canada (average citations of 67.6), France (average citations of 82), Switzerland (average citations of

102.5), and Columbia (average citations of 181.3) were other countries in that published studies had high impacts in the DVRP area.

Links in Vosviewer software represent the number of connections among items. Total Link Strength (TLS) refers to the total number of connections of an item with others (Van Eck and Waltman, 2010). In other words, TLS represents a prediction of the collaboration of a country with others. The US had the highest collaborations compared to other countries according to Table 1. Following the US, Canada had a great number of collaborations with a TLS of 949. China, ranked number one in terms of the number of publications, placed third with a TLS of 551 as can be seen in Table 1.

Table 1. Countries that published more than three studies (* Due to its special administrative situation with China and distinct data in Vosviewer software, the data related to Hong Kong is shown separately in the table).

Countries	Number of Studies	Percentage (%)	Citations	Average Citation per Document	Nominal GDP	Total Link Strength
China	219	20.2	2808	12.8	2	551
US	206	19.0	8333	40.5	1	1165
Germany	53	4.9	1306	24.6	4	491
Canada	52	4.8	3515	67.6	9	949
UK	35	3.2	938	26.8	5	104
India	34	3.1	288	8.5	6	71
Italy	34	3.1	954	28.1	8	220
Spain	29	2.7	940	32.4	14	164
Taiwan	28	2.6	688	24.6	21	142
France	26	2.4	2133	82.0	7	390
Australia	21	1.9	705	33.6	12	112
Hong Kong*	20	1.8	715	35.8	42	128
South Korea	20	1.8	371	18.6	10	58
Singapore	19	1.8	373	19.6	41	58
Japan	18	1.7	356	19.8	3	49
Netherlands	18	1.7	793	44.1	17	104
Brazil	16	1.5	310	19.4	13	214
Greece	14	1.3	597	42.6	54	194
Turkey	13	1.2	207	15.9	20	102
Austria	12	1.1	202	16.8	28	100
Malaysia	12	1.1	225	18.8	38	16
Switzerland	11	1.0	1127	102.5	18	243
Morocco	10	0.9	31	3.1	62	78
Poland	10	0.9	113	11.3	22	81
Iran	10	0.9	187	18.7	26	84
Denmark	9	0.8	670	74.4	37	301
Norway	8	0.7	385	48.1	31	97
Sweden	7	0.6	415	59.3	23	12
Thailand	7	0.6	56	8.0	25	15
Pakistan	6	0.6	74	12.3	48	0
Russia	6	0.6	23	3.8	11	0
Chile	5	0.5	60	12.0	45	38

Table 1 (Continue). Countries that published more than three studies (* Due to its special administrative situation with China and distinct data in Vosviewer software, the data related to Hong Kong is shown separately in the table).

Countries	Number of Studies	Percentage (%)	Citations	Average Citation per Document	Nominal GDP	Total Link Strength
Mexico	4	0.4	111	27.8	15	3
Belgium	4	0.4	283	70.8	24	52
Colombia	4	0.4	725	181.3	47	207
Portugal	4	0.4	27	6.8	51	77
Saudi Arabia	4	0.4	164	41.0	19	16
Israel	4	0.4	18	4.5	30	0
Other 26 Countries	44	4.1	613	13.9	…	156
Undefined	29	2.7	41	1.4	…	0

Figure 3 shows the country cooperation network on DVRP research. Countries in that at least three studies are published are taken into consideration. Moreover, Russia, Finland, Pakistan, Vietnam, and Israel are not considered since there are no research collaborations between those and other countries. The size of the circles demonstrates the number of publications, the larger circles, the more publications. The US had mostly collaborations with Germany, Greece, Italy, Mexico, Netherlands while Researchers from China collaborated with other researchers from Japan, Singapore, South Korea, Taiwan, Thailand, and Turkey. It is worth mentioning that most countries had strong collaborations with China, US, and Germany.

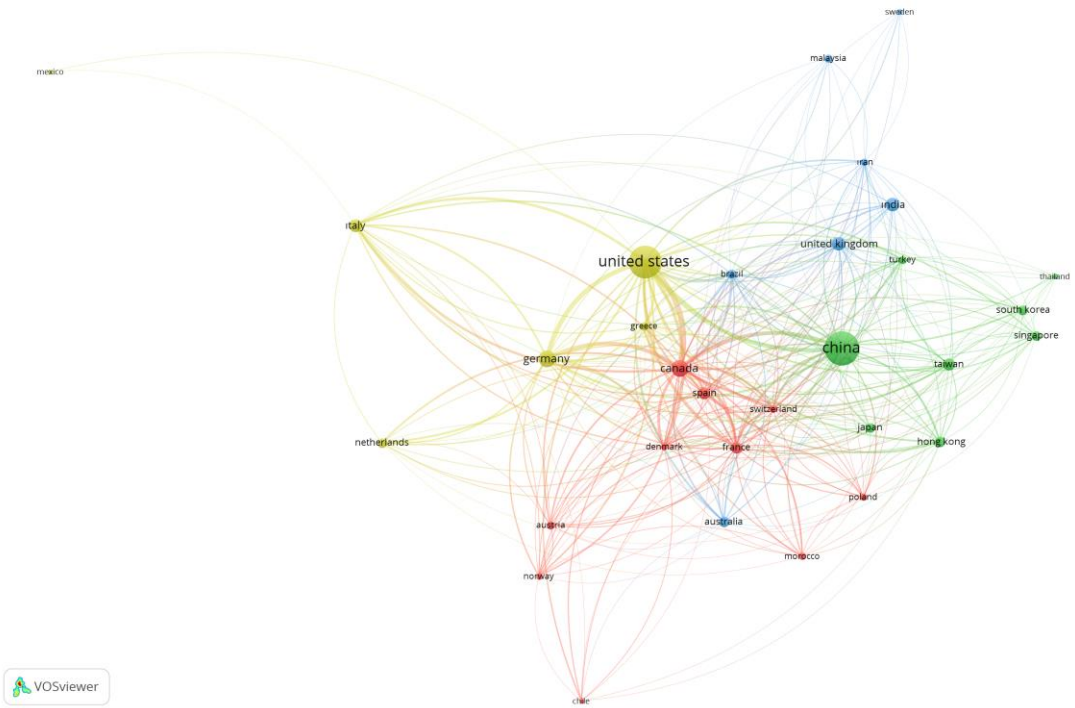

Figure 3. Country cooperation network on DVRP research (Countries in that at least three studies are published are taken into consideration. Moreover, Russia, Finland, Pakistan, Vietnam, and Israel are not considered since there are no research collaborations between those and other countries).

Table 2 shows the top institutions that published at least three studies with total citations, citations per document, and total link strengths. Unsurprisingly, H. M. Stewart School of Industrial and Systems

Engineering and Georgia Institute of Technology had the highest number of documents with School of Management, Xi'an Jiaotong University together. School of Industrial and Systems Engineering, Georgia Institute of Technology has been one of the top schools in Industrial and System Engineering area for long years. Since VRP and its variants have been commonly studied in Operations Research and Industrial Engineering communities, it is expected that one of the top universities in this area has a significant number of publications. Although Georgia Institute of Technology published the same number of documents as Xi'an Jiaotong University, their publications were cited considerably more than the publications of Xi'an Jiaotong University. Following these two institutions, University of Michigan published four studies with average citations of 52.8.

Table 2. Top organizations published at least three studies.

#	**Organization**	**Country**	**Documents**	**Citation**	**Citations per Document**	**Total Link Strength**
1	H. M. Stewart School of Industrial and Systems Engineering, Georgia Institute of Technology, Atlanta	United States	7	301	43	5
2	School of Management, Xi'an Jiaotong University, Xi'an	China	7	56	8	14
3	Department of Industrial and Operations Engineering, University of Michigan, Ann Arbor	United States	4	211	52.8	5
4	Laboratory for Information and Decision Systems, MIT, Cambridge	United States	3	528	176	2
5	Computer Science and Artificial Intelligence Laboratory, MIT, Cambridge	United States	3	493	164.3	2
6	Department of Civil and Urban Engineering, New York University, New York	United States	3	125	41.7	1
7	Department of Industrial and Systems Engineering, Hong Kong Polytechnic University, Hong Kong	China	3	118	39.3	2
8	Department of Civil and Environmental Engineering, MIT, Cambridge	United States	3	103	34.3	4
9	Department of Management, California State University, Hayward	United States	3	103	34.3	4
10	Technische Universität Braunschweig, Braunschweig	Germany	3	64	21.3	0
11	Department of Systems & Naval Mechatronic Engineering, National Cheng-Kung University, Tainan	Taiwan	3	59	19.7	0
12	Center for Control Dynamical Systems and Computation, University of California at Santa Barbara	United States	3	52	17.3	2
13	Department of Quantitative Methods, University of Brescia	Italy	3	48	16	0

Table 2 (Continue). Top organizations published at least three studies.

#	Organization	Country	Documents	Citation	Citations per Document	Total Link Strength
14	School of Traffic and Transportation, Beijing Jiaotong University, Beijing	China	3	25	8.3	1
15	Transportation Management College, Dalian Maritime University, Dalian	China	3	22	7.3	0
16	School of Economics and Management, Southwest Jiaotong University, Jiaotong	China	3	17	5.7	0
17	College of Computer Science, South-Central University for Nationalities, Wuhan	China	3	16	5.3	0
18	School of Economics and Management, Chongqing University, Chongqing	China	3	7	2.3	4

It is also worth mentioning that three different departments of MIT, Laboratory for Information and Decision Systems, Computer Science and Artificial Intelligence Laboratory, and Department of Civil and Environmental Engineering, were ranked fourth, fifth and eighth, respectively. If the ranking was made based on universities instead of institutions, MIT would be ranked the first with 9 publications, a total of 1124 citations, and average citations of around 377 per document. Lastly, US and China were the top countries whose institutions were highly specialized in the DVRP area.

3.3. Authors and Co-Authors Relationship

To be able to identify research groups that study particular research, authors and co-authors relationship analysis should be conducted. The only authors that published at least 8 studies are taken into consideration. Figure 4 shows six major research groups according to clustering and scores based on the publication years. The first research group we mention is the group of M. Ulmer, W. Thomas, and D. Mattfeld. M. Ulmer had the highest number of studies (number of documents = 18) as seen in Table 3. W. Thomas had 10 publications while 9 studies of D. Mattfeld had been published. In Figure 4, it seemed that W. Thomas mostly published their studies before Mattfeld and Ulmer. The average publication year of Thomas' studies was around 2016 while the average publication years of Mattfeld and Ulmer's studies were around 2019. M. Gendreau, M. Barkoaui, and J. Potvin had also a strong collaboration as seen in Figure 4. Although M. Gendreau ranked second in terms of the number of publications, he ranked first based on the total citations of 1509 and average citations per document of 137.2. High citation numbers could be raised from publication years. The average publication year of Gendreau's studies was around 2010 while Potvin's studies had total citations of 899 and the average citations per publication of 112.4, the second highest among all researchers, was around 2007. Y. Xu, H. Zhang, J. Zhang, and Z. Wang formed another important research group. Compared to the aforementioned groups, Y. Xu, H. Zhang, J. Zhang, and Z. Wang made more collaborations with other research groups. When considering earlier publication times and collaborations with J. Potvin, it could be said that Y. Xu worked with J. Potvin in the same group for a while and he formed his research group after that. The next research group that had active collaborations with other groups, was the group of X. Chen, J. Wang, and Y. Li. J. Wang had 10 publications while Y. Li had 6 and X. Chen had 5 publications as can be seen in Table 3. J. Wang published his studies much earlier than the other related fellows. X. Chen and Y. Li published approximately the same years. Moreover, X. Chen was interconnected with M. Ulmer and W. Thomas. It could be concluded that they focused on similar issues and applications on DVRPs and could collaborate in the near future.

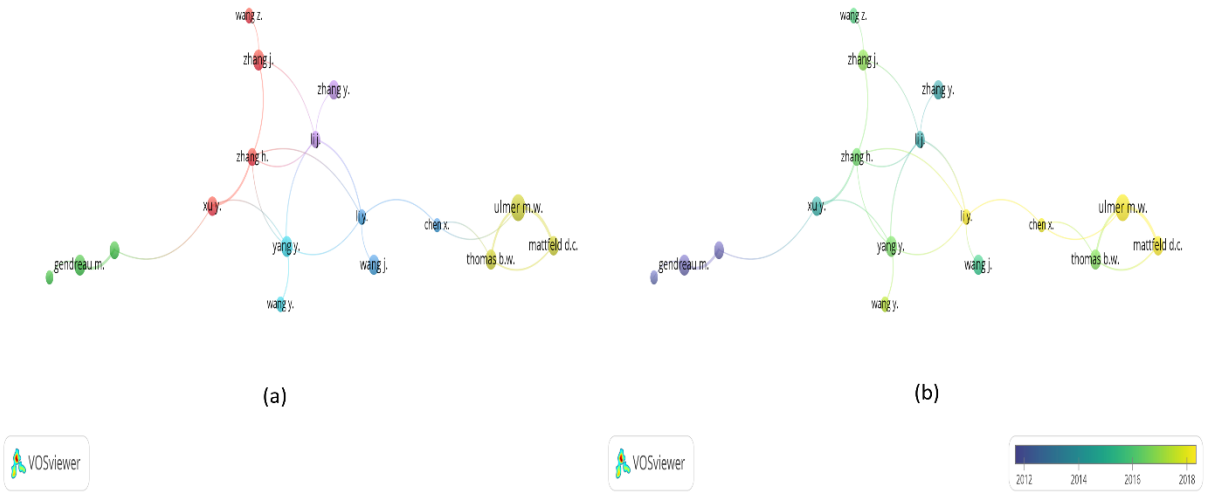

Figure 4. Six major research groups regarding clustering of authors and co-authors relationship (a) and scores based on the publication years (b).

Table 3. Authors published at least eight studies on DVRPs.

#	Author	Documents	Citation	Average Citations per Document	Total Link Strength
1	Ulmer M.W.	18	267	14.8	15
2	Gendreau M.	11	1509	137.2	6
3	Frazzoli E.	11	850	77.3	5
4	Yang Y.	11	146	13.3	2
5	Zhang J.	11	78	7.1	2
6	Thomas B.W.	10	302	30.2	8
7	Wang J.	10	171	17.1	0
8	Bullo F.	9	284	31.6	5
9	Zhang Y.	9	204	22.7	0
10	Xu Y.	9	191	21.2	6
11	Mattfeld D.C.	9	152	16.9	11
12	Potvin J.Y.	8	899	112.4	7
13	Jaillet P.	8	416	52	0
14	Zhang H.	8	79	9.9	7

3.4. Distribution and Source Relationship

Source relationship shows top journals published the related studies and the relationship based on the number of citations they have made to each other (Figure 5). Table 4 enlists top journals with the total and average citations per document, impact factors, and total link strengths. Only journals that at least eight and more studies on the DVRP area have been published are taken into consideration.

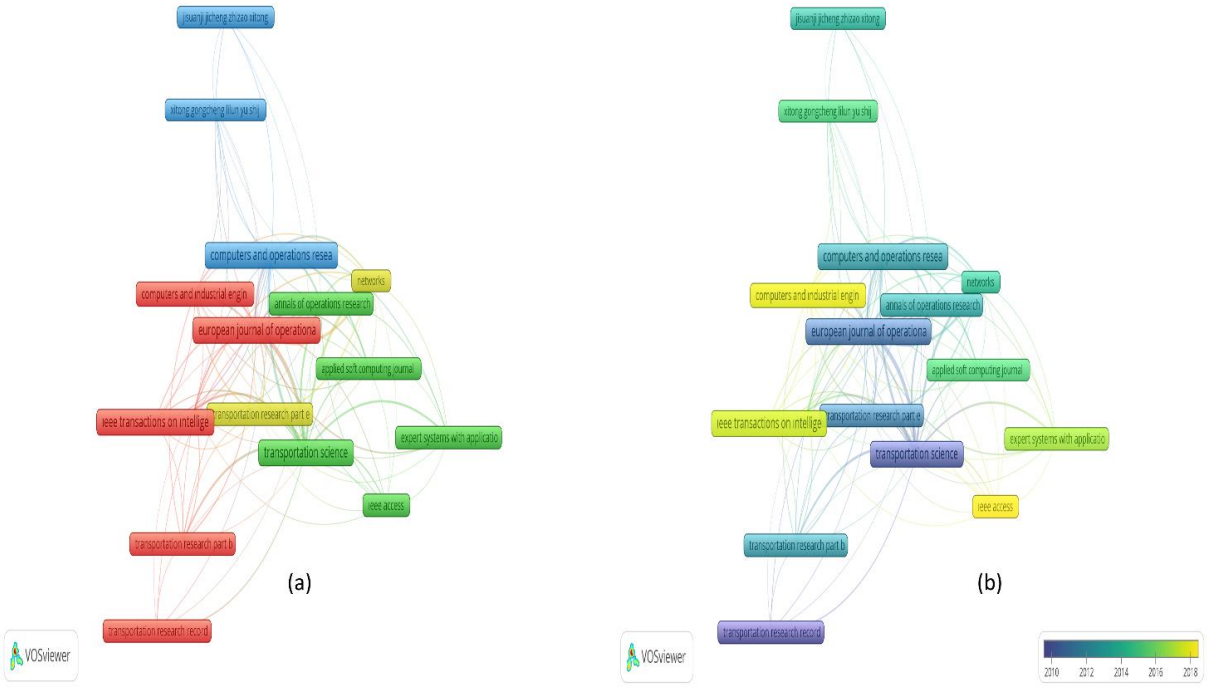

Figure 5. Source and citation relationship (a) and average publication years (b) for journals published at least eight studies related to DVRPs.

First, the DVRP studies were mostly published in journals related to transportation as expected. Moreover, four important journals in Industrial Engineering and Operations Research areas, European Journal of Operational Research, Computers and Operations Research, Computers and Industrial Engineering, and Annals of Operations Research, published almost 32% of all publications as can be seen in Table 4. It was also expected since developing solution methods for VRPs and variants have been highly popular in Industrial Engineering and Operations Research Community for long years. The journal published the highest number of documents related to DVRPs was IEEE Transactions on Intelligent Transportation Systems. Following this journal, Transportation Science, European Journal of Operational Research, and Computers and Operations Research ranked second, third and fourth with 27, 26, and 26 documents, respectively. However, European Journal of Operational Research and Computers and Operations Research seemed to have great impacts in terms of the average citations per document. One reason could be that the average publication years for studies in IEEE Transactions on Intelligent Transportation Systems was 2017 while it was 2011 for European Journal of Operational Research and 2012 for Computers and Operations Research. As can be seen in Figure 5, IEEE Transactions on Intelligent Transportation Systems, Computers and Industrial Engineering, and IEEE Access journal published more DVRP research recently. Based on the total link strength, it was also said that Transportation Science and European Journal of Operational Research were cited more from a variety of journals.

Table 4. Top journals in which eight and more studies have been published.

#	Source	Documents	Citations	Average Citations per Document	Impact Factor (2020)	Total Link Strength
1	IEEE Transactions on Intelligent Transportation Systems	28	1032	36.9	8.41	26
2	Transportation Science	27	1942	71.9	4.12	259
3	European Journal of Operational Research	26	2452	94.3	5.33	208
4	Computers and Operations Research	26	2391	92.0	4.01	139
5	Transportation Research Part C: Emerging Technologies	16	766	47.9	8.09	52
6	Computers and Industrial Engineering	14	329	23,5	5.43	61
7	Annals of Operations Research	13	789	60.7	2.58	83
8	Transportation Research Part B: Methodological	11	581	52.8	5.60	46
9	Transportation Research Part E: Logistics and Transportation Review	11	461	41.9	6.88	59
10	IEEE Access	11	105	9.5	3.37	21
11	Expert Systems with Applications	10	193	19.3	6.95	28
12	Transportation Research Record	10	156	15.6	1.56	13
13	Applied Soft Computing Journal	9	519	57.7	6.73	35
14	IEEE Transactions on Vehicular Technology	9	494	54.9	5.98	0
15	Networks	9	278	30.9	5.06	93
16	Xitong Gongcheng Lilun Yu Shijian	9	64	7.1	0.23	16
17	Jisuanji Jicheng Zhizao Xitong	8	58	7.3	0.89	9

3.5. Documents and Citations Relationship

Understanding documents and citation relationships is helpful to identify impactful studies that many other researchers have cited. Table 5 demonstrates publications cited at least 200 times by other studies. The review study of Pillac (2013) had the most citations compared to the other studies. The other review studies of Psaraftis (1995) and Berbeglia (2010) were highly cited as well. It could be expected that review studies had the highest number of citations. However, the study of Alonso-Mora (2017) had a considerable number of citations even though it proposed a mathematical model for a real-time high-capacity ride-sharing problem and was published later than the mentioned review studies. Moreover, it could be mentioned that the studies of Gendreau (1999) and Bent and Van Hentenryck (2004) proposed new solution methodologies for DVRPs had great impacts on the literature.

Table 5. Top studies cited at least 200 times.

#	Document	Author	Year	Citations	Links
1	Dynamic vehicle routing: Status and prospects	Psaraftis H.N.	1995	345	6
2	Drive: Dynamic routing of independent vehicles	Savelsbergh M.	1998	218	4
3	Parallel tabu search for real-time vehicle routing and dispatching	Gendreau M.	1999	298	7
4	Real-time vehicle routing: Solution concepts, algorithms and parallel computing strategies	Ghiani G.	2003	212	5
5	Scenario-based planning for partially dynamic vehicle routing with stochastic customers	Bent R.W.	2004	280	4
6	A dynamic vehicle routing problem with time-dependent travel times	Haghani A.	2005	233	2
7	Ant colony system for a dynamic vehicle routing problem	Montemanni R.	2005	270	4
8	Dynamic pickup and delivery problems	Berbeglia G.	2010	395	5
9	A review of dynamic vehicle routing problems	Pillac V.	2013	663	9
10	On-demand high-capacity ride-sharing via dynamic trip-vehicle assignment	Alonso-Mora J.	2017	428	2

3.6. Co-Occurrence Analysis (Keywords)

Figure 6 demonstrates the density visualization map based on the co-occurrence of keywords. The keywords that occurred at least 5 times in the studies are taken into consideration. Similar keywords such as “Heuristic Algorithm” and “Heuristic Algorithms” are detected and edited. The keyword, “Dynamic Vehicle Routing” and its variants quite occurred with other keywords as can be seen in Figure 6. Same-day delivery, logistics, real-time systems, dial-a-ride, etc. were closely related to DVRP keywords since DVRPs were applied in these areas. The keywords of heuristic, local search, tabu search, evolutionary algorithms, and genetic algorithm occurred with DVRPs since heuristic and metaheuristic algorithms were used frequently to solve DVRPs. On the other hand, machine and reinforcement learning methods started to be involved in DVRPs as new strategies.

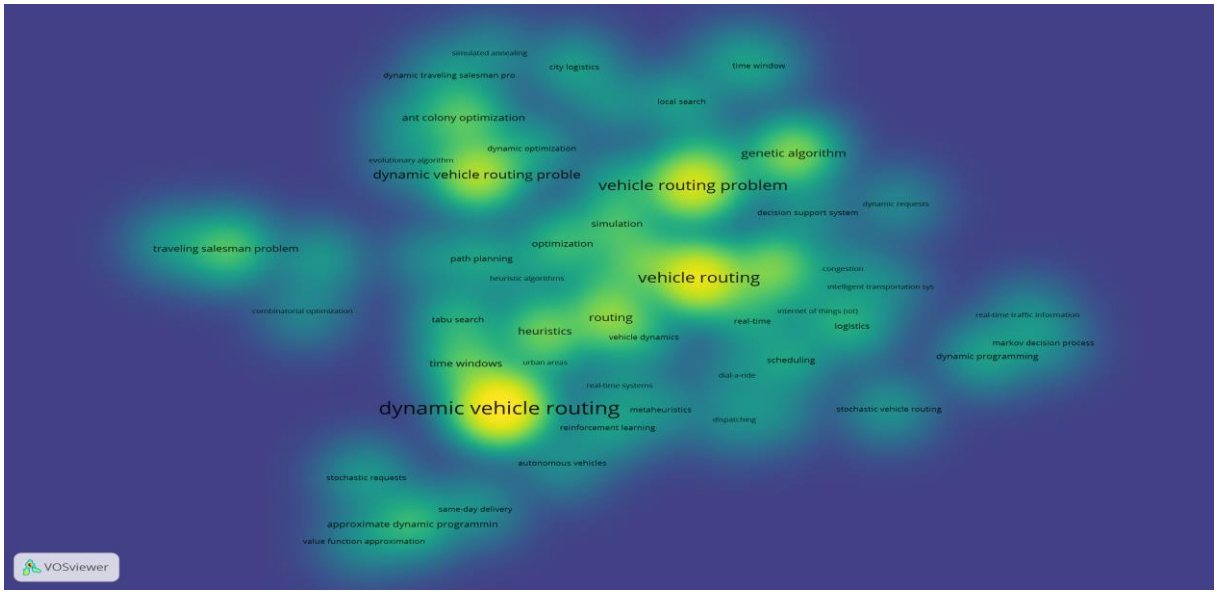

Figure 6. The density visualization map based on the co-occurrence of keywords.

4. Conclusion and Discussion

Dynamic Vehicle Routing Problems (DVRP) have attracted great attention for the last couple of decades since two important components of DVRP, GPS and mobile smart devices, have been significantly developed during this time. On the other hand, business models including DVRP applications such as ride-sharing, ride-hailing, and crowdsourced delivery are getting more popular day by day. Moreover, the ongoing pandemic for almost two years has changed supply chain and logistic activities to answer simultaneous and online data of requests and deliveries. Therefore, it can be expected that the applications and solutions in the DVRP area continue the inclining trend soon. To be able to understand the past studies, the top authors, the most important institutions, countries, etc., we conduct a bibliometric analysis related to DVRPs in this study. Bibliometric studies quite help researchers to understand a substantial amount of knowledge in a specific area in a relatively short time. These studies show relationships between authors, citations, institutions, and countries as well as recent trends in a specific topic.

VOSviewer software developed by van Eck and Waltman was employed to carry out the bibliometric analysis and mapping. A total of 1793 documents were retrieved from the Scopus database in November 2021. Only articles, 831 of all, were taken into consideration. Only 15 studies were published until 1990 while the number of publications was around 40 between 1990 and 2000. The number of publications significantly increase since then. The most important reason can be developments of technological necessities such as GPS and mobile smart devices to increase applications of DVRP. Particularly, the numbers have skyrocketed for the last two years due to the possible effect of the ongoing pandemic. The highest number of studies were conducted in China (20.2% of all studies) while the US was ranked the second with 206 out of 831 studies. Germany and Canada were ranked third and fourth with 53 and 52 publications respectively in the DVRP area. Top organizations that published more than three studies in the DVRP area were mostly located in the US. H. M. Stewart School of Industrial and Systems Engineering, Georgia Institute of Technology has the highest number of documents with School of Management, Xi'an Jiaotong University together. Given the presence of prominent e-commerce and retail companies like Amazon and Alibaba, along with their associated logistics and supply chain operations, it is understandable that the United States and China exhibit a substantial volume of research studies on the Dynamic Vehicle Routing Problem (DVRP), surpassing that of other countries. Considering density of research and development activities in DVRP applications in US and China, it is not surprising that some research institutions in these countries have emerged prominently worldwide. The DVRP studies were mostly published in journals related to transportation as expected. Almost 32% of all publications related DVRPs have been published by four important journals in Industrial Engineering and Operations Research areas, European Journal of Operational Research, Computers and Operations Research, Computers and Industrial Engineering, and Annals of Operations Research. This was not surprising either, as the Industrial Engineering and Operations Research community has long shown great interest in developing solution methods for VRPs and their variants. The study entitled, “A review of dynamic vehicle routing problems”, published by Pillac et al. (2013), is the most cited and linked study with 663 citations and 9 links to other publications in this study. From the application side, ride-sharing, ride-hailing, and crowdsourced delivery co-occur with DVRPs mostly while heuristic and metaheuristic solution approaches frequently co-occur with DVRPs.

In future studies, the other databases included especially Web of Science can be used for the bibliometric analysis. Moreover, SCIMAP, Cite Space, R, and Python can be considered for visualization purposes. Finally, one can focus on specific applications and solution methods in DVRPs instead of reviewing the broad research area as being in this study.

Statement of Support and Acknowledgment

There is no institution or organization to thank.

Conflict of Interest Statement, if any

The authors have no conflict of interest to disclose.

References

Abdirad, M., Krishnan, K., Gupta, D., (2020). A two-stage metaheuristic algorithm for the dynamic vehicle routing problem in Industry 4.0 approach. *Journal of Management Analytics*, 8(1), 69–83.

Agatz, N., Erera, A., Savelsbergh, M., Wang, X. (2012). Optimization for dynamic ride-sharing: A review. *European Journal of Operational Research*, 223(2), 295–303.

Alonso-Mora, J., Samaranayake, S., Wallar, A., Frazzoli, E., Rus, D., (2017). On-demand high-capacity ride-sharing via dynamic trip-vehicle assignment. *Proceedings of the National Academy of Sciences of the United States of America*, 114(3), 462–467.

Arslan, A. M., Agatz, N., Kroon, L., Zuidwijk, R. (2019). Crowdsourced delivery - a dynamic pickup and delivery problem with ad hoc drivers. *Transportation Science*, 53(1), 222–235.

Bent, R. W., & van Hentenryck, P. (2004). Scenario-Based Planning for Partially Dynamic Vehicle Routing with Stochastic Customers. *Operations Research*, 52(6), 977–987.

Berbeglia, G., Cordeau, J. F., Laporte, G. (2010). Dynamic pickup and delivery problems. *European Journal of Operational Research*, 202(1), 8–15.

Bonilla, C. A., Merigó, J. M., & Torres-Abad, C. (2015). Economics in Latin America: a bibliometric analysis. *Scientometrics*, 105, 1239-1252.

Bornmann, L., & Leydesdorff, L. (2014). Scientometrics in a changing research landscape: bibliometrics has become an integral part of research quality evaluation and has been changing the practice of research. *EMBO reports*, 15(12), 1228-1232.

Chang, T. S., & Yen, H. M. (2012). City-courier routing and scheduling problems. *European Journal of Operational Research*, 223(2), 489–498.

Chen, C. (2017). Science mapping: A systematic review of the literature. *Journal of Data and Information Science*, 2(2), 1-40.

Chiu, W. T., & Ho, Y. S. (2007). Bibliometric analysis of tsunami research. *Scientometrics*, 73(1), 3-17.

Dantzig, G. B., & Ramser, J. H. (1959). The truck dispatching problem. *Management Science*, 6(1), 80-91.

Demirbilek, M. (2021a). A-Static-Periodic Solution Strategy for Dynamic Vehicle Routing Problem with Simultaneous Pickup and Delivery. *Acta Infologica*, 5(1), 1–12.

Demirbilek, M. (2021b). A metaheuristic solution approach with two construction heuristics for vehicle routing problem with simultaneous Linehauls and Backhauls. *Sigma Journal of Engineering and Natural Sciences*, 39(3), 226–236.

Demirbilek, M. & Özulukale Demirbilek, **S.** (2022). İŞ SAĞLIĞI VE GÜVENLİĞİ ANLAYIŞININ ENDÜSTRİ 4.0 KAPSAMINDA DEĞİŞİMİ. *Multidisipliner Yaklaşımlarla Endüstri 4.0*, 139.

Demirbilek, M., Branke, J., & Strauss, A. K. (2021). Home healthcare routing and scheduling of multiple nurses in a dynamic environment. *Flexible Services and Manufacturing Journal*, 33(1), 253–280.

Dewinter, M., Vandeviver, C., Vander Beken, T., Witlox, F. (2020). Analysing the police patrol routing problem: A review. *ISPRS International Journal of Geo-Information*, 9(3).

Dial, R. B. (1995). Autonomous dial-a-ride transit introductory overview. *Transportation Research Part C: Emerging Technologies*, 3(5), 261–275.

Feng, G., Kong, G., Wang, Z. (2020). We are on the Way: Analysis of On-Demand Ride-Hailing Systems. *Manufacturing & Service Operations Management*, 23(5), 1237–1256.

Fikar, C., & Hirsch, P. (2017). Home health care routing and scheduling: A review. *Computers and Operations Research*, 77, 86–95.

Gaviria-Marin, M., Merigó, J. M., & Baier-Fuentes, H. (2019). Knowledge management: A global examination based on bibliometric analysis. *Technological Forecasting and Social Change*, 140, 194-220.

Gendreau, M., & Potvin, J.Y. (1998). Dynamic Vehicle Routing and Dispatching. *Fleet Management and Logistics*, 115–126.

Gendreau, M., Guertin, F., Potvin, J. Y., Taillard, É. (1999). Parallel Tabu Search for Real-Time Vehicle Routing and Dispatching. *Transportation science*, 33(4), 381–390.

Ghiani, G., Guerriero, F., Laporte, G., Musmanno, R. (2003). Real-time vehicle routing: Solution concepts, algorithms and parallel computing strategies. *European Journal of Operational Research*, 151(1), 1–11.

Haghani, A., & Jung, S. (2005). A dynamic vehicle routing problem with time-dependent travel times. *Computers & Operations Research*, 32(11), 2959–2986.

Han, H., & Ponce-Cueto, E. (2015). Problema de programación de rutas en la recogida de residuos: Revisión de la literatura. *Promet - Traffic - Traffico*, 27(4), 345–358.

Ichoua, S., Gendreau, M., Potvin, J. Y., (2007). Planned Route Optimization for Real-Time Vehicle Routing. *Operations Research/ Computer Science Interfaces Series*, 38, 1–18.

Koç, Ç., & Laporte, G. (2018). Vehicle routing with backhauls: Review and research perspectives. *Computers and Operations Research*, 91, 79–91.

Kumar, S., & Rathi, S. (2019). Bibliometric analysis of open access journal articles published in the field of library and information science during 2008-2017. *DESIDOC Journal of Library & Information Technology*, 39(1), 26-31.

Laporte, G. (2009). Fifty years of vehicle routing. *Transportation Science*, 43(4), 408–416.

Larsen, A., Madsen, O. B. G., Solomon, M. M., (2008). Recent Developments in Dynamic Vehicle Routing Systems. *Operations Research/ Computer Science Interfaces Series*, 43, 199–218.

Larsen, A., Madsen, O., Solomon, M. (2002). Partially dynamic vehicle routing models and algorithms. *Journal of the Operational Research Society*, 53(6), 637–646.

Martínez-López, F. J., Merigó, J. M., Valenzuela-Fernández, L., & Nicolás, C. (2018). Fifty years of the European Journal of Marketing: a bibliometric analysis. European Journal of Marketing, 52(1/2), 439-468.

Montemanni, R., Gambardella, L. M., Rizzoli, A. E., Donati, A. V. (2005). "Ant Colony System for a Dynamic Vehicle Routing Problem. *Journal of Combinatorial Optimization*, 10(4), 327–343.

Ojeda Rios, B. H., Xavier, E. C., Miyazawa, F. K., Amorim, P., Curcio, E., Santos, M. J. (2021). Recent dynamic vehicle routing problems: A survey. *Computers and Industrial Engineering*, 160.

Pillac, V., Gendreau, M., Guéret, C., Medaglia, A. L. (2013). A review of dynamic vehicle routing problems. *European Journal of Operational Research*, 225(1), 1–11.

Psaraftis, H. N. (1980). A Dynamic Programming Solution to the Single Vehicle Many-to-Many Immediate Request Dial-a-Ride Problem. *Transportation Science*, 14(2), 130–154.

Psaraftis, H. N. (1995). Dynamic vehicle routing: Status and prospects. *Annals of Operations Research*, 61(1), 143–164.

Rios, B. H. O., Xavier, E. C., Miyazawa, F. K., Amorim, P., Curcio, E., & Santos, M. J. (2021). Recent dynamic vehicle routing problems: A survey. *Computers & Industrial Engineering*, 160, 107604.

Ritzinger, U., Puchinger, J., Hartl, R. F. (2016). A survey on dynamic and stochastic vehicle routing problems. *International Journal of Production Research*, 54(1), 215–231.

Savelsbergh, M., & Sol, M. (1998). Drive: Dynamic routing of independent vehicles. *Operations Research*, 46(4), 474–490.

Talarico, L., Meisel, F., Sörensen, K. (2015). Ambulance routing for disaster response with patient groups. *Computers and Operations Research*, 56, 120–133.

Tlili, T., Harzi, M., Krichen, S. (2017). Swarm-based approach for solving the ambulance routing problem. *Procedia Computer Science*, 112, 350–357.

Toth, P., & Vigo, D. (Eds.) (2014). Vehicle routing: problems, methods, and applications. *Society for Industrial and Applied Mathematics*, 463.

Ulmer, M. W., Thomas, B. W., Campbell, A. M., Woyak, N. (2021). The restaurant meal delivery problem: Dynamic pickup and delivery with deadlines and random ready times. *Transportation Science*, 55(1), 75-100.

Van Eck, N. J., & Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics*, 84(2), 523–538.

van Eck, N. J., & Waltman, L. (2017). Citation-based clustering of publications using CitNetExplorer and VOSviewer. *Scientometrics*, 111(2), 1053-1070.

Voccia, S. A., Campbell, A. M., Thomas, B. W. (2019). The same-day delivery problem for online purchases. *Transportation Science*, 53(1), 167–184.

Waltman, L., van Eck, N. J., & Noyons, E. C. (2010). A unified approach to mapping and clustering of bibliometric networks. *Journal of Informetrics*, 4(4), 629-635.

Wilson, N. H. M., & Colvin N. J. (1977). Computer control of the Rochester dial-a-ride system. *Massachusetts Institute of Technology, Center for Transportation Studies*, 79.