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A Bibliometric Analysis of DevOps Metrics

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ABSTRACT

DevOps has become an important set of organisational and technical practices in software development under the agile umbrella. Many efforts are still being made in this field, mainly focused on the inclusion of metrics for monitoring progress. Gathering metrics is a difficult task, but it can provide insight into the performance of the software delivery process. The current status of the definition, application and implementation of metrics in DevOps projects and processes is of interest to software practitioners. Thus, the objective of this article is to analyze documents regarding the impact of metrics in DevOps projects. 103 documents were obtained from the Scopus database to analyze them through the bibliometric method considering several aspects. The bibliometric analysis performed included author analysis, author affiliation, authors' countries, keyword analysis, citation analysis, and network analysis. The results indicate that DevOps research is not centralized in a specific group of researchers. Moreover, the most significant contributions of DevOps are related to continuous integration, software design, and software testing. The bibliometric analysis presented in this article helps to identify the current state of the DevOps literature and provides an insightful discussion of future research trends.

Keywords: DevOps; Metrics; Bibliometric analysis; Bibliometrics

1. INTRODUCTION

Development and Operations (DevOps) comprises organisational and technical practices that have been implemented in the software development cycle to reduce the time from software development to the production environment, ensuring high-quality standards[1]. Effective cooperation between Development and Operations teams leads to improved business processes that are more adaptable and faster than usual, which is due to cultural and organisational factors that DevOps considers important to achieve its effects[2].

DevOps practices focus on automating software deployment processes. The development cycle is highly automated, with decoupled products and cultural changes, which demands changes in talent, processes, and technologies[3]. DevOps urges organisations to survive within the trendy digital ecosystem, that demands quick releases, continuous package updates, constant evolution of market needs, and adoption of climbable technologies[4].

Although information, practices, and tools on DevOps are available, they have not been organised in the literature to guide the implementation of this management tool[5]. One way to organise DevOps-related information is to better define the processes and steps involved, and then define and collect metrics to analyse these processes and steps.

As measuring has become a fundamental aspect of software engineering[6], it is critical to include a measuring process in emerging software processes like DevOps. Accurate measurement is required to evaluate and foster a system's quality, and it is also essential to determine better practices to assist practitioners and researchers in their work[7].

One of the main drivers for measuring the DevOps process centers on many firms appearing to have virtually no visibility or meaningful measurement of their activities. The sooner a company undertakes to measure, the sooner a baseline is set and may be utilised to assess relative improvement[8]. A good measurement program can be applied to understand the DevOps process, allowing teams to implement technologies and procedures for monitoring progress. The definition of DevOps-oriented metrics will be able to model the quality elements of the process, allowing DevOps engineers to evolve and manage the developed software products with effective quality assurance criteria.

The application of DevOps in the software industry has increased due to the frequent creation and updates of the software used in mobile devices. DevOps enables organisations to provide rapid responses to increasing demands driven primarily by the continuous development of solutions for mobile applications, virtual environments, augmented reality, and the Internet of Things (IoT). As a result, this study performs a bibliometric analysis of the impact of metrics applied to DevOps projects. This analysis is necessary to understand its evolution as an emerging field of software development literature.

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2. LITERATURE REVIEW

The literature on metrics in DevOps highlights the importance of its implementation. The transformation of organisations towards DevOps requires the implementation of software analytics to assess progress. Snyder and Curtis[9] found that organisations use DevOps metrics for quality analysis within the software development process. For example, Rossi *et al.*[10] demonstrated the usefulness of applying metrics in the evaluation of the implementation process of Facebook mobile solutions. These researchers measured developer productivity and the number of problems encountered in production, considering severity levels and the number of cherry-picks per push. They concluded that the application of metrics improves the results intended by the DevOps implementation. In addition, the metrics analysis for agile DevOps teams developed by Huijgens *et al.*[11] includes indicators that evaluate the evolution of software development stages. According to Forsgren and Kersten[8], by using system-based metrics and survey-based metrics in a complementary way, organisations can obtain a better picture of their software development and operations environment.

The evaluation of the deployment pipeline in continuous delivery is proposed in the study of D'Ambrogio *et al*.[12], as they establish the introduction of appropriate metrics to monitor DevOps processes such as cycle time, throughput, flow efficiency, and deliveries per month. Moreover, Farshchi *et al*.[13] analysed the problem of resilience in cloud application operations due to outages caused by the execution of continuous DevOps operations (such as Rolling Upgrade). The authors applied a regression model-based approach to detect errors in the execution of DevOps operations by searching for relevant metrics. This approach was evaluated on Amazon's public cloud computing service (EC2), which was able to successfully detect injected failures.

To improve DevOps time efficiency, Marijan's study[14] presents an approach to smaller test suites under three metrics: the industry practice of test selection for continuous integration, the retest-all approach, and random test selection. The results showed that continuous integration test cycles are shorter when redundancy is avoided through more release cycles. Lastly, the evaluation and measurement of DevOps' attributes, using Exploratory and Confirmatory Factor Analysis in the research developed by Gupta *et al*.[15], allowed them to be categorised under the latent variables: Automation, Source Control, Cohesive Teams, and Continuous Delivery. The study determined the dependency between the attributes using Structural Equation Modeling (SEM), which also contributed to determining the maturity of the DevOps implementation in a business case.

The adoption of DevOps entails the improvement of processes to make them faster while ensuring high-quality standards, so metrics provide key information for an effective software value stream. The contributions on metrics from the literature present ways to analyse DevOps processes by considering quality aspects, frameworks, agile approaches, process cycles, and cloud computing. However, no bibliometric studies on the topic of DevOps metrics have been found to date in the literature. Therefore, it is relevant to analyse the scientific activity on metrics applied to DevOps, since it is an essential tool for the improvement of software development processes.

3. OBJECTIVES OF THE STUDY

The main objective of this article is to analyse documents regarding the impact of metrics in DevOps projects, using 103 documents indexed in the Scopus database between 2010 and 2022. These documents were analysed and evaluated according to publication and used to determine the quantitative research characteristics of metrics in DevOps. The research questions derived from this objective and answered in this article are:

- What is the trend in terms of the number of scientific publications related to metrics applied in DevOps?
- What are the most relevant bibliographic sources that generate publications on metrics applied in DevOps?
- Which are the most representative and cited authors in the scientific literature on metrics applied in DevOps?
- What are the top institutions worldwide that focus on metrics applied in DevOps research?
- What is the contribution by country in terms of research on metrics applied in DevOps?
- What are the patterns of institutional collaboration on metrics applied in DevOps?

4. LIMITATIONS OF RESEARCH

The bibliometric analysis presented in this article has some methodological limitations that should be considered. First, only the Scopus database was used. Secondly, it specifically addresses the relationship of DevOps with the application of metrics but does not address the former from a general perspective. Finally, the bibliometric analysis is limited to English language papers published in conferences, journals, and books between 2010 and 2022.

5. BACKGROUND

DevOps is a current trend in the software industry, which can be understood as a cross-disciplinary practice that enhances communication and collaboration between the development team, the operation team, the business, and QA[16-17]. DevOps takes advantage of automated development, deployment, and infrastructure[18]. It has positively affected software development by decreasing the time between a modification and its operational availability to end users[1]. Its application implies a set of considerations such as IT operational skills[19], cultural aspects, and capabilities (it referred to maintaining constant planning, integration, testing, release, deployment, infrastructure monitoring, optimisation, collaborative development, monitoring of user behavior and feedback)[20].

5.1 DevOps Principles

According to Humble and Molesky[21], four guiding concepts define DevOps:

- Culture: Teams to assume shared responsibility for providing high quality to the end-user, a culture of change is necessary.
- Automation: To achieve rapid delivery and end-user

feedback, full automation is essential to complete software development, deployment, and testing on time.
- Measurement: It enables the existing delivery capabilities and improvement objectives to be determined.
- Sharing: Knowledge transfer, tools, and infrastructure.

5.2 DevOps Stages

The DevOps process is composed of the following stages, which can be adjusted according to the development and performance of the software architecture[22-23]:

- Plan: Definition of planning and task scheduling activities for the releases.
- Develop: Code development, integration, and unit testing activities are performed.
- Verify: Software evaluations are performed regarding its requirements.
- Test: Continuous and automated tests are performed to guarantee software quality.
- Release: It is related to a new software version that is complete to be released.
- Deploy: Software installation and execution activities are performed in the production environment.
- Operate: It is related to the configuration and management of the software once deployed.
- Monitor: Application monitoring by gathering and analyzing data.

5.3 DevOps Capabilities and Enablers

DevOps is a collection of competencies supported by cultural and technical enablers[20]. Continuous execution of software activities (planning, development, testing, and deployment) constitutes capabilities. Software activities require tools to automate testing and deployment chains. Cultural enablers aim at collaboration and working in solidarity, creating an environment to foster learning and pursue common team goals. The capabilities and enablers are presented in Table 1.

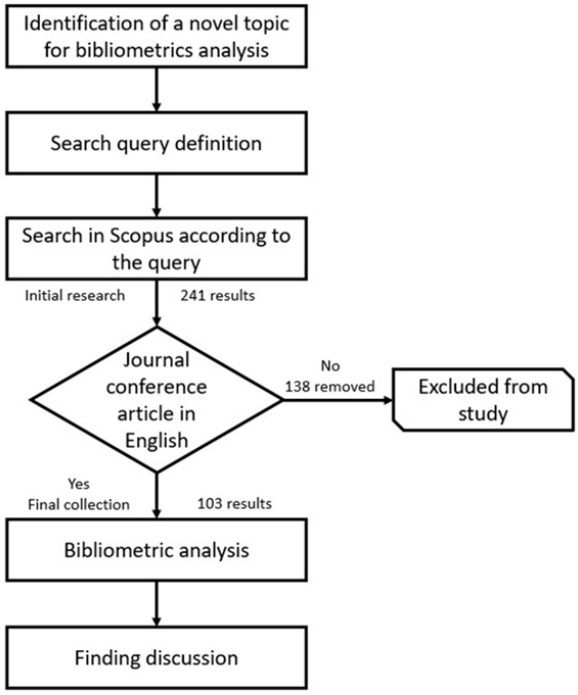
5.4 DevOps Metrics

According to Forsgren and Kersten[8], the approaches of metrics for developing and delivering are presented as follows:
- System-Based Metrics: It is associated with data from various systems or registries in which the following aspects are considered: completeness and correctness.
- Survey-Based Metrics: These relate to data of systems coming from surveys sent to people working on the systems, with aspects to consider such as cohesiveness and correctness.

In addition, DevOps considers four key metrics: deployment frequency, change lead time, service restoration time, and change failure rate[8].

6. MATERIALS AND METHODS

We applied the bibliometric method for evaluating documents from a representative database of scientific activity in a descriptive way. The method analysed the highlights of the boundaries of metrics impact on DevOps and the drawbacks and gaps. The methodology implemented herein consisted mainly of elaborating a search query, searching on a representative database, and analyzing and synthesizing the results (Fig. 1).



Source: Authors' elaboration.

Figure 1. Overview of the methodology.

Table 1. Capabilities and enablers of DevOps

Capabilities and enablers	Description
Capabilities	Continuous application of planning, collaborative development, integration, testing, release, development, detection of the condition of the infrastructure, infrastructure optimization, monitoring of user behavior, comments from users, rapid recovery from service interruptions, shared objectives, success criteria, and incentives for collaboration, accountability, and collective ownership.
Cultural enablers	Shared principles, mutual respect, trust, easy communication, continuous experimentation and learning, building, testing, and implementing automation.
Technological enablers	Monitoring, recovery and infrastructure automation, and management of configuration for code and infrastructure

Source: Smeds *et al*.[20]

6.1 Search Strategy

First, we defined the appropriate keywords, based on the study's objective, to form the next query search:

(Metrics OR Measure OR Measuring OR Measurement OR Analytics) AND (DevOps OR "Software Development and IT Operations" OR "Developer Operations" OR "Continuous Integration" OR "Continuous Deployment" OR "Continuous Delivery" OR "Continuous Verification" OR "Continuous Testing" OR "Continuous Security" OR "Continuous Compliance" OR "Continuous Evolution" OR "Continuous Use" OR "Continuous Trust" OR "Continuous Run-Time Monitoring")

The data was only obtained from the Scopus database for performing the bibliometric analysis, which is justified from two perspectives: On the one hand, said database is more extensive than the Web of Science (WoS)[24-25]; on the other hand, the Scopus database includes the types of sources: journals, books, and conference papers[26] that were established in the methodology for performing the bibliometric analysis.

6.2 Collecting Data

Specific criteria, as follows, were applied for the inclusion of research documents.:

- Documents published in conferences, journals, and books were included in the bibliometric analysis because the topic analysed is a recent field of study, which requires an overview of the contributions that have been made in the literature on DevOps
- Documents published between 2010 and 2022
- Documents published in the English language
- Contributions that discuss DevOps, activities, and metrics.

After executing the search query in the Scopus database, two hundred forty-one documents were obtained. The obtained bibliographic data was stored in the BibTeX and CSV formats, including fields to register mainly the name and identification of the authors, document title, publication year, source title, volume, issue, cited by, link, DOI, affiliations, abstract, keywords, references, correspondence address, conference name, conference location and date, editors, publisher, ISSN, ISBN, document type, language, open access, publication stage, and source. One hundred thirty seven results were removed from the initial search because they did not match the study's focus. As a result, the bibliometric analysis was performed using a final collection of 103 results related to the DevOps topic.

6.3 Bibliometric Analysis

The selected papers were evaluated using the Bibliometrix package from R software. Performing a bibliometric analysis allows bringing information about research activities from scientific communities to explore and visualise their evolutions over time, obtaining a global and specialised vision of the literature.

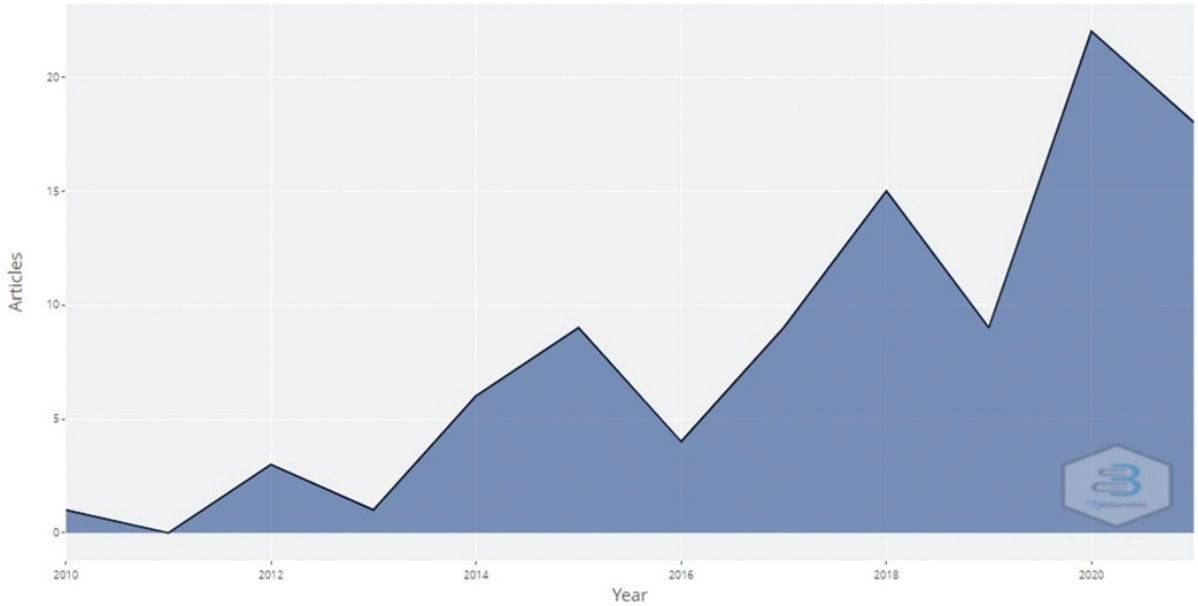
7. DATA ANALYSIS

A study of bibliometric data, from many perspectives, is presented as follows.

7.1 Description Analysis

An overview of the selected studies from the literature shows the evolution of publications from 2010 to 2022 (Fig. 2). In recent years, the number of publications has grown, which demonstrates the high interest in applying DevOps in the software industry. In addition, Table 2 shows some descriptions of the characteristics of the collected data for the bibliometric analysis. These documents were collected from Scopus, belonging to conferences, journals, and other sources, filtered by title and content.

Table 3 presents the publications that are the most frequent sources related to DevOps-oriented metrics. The most relevant conference related to these areas is the International Conference on Software Engineering (11 articles), followed



Source: Authors' elaboration using Biblioshiny.

Figure 2. Evolution of annual publications about DevOps

Table 2. Overview of the collected data

Description	Results
Total documents	103
Articles	30
Conference papers	66
Books	1
Books chapters	2
Proceeding articles	1
Review	3
Sources (Journals, Books, etc.)	64
Authors	340
Author's keywords	337
Average citations per document	29.85

Source: Authors' elaboration using Biblioshiny.

based on the number of authors by article (Table 4). A few of the authors presented only three publications (10 %), and the rest two publications (40 %) and one publication (50 %), respectively. The authors with only one publication were 25, which are not included in Table 4. According to these results, the metrics applied to DevOps lack authors that present dominance in the field analysed.

7.2.2 Affiliation and Country Analysis

The organisations or institutions that contributed more to research regarding DevOps were "Universidad de Los Andes", "Warsaw University", "Nanjing University", and "Tilburg University" together with "The University of Zurich". We found 60 articles from academic institutions and organisations (Table 5). No institutions were found that stand out for a high number of contributions in the area of metrics applied to DevOps. Therefore, this field of research should be considered novel and in a stage of exploration in the identified institutions.

In addition, it was identified that most of the research publications on DevOps metrics come mainly from the United States of America and Germany (with 66 and 48 frequencies, respectively), followed by China, Canada, and Sweden (with 27, 23, and 20 frequencies, respectively). The rest of the contributions originated predominantly in some European countries, followed by Asia, Oceania, and South America (Table 6). As a result, developed countries have produced a greater number of contributions on metrics applied to DevOps.

Table 3. Sources of the collected data

Sources	Number of studies per source*
Proceedings of the International Conference on Software Engineering	11
ACM International Conference Proceeding Series	7
CEUR Workshop Proceedings	5
IEEE Software	5
Journal of Systems and Software	4
IEEE Transactions on Software Engineering	3
Information and Software Technology	3
Journal of Software: Evolution and Process	3
Proceedings of the ACM Sigsoft Symposium on the Foundations of Software Engineering	3
CLOSER 2015 – Proceedings of the 5th International Conference on Cloud Computing And Services Science	2
ESEC/FSE 2021 - Proceedings of the 29th ACM Joint Meeting European Software Engineering Conference and Symposium on the Foundations of Software Engineering	2
ICSOFT 2020 - Proceedings of the 15th International Conference on Software Technologies	2
IEEE International Working Conference on Mining Software Repositories	2
Proceedings of the Lecture Notes in Informatics (LNI) - Series of the Gesellschaft Fur Informatik (GI)	2
Software - Practice and Experience	2

Source: Authors' elaboration using Biblioshiny.
Note: 8 sources were not specified in Bibliometrix.

by the ACM International Conference Proceeding Series (7 articles). Other referenced publications are CEUR Workshop Proceedings, IEEE Software, and the Journal of Systems and Software.

7.2 Bibliometric Analysis

The bibliometric analysis relating to the author, affiliation and country, citation, and network are discussed below.

7.2.1 Author Analysis

The productivity of authors concerning DevOps topics was identified according to the number of studies published and the ratio of participation in the elaboration of each article,

Table 4. Contribution per author (2 and 3 documents)

Authors	Articles	Articles fractionalised*
Di Nucci D	3	0.83
Hassan AE	3	0.61
Marijan D	3	1.83
Tamburri DA	3	0.83
Wettinger J	3	1.67
Alperowitz	2	0.58
Bosch J	2	1.33
Breitenbücher U	2	0.67
Bruegge B	2	0.58
Da Costa DA	2	0.58
Dalla Palma S	2	0.58
Demeyer S	2	0.67
Gotlieb A	2	0.53
Huijgens H	2	1.17
Hwang J	2	0.42
Leitner P	2	0.75
Leymann F	2	0.67
Palomba F	2	0.50
Shang W	2	0.58
Shi A	2	0.53
Stencel K	2	0.67
Timoszuk G	2	0.67
Vasilescu B	2	0.45
Wang H	2	0.45
Zeng Z	2	0.36

Source: Authors' elaboration using Biblioshiny.
*Note: Fractional authorship quantifies an individual author's contributions to a published set of papers (following the hypothesis of the uniform contribution of all co-authors in each document).

Table 5. Production of authors' affiliations.

Affiliations	Articles
Universidad de Los Andes	6
Warsaw University	6
Nanjing University	5
Tilburg University	4
University of Zurich	4
Amity University Uttar Pradesh	3
Chalmers University of Technology	3
ITA - Aeronautics Institute Of Technology	3
Not Reported	3
Queen's University	3
Università Degli Studi Di Napoli Federico II	3
University of Quebec	3
CNR	2
Eindhoven University of Technology	2
Federal University of Paraná (UFPR)	2
Khalifa University	2
Saab Electronic Defense Systems	2
Simula Research Laboratory	2
Kiel University	2

Source: Authors' elaboration using Biblioshiny.

Table 6. Authors belonging to a country

Country	Frequency	Country	Frequency
USA	66	Austria	6
Germany	48	Colombia	6
China	27	Poland	6
Canada	23	Spain	6
Sweden	20	Turkey	6
Norway	17	Portugal	5
Italy	16	France	4
Brazil	15	Indonesia	4
The Netherlands	12	Belgium	3
Switzerland	12	Sri Lanka	3
Finland	10	New Zealand	1
India	10	Singapore	1
Greece	8	UK	1
Australia	7		

Source: Authors' elaboration using Biblioshiny.

7.2.3 Keyword Analysis

Keyword analysis shows the most frequent terms used in the documents analysed, highlighted by font size according to the frequency of use, as shown in Fig. 3. The five most relevant terms identified were: "software design", "software engineering", "software testing", "DevOps", and "integration testing". These results are consistent with the literature, as DevOps is oriented to successfully implement software projects from design to deployment.

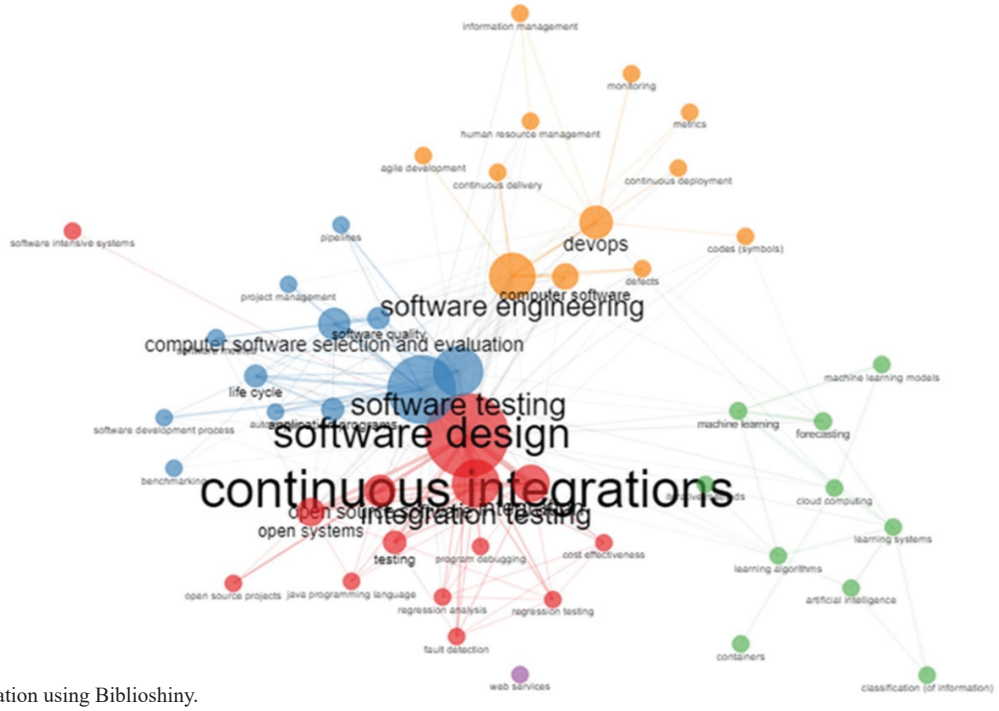
The co-occurrences of terms are represented in Fig. 4. The clustering is performed based on the strong connections among terms. Four groups were identified, which are associated with the most important terms: (1) "continuous integration", "integration testing"; (2) "software design", "software testing"; (3) "software engineering", "DevOps"; and (4) "artificial intelligence". These results coincide with the main stages of DevOps. However, it is striking that artificial intelligence has emerged as a term that intersects with DevOps.

Source: Authors' elaboration using Biblioshiny.

Figure 3. Relevant keywords used in studies.

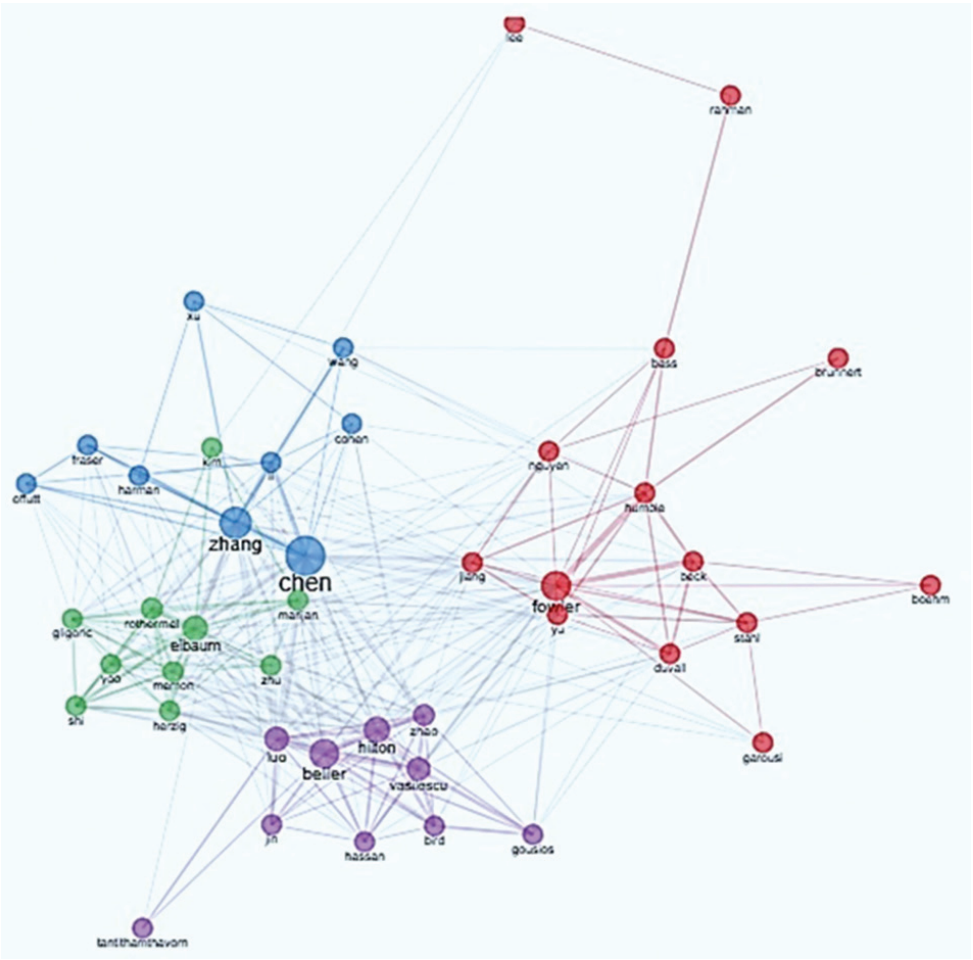
7.2.4 Citation Analysis

Citation analysis establishes links and thematic relationships between researchers' contributions based on the



Source: Authors' elaboration using Biblioshiny.

Figure 4. Linkages of co-occurrences of terms.



Source: Authors' elaboration using Biblioshiny.

Figure 5. Co-citations network.

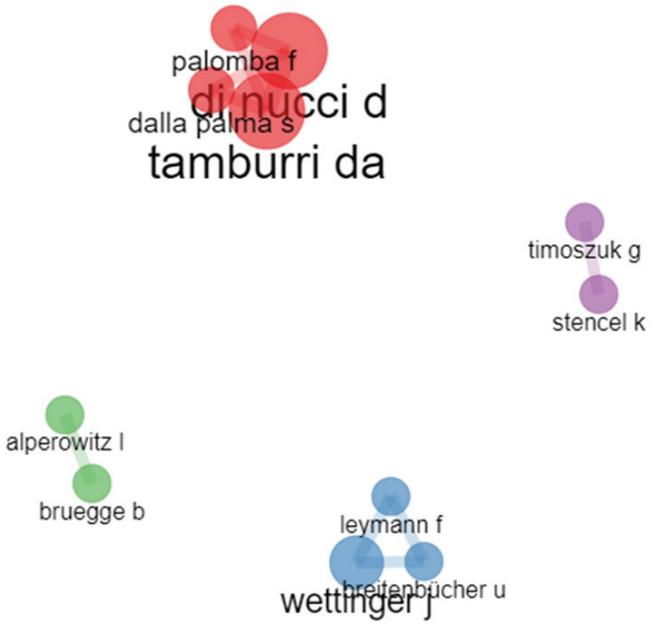
citations incorporated in their work. It includes the study of the frequency and patterns of citations in the works by establishing connections among them[27].

Figure 5 presents a co-citation network in which most of the articles cite each other. It shows that the articles found are closely related and comprise a body of knowledge in DevOps-oriented metrics. Cheng, Zang, and Fowler have the highest PageRank metric (0.0292, 0.299, and 0.0269, respectively), being the most cited authors. These articles also present high values of betweenness and closeness.

7.2.5 Network Analysis

Network analysis indicates the relationships, links, or contacts between different bibliographic elements that make up a scientific work. The application of network analysis has positively contributed to the visualisation of patterns and clusters of scientific collaboration.

Four clusters were detected from the analysed articles (Fig. 6). It was identified that few collaboration networks are presented between the different authors. The number of authors linked to each cluster is 4, 3, 2, and 2, respectively. These results show that the research topic is relatively recent and that few researchers are working together.



Source: Authors' elaboration using Biblioshiny.

Figure 6. Clusters of authors.

8. DISCUSSION AND FUTURE WORKS

The state of DevOps metrics as a field of research is discussed below. Some recommendations for future research are also suggested.

8.1 Remarks on DevOps Metrics Status

The bibliometric analysis carried out identified the size, growth, and distribution of scientific documents related to DevOps-oriented metrics, investigating the structure and dynamics of the various groups and authors that produce and consume these documents.

The bibliometric analysis determined that DevOps is a very relevant topic at present. Today's software projects use DevOps as a mechanism to develop software with approaches based on continuous integration and deployment using automated tools.

The results of the bibliometric analysis indicate that there is no group of relevant researchers in the area. As a result, the most outstanding works are carried out by a few researchers in a dispersed manner. As of 2016, the research field began to generate and publish more articles. The topic is a reasonably current area of research, where a representative source is the International Conference on Software Engineering. Relevant topics covered in DevOps include continuous integration and software design and testing. Finally, the most representative authors come from the United States of America, Germany, China, and Canada. However, no authors with a large volume of publications on DevOps were found.

8.2 Future Research

Research papers and other contributions on DevOps-oriented metrics are relatively recent. The collection of research papers can serve as a starting point for more rigorous conceptual studies, such as a systematic mapping or a systematic literature review. Future works may focus on global and general DevOps metrics or specific stages of the software delivery pipeline (integration, testing, deployment, and delivery). Moreover, a huge number of software solutions have arisen for the implementation of DevOps-specific stages or DevOps globally. The study of tools or state of practice is also an up-and-coming area of research.

9. CONCLUSIONS

A bibliometric analysis regarding DevOps metrics was carried out, which is a recent field of study. The bibliometric analysis comprised 103 selected studies from the literature, and according to the analysis, an increasing trend in publications on DevOps was identified. However, the number of citations has decreased in the last two years. Interestingly, most articles co-cited each other, and the analysed studies referenced 340 authors. An important topic discussed in the studies identified was continuous integration, which is representative of software development and release management by releasing continuously quality artifacts to customers under integrated feedback[28]. The "Universidad de Los Andes" and "Warsaw University" were the more relevant contributor institutions, and the country with more publications was the United States. Although the country with the highest number of citations was Australia, most citations come predominantly from European publications.

The information presented herein may be useful for software developers, DevOps researchers, and agile project managers interested in the use of metrics in DevOps, and since the research topic is recent, there are few collaboration networks detected yet.

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