

1. Background

DevOps has become a trending technology term and gained popularity in the software industry and academia. It refers to improving the performance of software development operations by incorporating the Software Development (Dev) team and IT Operations (Ops) team in one process (Hussain, Clear, & MacDonell, 2017). Security appears as a key non-functional requirement of software development but is often ignored and devalued in DevOps programs, because of regarding security as an inhibitor to the high velocity required in DevOps (Mohan & Othmane, 2016). Growing importance of security includes privacy to users in larger scale systems, the rise of Software as a Service (SaaS), globally distributed systems, and how incorporating security conflicts with rapid delivery cycles. Specially, the use of containers, cloud and serverless computing brings increasing security complications.

To build security in DevOps, the term “DevSecOps” has been created as a security-oriented variant of DevOps. It aims to integrate security into DevOps processes without losing speed and quality, to effectively reduce risks and address security issues, by promoting the collaboration amongst security, development and operations teams (Zaydi & Nassereddine, 2019).

This study aims to observe, document and analyze the current state of DevSecOps; and investigate the application of DevSecOps in the Global Software Engineering (GSE) context. DevSecOps is an increasingly topical concept in both of the academic and industrial settings, so the voices from academia and industry are equally essential. Hence, a Multi-vocal Literature Review (MLR) was conducted by executing a “dual-track” strategy covering published and unpublished literature, in order to identify recent research and practical trends and to find out opportunities for further research.

2. Research Questions

We will review white and grey literature to identify recent research and practical trends of DevSecOps, aiming to: (a) observe, document and analyze the state of art of DevSecOps; and (b) investigate the application of DevSecOps in the Global Software Engineering (GSE) context. Regarding the research objectives, research questions were posed

- RQ1: What is the current state of DevSecOps in the existing (white and grey) literature?
 - Sub-question 1.1: What aspects of DevSecOps can be found in the existing (white and grey) literature?
 - Sub-question 1.2: What themes do these aspects contain?
 - Sub-question 1.3: How do the themes link to each other?
- RQ2. How does Global Software Engineering (GSE) relate to DevSecOps?

3. Research Methodology

A Systematic Literature Review (SLR) is a form of secondary study to identify, evaluate, analyze and interpret all of the possible existing literature relevant to particular research questions, and to synthesize these available researches in a fair manner (Kitchenham & Charters, 2007). However, a normal SLR mainly uses formally published literature (e.g., journal and conference papers) and is not quite adequate for this research, because we find that there are only a limited number of academic papers available relevant to this topic, after a quick pre-searching process. Therefore, a Multi-vocal Literature Review (MLR) needs to be conducted. MLR is a special form of SLR which does not only use formally published literature (called White Literature) but also includes the Grey Literature (any unpublished work such as technical reports, news, websites, blog posts, white papers, speeches, videos, etc) (Garousi, Felderer, & Mäntylä, 2019). Another important reason for conducting MLR is that the investigation of DevOps should contain both of the researcher-oriented and practitioner-oriented sources. Software engineering practitioners outside of academia constantly produce all kinds of grey literature based on their practical experience. Researchers should not ignore these valuable sources of knowledge and information during the process of literature review.

In this case, a protocol for a multi-vocal literature review of DevOps and its security has been developed, based on the guidelines for performing SLR in SE (Kitchenham & Charters, 2007) and guidelines for conducting MLR in SE (Garousi, Felderer, & Mäntylä, 2019).

4. Search Strategy

An exhaustive search strategy for the multi-vocal literature review is presented in this section, after having consulted the guidelines for both SLR and MLR in SE. Some subsections will describe separately, if there are differences between searching white literature and grey literature.

4.1. Source to be searched

4.1.1 Source to be searched for White Literature

- Automatic searching in well-known digital databases: ACM digital library, IEEE Xplore and Scopus.
- Searching in Google Scholar and the digital library of AUT University.
- Snowballing technique will be conducted on selected literature if necessary, so that more relevant studies can be included.

4.1.2 Source to be searched for Grey Literature

- General web searching engine i.e. Google.
- Source with high credibility, such as books, magazines, specialized databases, government reports, white papers, method creators and consultants' websites and case studies.
- Source with medium credibility, such as technical reports, news, Q/A sites (like StackOverflow), Wiki articles, blog posts, presentations and videos.
- Contacting individuals or organizations for un-published work or specialized databases of theses, via multiple methods, such as direct requests, emails and social media.
- Like snowballing in WL searching, backlinks can be navigated either forward or backward to find more relevant information.

4.2. Search Strings

To address RQ1, Search String 1 = *“DevOps” AND (“security” OR “secure” OR “safe”) OR “SecDevOps” OR “DevSecOps”*. After applying Search String 1 in all search sources, we find that the results do not include any studies involving global DevSecOps. To address RQ2, we will use an additional Search String 2 = *“DevOps” AND (“security” OR “secure” OR “safe”) AND (“global software engineering” OR “global software development” OR “GSE” OR “GSD” OR “globally distributed software*”) OR “SecDevOps” OR “DevSecOps”*. Search strings might vary according to the differences between databases, because of their acceptability of Boolean operators.

In addition, some limitations need to be preset on the searches. Strings will be searched within Metadata (title, abstract and keywords); the written language should be set to be English; the publication year should be between 2011 and 2021 (as this decade was the period within which we deemed DevOps to have become common and DevSecOps was first mentioned in 2012); and books (chapters), posters and abstracts would be excluded. All results sort by relevance so that searches can finish when the relevance is extremely weak. Based on the search results, the research questions and search terms would be refined; further, search strings would possibly be re-formulated. Meanwhile, a list of key papers will be generated to ensure the reliability and relevancy of search results (Jalali & Wohlin, 2010).

4.3. Study Selection

4.3.1. Study selection criteria

Study selection criteria are defined to ensure that selected studies provide direct evidence about the research questions, including both inclusion and exclusion criteria (Kitchenham &

Charters, 2007). There are only selection criteria for White Literature being listed here, because in practice, inclusion and exclusion criteria for Grey Literature usually overlap and can be integrated with study quality assessment (Section 4.4) (Garousi, Felderer, & Mäntylä, 2019). Also, a large piece of GL has no accurate information so that selection should be made according to specific circumstance. Hence, the following inclusion and exclusion criteria apply to all WL, and have some reference value for selecting GL, although not entirely appropriate.

- Inclusion criteria:
 - a) The study fully or partially answers the research questions;*
 - b) The study is written in English;*
 - c) The study is published between 2012 and 2021;*
 - d) The study has a clearly stated methodology/research design;*
 - e) The study has credible source;*
- Exclusion criteria:
 - a) The study does not have a full-text;*
 - b) The study is external to the subject area of computer science and software engineering;*
 - c) The study does not have a rigorous research method to prove the correctness of findings;*
 - d) Duplicate studies;*
 - e) Secondary studies (However, we can use them to help validate and complement our results based on primary studies).*

4.3.2. Study selection process

- Selection process for White Literature:
 - a) Firstly, the defined search strings are applied to search full-text papers in digital databases, e.g. ACM digital library, IEEE Xplore and Scopus.*
 - b) Second, inclusion and exclusion criteria are applied to select papers quickly, based on their titles and abstracts.*
 - c) Duplicates will be removed.*
 - d) The full-texts of papers need to be read, if difficult to determine inclusion or exclusion based on titles and abstracts.*
 - e) Snowballing technique can be performed based on the reference lists of included*

papers, so that more relevant papers can be found.

f) Finally, stop searching and selecting studies, when data exhaustion.

- Selection process for Grey Literature:

a) Firstly, web searching engine (Google) is used to search defined strings, then some relevant information (websites, news, white books, blogs, etc) will be found.

b) Second, all relevant information need be filtered and determined inclusion or exclusion, by browsing and reading them in detail.

c) Duplicates will be removed.

d) Backlinks can be navigated either forward or backward to search more relevant information.

e) Individuals or organizations of GL studies can be contacted for un-published work or specialized databases, if necessary.

f) Finally, stop searching and selecting studies, when theoretical saturation, effort bounded or evidence exhaustion.

- After performing the selection process for WL and GL, all selected WL studies and GL studies will be combined together and ready for further processing.

4.4. Study Quality Assessment

Study quality assessment is a necessary procedure to provide more detailed inclusion/exclusion criteria; to determine the valid extent of sources; to assess importance of studies; and to minimize bias (Kitchenham & Charters, 2007). The table shows the study quality assessment checklist adapted from MLR guidelines of Garousi et al. (2019). Garousi et al. (2019) only presented quality assessment checklist of grey literature, here is an extension including both white and grey literature. The first 14 questions were grouped into 6 categories and would be answered YES/NO, so the criteria would be marked 0/1. "Literature Type" would be marked on a scale from 0 to 4. Out of 18 points (14+4), the borderline was set as 11 (60% of 18).

Criteria	Questions
Authority of the producer (Measure = 0 or 1)	<ul style="list-style-type: none"> • Is the author or the publishing organization reputable? • Has the author published other work in the field? • Does the author have expertise in the area?
Methodology (Measure = 0 or 1)	<ul style="list-style-type: none"> • Does the work have a clearly stated aim? • Does the work have a stated methodology? • Does work have authoritative and contemporary references? • Are any limits clearly stated?
Objectivity (Measure = 0 or 1)	<ul style="list-style-type: none"> • Does the work provide objective statements or credible findings? • Is there vested interest? E.g., a tool comparison by authors that are working for particular tool

	<p>vendor.</p> <ul style="list-style-type: none"> Is the conclusion supported by the data?
Publication Date (Measure = 0 or 1)	<ul style="list-style-type: none"> Does the work have a clearly stated date?
Novelty (Measure = 0 or 1)	<ul style="list-style-type: none"> Does the work have a novel idea or something unique? Does the work strengthen or refute a current position?
Impact (Measure = 0 or 1)	<ul style="list-style-type: none"> For WL, is the author's work cited often? / For GL, is the source viewed/shared/discussed often?
Literature Type (Measure = 0 to 4)	<ul style="list-style-type: none"> WL: peer-reviewed academic papers (Measure = 4). WL: PhD/Master thesis (Measure = 3). GL with high credibility, such as books, magazines, specialized databases, white papers, method creators and consultants' websites and case studies (Measure = 2). GL with medium credibility, such as technical reports, news, Q/A sites, blogs, presentations and videos (Measure = 1). GL with low credibility, like ideas/opinions/thoughts/commentaries without evidences (Measure = 0).

4.5. Data extraction

Data extraction phase is to extract all relevant information from the selected papers. The following data should be extracted from each selected study:

- Paper information: paper id, title, authors, publication year, sources, etc.
- Key data items (e.g. for RQ1 and S1, data like definitions, terms, meanings etc. should be excerpted as key data items).
- Assessing paper by using exclusion/inclusion criteria
- Quality assessment score of the study.
- Context of study: study types.
- Qualitative data extraction

A data extraction form (available on final page) will be designed to accurately record all this information. Most contents of data extraction forms for MLR are similar to those in the SLR guidelines of Kitchenham and Charters (2007). Besides, Garousi et al. (2019) suggest that explicit traceable links between the extracted data and primary sources should be added in data extraction form, because it is helpful to deal with some GL sources without standardized structure.

Kitchenham & Charters (2007) recommend that data extraction process should be performed independently by at least two researchers (One is data extractor, another is data checker). For single researchers such as PhD students, it is necessary to use some checking techniques.

Moreover, during the process of data extraction, multiple publications of the same data should

not be included because duplicate reports would cause heavy bias to influence the results. The right way is to use the most completed version (Kitchenham & Charters, 2007). For example, if having a PhD 1st or conference paper, its subsequent journal version would be more highly rated as most thoroughly reviewed (in theory depending on standing of the journal).

4.6. Data synthesis

Data synthesis is a procedure to collate and summarize the results of the included primary studies (Kitchenham & Charters, 2007). There are various data synthesis techniques, including: descriptive (narrative) synthesis, quantitative synthesis, qualitative synthesis, and the combination of quantitative and qualitative synthesis (Garousi, Felderer, & Mäntylä, 2019). In this research, qualitative synthesis method will be mainly used, because there will be much qualitative data collected in the WL and qualitative and experience-based evidence is also very common in the GL. Hence, we will perform the data extraction and synthesis by conducting a Thematic Analysis (TA) which is a method for identifying, analyzing and reporting themes within data for qualitative analysis (Braun & Clarke, 2006).

In accordance with the TA steps recommended by Cruzes & Dyba (2011): data will be firstly extracted in initial reading, iteratively in consultation with PhD supervisors, and large amounts of raw data will be labeled as codes; subsequently overlap should be reduced and all the codes will be translated into themes; then themes will be further classified into categories; finally a model of higher-order themes would be built.

5. Evaluation, Validation and Amendment

The first draft of this review protocol will be presented to PhD supervisors (Dr Ramesh Lal & Assoc. Prof. Tony Clear) for evaluation and criticism. According to the SLR guidelines of Kitchenham & Charters (2007), the protocol can be approved to be validated if following conditions are checked to meet:

- The search strings are derived from the research questions.
- The study selection criteria and process for WL and GL are appropriate.
- The data extraction procedure is appropriate to address the research questions.
- The data synthesis procedure is appropriate to answer the research questions.

In addition, there may be some further amendments of this MLR protocol when executing the procedures in new situations. Some necessary changes can make up for deficiencies and improve the current version of this protocol. Each revision of the MLR protocol will be recorded timely and the protocol will be updated accordingly.

6. Dissemination

The final phase of an MLR is dissemination (Reporting the review). This review will be reported in a technical report or in a section of the PhD thesis.

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Appendix A: Search Record

ACM Digital Library:

Search String 1:

[[All: "devops"] AND [[All: "security"] OR [All: "secure"] OR [All: "safe"]]] OR [All: "secdevops"] OR [All: "devsecops"]

Filters: English, Research articles (including proceedings and journals)

Search results: 416 results

(ACM has reported hundreds of results for this search, including many false positives. We could sort results by relevance and finish searching when the relevance is extremely weak, i.e. there are no searching terms in the topic and abstract of papers.)

Search String 2:

[[All: "devops"] AND [[All: "security"] OR [All: "secure"] OR [All: "safe"]]] AND [[All: "global software engineering"] OR [All: "global software development"] OR [All: "gse"] OR [All: "gsd"] OR [All: "globally distributed software*"]]] OR [All: "secdevops"] OR [All: "devsecops"]

Filters: English, Research articles (including proceedings and journals)

Search results: 42 results

IEEE Xplore:

Search String 1:

"DevOps" AND ("security" OR "secure" OR "safe") OR "SecDevOps" OR "DevSecOps"

Filters: English, Conferences, Journals

Search results: 100 results

Search String 2:

"DevOps" AND ("security" OR "secure" OR "safe") AND ("global software engineering" OR "global software development" OR "GSE" OR "GSD" OR "globally distributed software*") OR "SecDevOps" OR "DevSecOps"

Filters: English, Conferences, Journals

Search results: 22 results

Scopus:

Search String 1:

TITLE-ABS-KEY ("DevOps" AND ("security" OR "secure" OR "safe") OR "SecDevOps" OR "DevSecOps") AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (DOCTYPE , "cp") OR LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "cr")) AND (LIMIT-TO (SUBJAREA , "COMP") OR LIMIT-TO (SUBJAREA , "ENGI"))

Filters: English, Conference papers, Articles, CS, Engineering

Search results: 176 results

Search String 2:

TITLE-ABS-KEY ("DevOps" AND ("security" OR "secure" OR "safe") AND ("global software engineering" OR "global software development" OR "GSE" OR "GSD" OR "globally distributed software*") OR "SecDevOps" OR "DevSecOps") AND (LIMIT-TO (DOCTYPE , "cp") OR LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (SUBJ

AREA , "COMP") OR LIMIT-TO (SUBJAREA , "ENGI")) AND (LIMIT-T
O (LANGUAGE , "English"))

Filters: English, Conference papers, Articles, CS, Engineering

Search results: 32 results

Appendix B: Data Extraction Form

Phase1: Paper Selection	Your Response	Comments
Paper Information		
Paper id		ID of paper, including search No. and databases, e.g. S1_ IEEE_01, S2_ACM_02.
Paper title		Title of paper, short version suffices
Authors		Authors' names of paper
Publication year		Year of Publication
Key data items		e.g. for RQ1, data like secure, security, SecDevOps, etc. should be excerpted as key data items
Date researcher analyzed this paper		When researcher completed this form
Exclusion/Inclusion Criteria (Some criteria have been pre-performed during searching papers, e.g. language, years and subject area.)		
Ex (a): Is the study external to the terms of Search 1 (DevOps security & SecDevOps/DevSecOps)?		Paper needs to focus on DevOps and its security aspects (for RQ1)
Ex (b): Is the study external to the terms of Search 2 (DevOps & security & GSE/GSD)?		Paper also needs to focus on DevOps security and GSE/GSD topic (for RQ1)
Ex (c): Is the study based on personal opinion?		We reject papers without rigorous methodology or research design to prove the correctness of findings
Ex (d): Is this a repeated study?		We only include the key study (most comprehensive) because repeated study would bias results
In (a): Is RQ addressed?		Which research question is addressed by the paper
In (b): Is the study from acceptable source		Include: conference and journal papers; Exclude: books (chapters), posters and abstracts.

Quality assessment score of study		To assess and grade the quality
Decision		
Decision status: {Accept/Reject/Waiting for Full paper/Don't Know}		Define decision status. "Don't know" status will go to peer review and arbitration
Decision based on: {Title/Abstract/Introduction/Conclusion/Methods/Whole Paper/Peer Review/Arbitration}		At what point did researcher make decision.
Context of Study		
Type of papers		Indicate type: solution proposals, philosophical papers, evaluation research, validation research, opinion papers, and personal experience papers.
For Empirical Studies Add		
Type of empirical study methods		Indicate type: experiments, survey, interviews, observation, case study, action research, focus groups, etc
Country/Location		List countries involved in the study
Phase2: Qualitative Data Extraction (Go to Phase 2 if paper has passed all criteria in Phase 1 above.)		
Understanding of DevSecOps (RQ1), including: definitions, challenges, practices, tools, and metrics.		RQ1. What is the state of art of DevSecOps in the existing literature? (List as many as you find)
The relationship between GSE and DevSecOps.		RQ2. How does Global Software Engineering relate to DevSecOps? (List as many as you find)
Additional Data/Follow Up		
Other observations or useful quotes found in paper		Record useful texts or exact quotes which can be used in our report
References found in paper/snowballing (to follow up)		Include more relevant studies based on the references of selected papers.