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**Case study analysis of the relationship between capabilities, practices,
challenges, and benefits when employing DevOps**

Alfredo Tiago Fânzeres Nunes Martins

Department of Information Sciences and Technologies

Master's in Telecommunications and Informatics Engineering

Supervisor:

Phd. Rúben Filipe de Sousa Pereira, Assistant Professor
ISCTE-IUL

Co- Supervisor:

Phd. João Carlos Marques Silva, Assistant Professor
ISCTE-IUL

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**Análise da relação das capacidades, práticas e dificuldades nos benefícios
presentes nos Casos de Estudo sobre a utilização de DevOps**

Alfredo Tiago Fânzeres Nunes Martins

Departamento de Ciências e Tecnologias da Informação

Mestrado em Engenharia de Telecomunicações e Informática

Orientador:

Phd. Rúben Filipe de Sousa Pereira, Professor Auxiliar
ISCTE-IUL

Co-Orientador:

Phd. João Carlos Marques Silva, Professor Auxiliar
ISCTE-IUL

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Resumo

As Tecnologias de informação, soluções e os serviços tecnológicos estão a ser cada vez mais adotados, num espectro de setores de indústria cada vez mais amplo o que indica uma tendência de crescimento. Esta tendência é inerente à necessidade constante de mudança e adaptação das empresa e organizações, num mercado global cada vez mais competitivo, que requer também a escolha de metodologias que permitam uma grande capacidade de adaptação e rápida integração das mudanças necessárias, para que os clientes não pensem em mudar-se para os seus concorrentes.

A metodologia DevOps favorece a rápida e constante integração de alterações, promove a melhoria dos processos, permite uma maior capacidade de entrega e melhoria das soluções, serviços e aplicações, garantindo assim uma maior capacidade de competir no mercado global e manter clientes.

Face ao interesse em estudar a adoção prática desta metodologia do lado das indústrias e do lado académico, casos de estudo em e sobre DevOps estão a ser publicados mais frequentemente.

Esta pesquisa contribui ao reunir o maior número possível de casos de estudo em DevOps de ambos os lados através de um Revisão Multivocal da Literatura. Permitirá quantificar as capacidades, práticas, benefícios e desafios que foram observados nos mesmos e analisar se existe associação e significância estatística entre as capacidades, práticas e desafios e os benefícios.

Palavras-Chave: DevOps, Caso de Estudo, Revisão Multivocal da Literatura, Capacidade, Capacidade Cultural, Capacidade Técnica, Capacidade Processual, Capacidade Medição, Prática, Benefício, Desafio.

Abstract

Information technologies, technological solutions and services are being widely adopted, in an increasingly broader spectrum of industry sectors, which indicates a growth trend. This trend is inherent to the constant need for change and adaptation of companies and organizations, in an increasingly competitive global market. Requiring methodologies that allow better adaptability and rapid integration of the necessary changes and improvements, so customers do not think about moving to their competitors.

The DevOps methodology favours the rapid and constant integration of changes, promotes the improvement of processes, and allows more effective delivery and improvement of solutions, services, and applications. Ensuring a more robust ability to compete in the global market and retain customers.

This is leading to case studies in and about DevOps being published more frequently, reflecting the growing interest in the industry and academic sides in examining the practical application of this methodology.

Using a Multivocal Literature Review, this research gathers as many case studies on DevOps as possible from both sides. This will enable quantifying the capabilities, practices, benefits, and challenges observed in them and analyzing the association and the statistical significance that the capabilities, practices, and challenges have on the benefits.

Keywords: DevOps, Case Study, Multivocal Literature Review, Capability, Cultural Capability, Measurement Capability, Process Capability, Technical Capability, Practice, Benefit, Challenge

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CHAPTER 1

Introduction

The use of Information Technology (IT), Technological Solutions and Services show a tendency for growth, as shown in a study made by Gartner “*Worldwide IT spending is projected to total \$4.5 trillion in 2022, an increase of 5.5% from 2021*”[1] in a market with a constant change of perspectives, ways, and needs[2]–[4].

The last two decades brought a constant need to survive, adapt and flourish which is only possible in industries and organizations with technology. The industries sectors where technology can be applied, according to Forbes[5] and CB Insights[6] will be broadened, due to an increasingly competitive global market. In these circumstances, the implementation of technology becomes crucial to the management and success of industries and organizations, enabling considerable gains when used and improved appropriately [3], [4], [7]. COVID-19 brought a reinforcement of IT solutions or services [8],[9] and the use of a methodology that allows greater adaptability and rapid integration of the necessary changes, so that customers do not think about moving to their competitors [10]. These requires an IT Team to develop them and the implementation of an interactive process between clients and providers [2], [11].

Traditionally IT Teams are divided into development (Dev) and operations (Ops) teams that operate as silos. This teams even using an agile methodology, focus on the Dev team bringing together developers, testers, and other stakeholders, but kept the Ops team as a separate silo that uses practices that would allow for better stability and performance.

This approach has several issues such as the existence of problems with the configurations at any phase of development [12] could have a large impact on the Software rate of release and quality. This affects the overall solution and could affect the company’s image, and loss of clients and/or users[12], [13]. This could lead to a lack of information exchange in a continuous release mode[14], and a struggle with communication[10] and collaboration. Also, having teams with separate technical and organisational levels and using different tools[15].

So, since their main purpose is to serve the same solution or service[16], increased collaboration between the teams is essential.

Therefore, demanding to move away from a traditional siloed Dev and Ops to a DevOps perspective[10], [14] to increase the cooperation between teams, to ensure successful deployment and a stable IT operations system[17], [18].

DevOps is a development methodology aimed at bridging, overcoming, and eliminating the gap between Dev and Ops teams, emphasizing cross-team communication, cooperation and collaboration, continuous integration, monitoring, quality assurance and delivery with automated deployment utilizing a set of agile development practices[13], [19]–[21] and in some cases, have people/teams actively, integrated and focused on the security aspect. That facilitate the integration and improvement of systems and processes, as well as delivering/improving products, services, projects, or applications [22] that can guarantee a more effective way of competing in the market and sustaining clients[14], [23]. This is possible because they use the same tools, work with a mutual development philosophy, which enables to have a wide range of multidisciplinary skills in the same team.

It appears that the industries are increasingly adopting DevOps [24] due to the increasing perception that “*DevOps is critical to meet with the rising pressure to innovate faster*” and this is only possible by “*reducing friction between developers and operations*”[25], thus influencing the major technology companies to sponsor a regular release of state reports[26]–[37] and conferences[38]–[41]. Also on the academic side, using a search of DevOps in Google Scholar resulted in 33 200 records in 2022-09-04, even considering the possibility of multiple duplicated records this shows a trend to study this methodology and the implications of its adoption.

Given the interest in studying the practical adoption of this methodology on the industries and academic sides, more frequently case studies in and about DevOps are being published on both sides.

Thus, this research aims to explore the capabilities, practices, benefits, and challenges that are present in the case studies and analyze the association and significance that the capabilities, practices, and challenges have on the benefits. To accomplish this, it is necessary to collect as many DevOps case studies as possible from both sides through a Multivocal Literature Review (MLR).

The remaining document consists of three chapters that are organized as follows: the Theoretical Background, the Research Methodology, and the Conclusion with the Limitations, Threats to Validity and Future Work.

Theoretical Background

This chapter is to clarify the concepts and definitions, related to our topic and derived from existing theories and empirical studies available in the academic literature. The topics that will be further detailed are DevOps, Case Studies, and ‘Grey’ Literature.

2.1. DevOps

A methodology that must integrate teams of development, IT operations, quality engineering, and security, that are working collaboratively throughout the product/service, project, or application lifecycle, to accomplish a goal and develop a range of skills not limited to a single function[42]–[45].

The influence of this methodology in the lifecycle is felt throughout all the phases. They rely on each other because the phases are not role specific. So, in a true DevOps methodology, each role is involved in each phase to some extent[42]–[45], in Figure 1 is possible to see all the phases of DevOps.

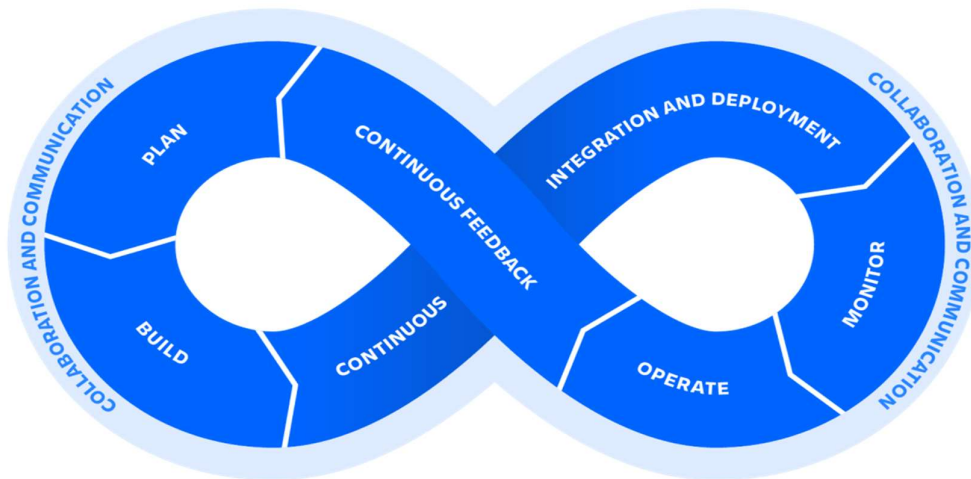


Figure 1 - DevOps Lifecycle retrieved from Atlasian[45]

The teams use a set of the most effective practices[42]–[46] that enables them to benefit from better collaboration between teams, increase the capacity of reaction and adaptation to change (speed), and better time to market (Rapid Delivery or Deployment), better adaptation to the market and competition, guarantee high quality and reliability, maintain system stability (improving the time to restore service), dynamic usage of infrastructure, scalability, flexible provisioning and security insurance and compliance[22], [42]–[45], [47].

These teams use tools that enable them to automate, and accelerate processes that lead to an increase in reliability and avoid common problems of working separately[42]–[45], [47], [48].

Since most tools can give measures, teams need to base their project performance on these metrics to improve efficiency and effectiveness. From there, it is possible to learn and invest in the processes and tools necessary to improve the project performance [42]–[45].

2.2. Case Study

This research method is used when a question of “why”, “what” or “how” will try to investigate a contemporary phenomenon or event that has little control over it within a real-life context *“when the boundaries between phenomenon and context are not evident; and in which multiple sources of evidence are used”* [49], [50], in areas with lack of research or prior work [50], [51].

This enables to gain an in-depth understanding of the subject studied, develop an initial hypothesis, establish a basis for future research, develop new theories, extend existing theories or test existing theories [52].

It can have a Single Case or Multiple Cases, but both must have multiple sources of evidence[53], [54] to be able to triangulate conclusions, which can be between different data sources (data triangulation), between different evaluators (investigators triangulation), between different perspectives on the same data set (theory triangulation) and of methods (methodological triangulation)[54].

2.3. ‘Grey’ Literature

This term was generally first defined in 1975 and used in public in 1978 by Auger[56], [57] when referring to the military intelligence reports and notes that were vastly produced after World War II.

The most widely used and accepted definition is the so-called Luxembourg created in 1997 [55] that was expanded in 2004[56] and in 2010[57] in the Conferences on ‘Grey’ literature (GL), moving away from the more economic-driven version of 1997[55] and 2004[56], introducing 4 brand-new attributes the *“(1) character of the document; (2) the presence of intellectual property protection; (3) a threshold level of quality review; and (4) overall collectability”*[57]–[59].

The revised definition is “*Grey literature stands for manifold document types produced on all levels of government, academics, business, and industry in print and electronic formats that are protected by intellectual property rights, of sufficient quality to be collected and preserved by library holdings or institutional repositories, but not controlled by commercial publishers i.e., where publishing is not the primary activity of the producing body*”.

Cochrane defines GL as “*literature that is not formally published in sources such as books or journal articles*”[60] but this does not mean that they are not subject to a review process James et al.[61] suggest that “*Many types of grey materials, such as patents and standards, undergo rigorous scrutiny through the process of establishing and passing the requirements of application and acceptance by experts in the discipline(s) they represent.*

The same is true for technical reports, as these digests from the field are vetted by the academy and the government agencies and corporations that fund them”.

So, GL should be formally recognized, because it can lead to the identification of emerging research topics and add additional value to the review[55]–[59], [62], [63] but still requires “*more specific guidelines for scholars on including grey literature in reviews are important as the practice of systematic review in our field continues to mature*”[64].

As shown in Table 1, ‘White’ literature sources are listed in the 1st tier with highest credibility, ‘Grey’ literature sources are listed in the 2nd tier with moderate credibility, and the in 3rd tier sources are listed with low credibility and will be disregarded[64]–[67].

Table 1 - Brief of the Spectrum of the ‘White’, ‘Grey’ and ‘Black’ literature

‘White’ literature[66]	‘Grey’ literature[66]	‘Black’ literature[67]
Published Journals	Preprints	Ideas
Published Magazines	e-prints	Concepts
Proceedings	Technical reports, Short-Papers, Poster, Thesis and Dissertations	Thoughts
Conference	Lectures	
Books	Data sets	
	Audio-Video (AV) media	
	Blogs	

Research Methodology

This study follows an MLR methodology which combines the ‘Grey’ and ‘White’ literature as seen in Figure 2, for this methodology, it is imperative to have a set of guidelines to ensure the high quality of MLR processes and their results [66], [68], [69], which need to be built upon the guidelines for conducting an SLR[70]–[73].

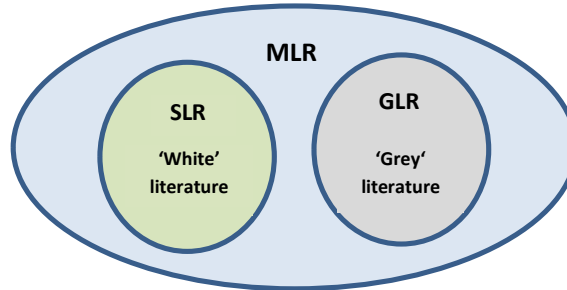


Figure 2 - MLR relationship with SLR and GLR

MLRs are critical for the expansion of the research since they provide summaries of both the state-of-the-art and practice in each area and this can give a richer synthetization of the chosen questions and/or subject[65], [66].

Some MLRs about different aspects of DevOps have already been done [10], [68], [74]–[79].

The following subsections will report all the decisions taken during the Planning and Conducting phases of the study. The Reporting the Review section, of the paper, will serve as the output of this research.

3.1 Planning the MLR

This section details the first phase of the MLR process, where it must be explained and presented what is the motivation for this research, what is the goal to do this research, what are the questions this research intends to address and answer, and then a Review Protocol is developed [66], [68].

3.1.1. Establishing the need and goals for an MLR

The need for an MLR and to include the “Grey” literature is due to the increased interest in DevOps which led to an increase in case studies from academics and industries published, that

explored and analyzed different but correlated aspects of the DevOps impacts in organizations, teams, and individuals.

Thus, the purpose of this Multivocal Literature Review is to combine both sides, enhancing the diversity of sources used, then using a concept-matrix approach[80] to fill in a table as each article is assessed, providing nominal data that can be analyzed to determine the extent that DevOps capabilities, practices, and challenges are associated with each benefit.

To the best of our knowledge, this is the first MLR on the topic.

3.1.2. MLR Research Questions

Based on the goal defined in section 3.1.1, it was formulated two research questions.

RQ1 – What are the capabilities, practices, benefits, and challenges identified in the Case Studies in DevOps in the ‘White’ literature and in the ‘Grey’ literature?

RQ2 – What is the significance that capabilities, practices, and challenges have on the benefits?

3.1.3. Review Protocol

This protocol describes how the literature is systematically gathered and what were the criteria’s used for including each source of data.

The first stage of the review protocol is a literature search, so a search string must be defined and applied to the chosen data sources with the intent of retrieving the highest possible number of studies related to the proposed research questions. The **search string** is “DevOps” And “Case Study”.

To gather the maximum number of studies related to the proposed research questions, a set of online repositories were chosen. The ‘White’ literature repositories chosen are as follows:

- IEEE Xplore Digital Library (IEEE) (<https://ieeexplore.ieee.org/Xplore/home.jsp>);
- Elsevier (<https://www.sciencedirect.com/>);
- ACM Digital Library (ACM) (<https://dl.acm.org/>) in The ACM Guide to Computing Literature;
- Web of Science (WOS) (<https://login.webofknowledge.com/>);
- SpringerLink (<https://link.springer.com/>);
- Scopus (<https://www.scopus.com/home.uri>);
- Google Scholar (<http://www.scholar.google.com>).

The filtering and snowballing MLR processes presented in Figure 3 will be done in each repository.

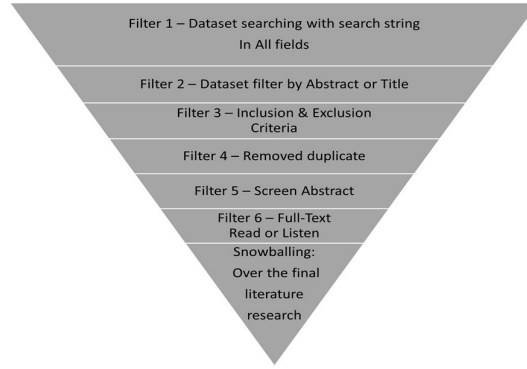


Figure 3 - MLR process (adapted) [66]

To these repositories, Google was added as a search tool to find ‘Grey’ literature to the proposed search string.

The Filter 3 - Inclusion and exclusion criteria are applied to the results of the Filter 2 in all data repositories. The criteria are presented in Table 2.

Table 2 - Inclusion & Exclusion Criteria's

Inclusion Criteria	Exclusion Criteria
Written in English or Portuguese	Not Written in English or Portuguese
Full-text accessible	Inaccessible Literature
Scientific papers in Conferences, Proceedings Journals, Magazines, or Books	Short-Papers, Poster
‘Grey’ Literature in Blogs, Sites or other	No Publication date
Explicit discuss DevOps Case Studies	Vendor Tool Advertisement
Thesis and Dissertations	Videos with less than 10 minutes

When applied the inclusion and exclusion criteria presented in Table 2 to the ‘White’ literature and ‘Grey’ literature a set of articles is retrieved. First, the duplicated results need to be removed from the last set of articles. Second, the abstract must be screened and remove the unrelated literature from the last set of articles. Third, the full text of the article must be assessed or listen to and remove the unrelated literature from the last set of articles. Then, a backwards and forwards snowballing[81] in the last set of the relevant article is done with an additional approach that was introduced of considering as a different case study if this had significant data about them, only at this point the final selection of studies is obtained.

3.2 Conducting the MLR

This section describes how the review is conducted which is the second phase of the MLR [66], [68].

After the search string is determined, it is determined the selection criteria and the selection

process is performed in the chosen repositories to retrieve a set of ‘White’ and ‘Grey’ literature. To this set, their quality must be assessed via the inclusion and exclusion criteria, where it should be determined the extent to which a source is valid and free of bias.

Initially, a search with the selected search string in each repository is done with its default filter. However, all the electronic libraries use different “search approaches,” so a filter adaptation for each repository is implemented, to guarantee a similar protocol per repository.

The **Filter 1** in the ‘White’ literature searches the **search string** in all the text of the repository so for **ACM** is the “*Full Text*” criteria, for **Elsevier** is the “*Find articles with these terms*” criteria, for **Google Scholar** is the “*Search in any part of the article*”, for **IEEE Xplore** is the “*Full Text Only*” criteria, for **Scopus** is the “*ALL*” criteria, for **Springer** is the “*With all of the Words*” criteria and for **WOS** is the “*All Fields*” criteria. This resulted in a total of **15047** articles following the distribution per repository in Table 3.

The **Filter 1** in the ‘Grey’ literature searches the **search string** in the **Google Search Engine** which returned at least **1 350 000** results, requiring a more direct approach assessment of quality per result to go through the search results faster without disregarding. The Search is stopped when reaching theoretical saturation (no more relevant sources appear). This resulted in a total of **228** publications and/or videos in Table 3.

The **Filter 2** in the ‘White’ literature searches the keywords in the abstract and/or title when the abstract is not available in the repository so for **ACM** is the “*Abstract*” criteria, for **Elsevier** is the “*Title, abstract or author-specified keywords*”, for **Google Scholar** is the “*Title*” criteria, for **IEEE** is the “*Abstract*” or “*Document Title*” criteria, for **Scopus** is the “*Abstract*” criteria, for **Springer**, there are no “*Abstract*” criteria, so it has to be used only the “*Title*” criteria and for **WOS** is the “*Topic*” criteria. This resulted in a significant reduction from a total of **15047** to **644** articles following the distribution per repository in Table 3.

The **Filter 2** in the ‘Grey’ literature has the same literature **228** publications and/or videos in Table 3 of **Filter 1**.

The **Filter 3** in the ‘White’ literature applies the inclusion/exclusion criteria. This resulted in another significant reduction from a total of **644** to **461** articles following the distribution per repository in Table 3.

The **Filter 3** in the ‘Grey’ literature applies the inclusion/exclusion criteria. This resulted in a reduction from a total of **228** to **219** publications and/or videos that require further analysis in Table 3.

A data extraction form and procedure must be designed to collect the final set of articles that will help to address the review questions. So, all the literature encountered after the **Filter 3** must be retrieved and put in an excel sheet that needs to have the Source, Title, Type and Year per article, at this point this extraction as total of **680** articles. The below filters will be used to obtain a unique final set of articles, disregarding the articles that were not chosen after each filter.

In the **Filter 4**, the title articles (disregarding the source) will be put in alphabetical order, to find duplicated articles and chose their ‘representative’. This resulted in a reduction from a total of **680** to **524** articles following the distribution per repository in Table 3.

The **Filter 5** assesses the article’s Abstract, to verify if this article is about a Case Study in DevOps, this can only be done in the ‘White’ literature. This resulted in a significant reduction from a total of **524** to **280** articles following the distribution per repository in Table 3.

The **Filter 6** requires reading the whole text or listening if indeed, to validate if it is a DevOps Case Study. This resulted in a reduction from a total of **280** to **179** articles in Table 3.

Snowballing – Backwards and Forwards[81] in the references of the articles that resulted from the **Filter 6**. An additional approach was introduced of considering as a different case study if the literature was talking about multiple companies, teams or projects and had significant data about them, **43** new case studies were derived from the Sixth Filter. Resulting in a total of **222** articles in Table 3.

Table 3 - Filters Used in the MLR

Repository	Filter 1	Filter 2	Filter 3	Filter 4	Filter 5	Filter 6	Snowballing
ACM	1652	215	103	129	34	11	43
Elsevier	269	7	7	5	5	3	
Google	228	228	219	214	155	123	
Google Scholar	8080	19	13	9	5	3	
IEEE Xplore	1492	58	55	45	31	14	
Scopus	1579	162	121	56	33	15	
Springer	1839	58	44	30	8	5	
Web of Science	136	125	118	36	10	6	
Total	15275	872	680	524	280	179	222

3.2.1. Data synthesis

Of the **222** articles, **33** were YouTube videos that had a total of 18 hours, 43 minutes, and 59 seconds. In Table 4 is possible to validate that DevOps can affect and be used in several Sectors such as Entertainment, Banking, Consulting, Telecommunications, Information Technology, and Government, and the number of case studies identified per sector.

Table 4 - Distribution of Articles in a Sector per Year

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Articles
01	0	0	0	0	[82]–[84]	[85]–[87]	0	[88]	[89], [90]	0	0	9
02	0	0	[91]–[93]	[94], [95]	[96]	[97]	[98]	[99], [100]	[101], [102]	[103]	[104], [105]	15
03	0	0	[106]	[107], [108]	[109]–[112]	[113]–[116]	[117], [118]	[119]–[121]	[122]–[125]	[126]	[127]	22
04	0	0	0	0	[128]	[129]–[132]	[133]	[134]	[135]	[136]	[137]–[139]	12
05	0	0	0	[140]	[141], [142]	[143]–[145]	0	0	[146]–[148]	[149], [150]	[151]	12
06	0	0	[152]	0	[153], [154]	[155], [156]	[157], [158]	[159]	0	0	0	8
07	0	0	0	[160], [161]	[162]	[163]	0	[164]	[165]	0	0	6
08	0	0	0	[166]	[167]	[168]	0	0	[169]	0	[170]	5
09	0	0	0	0	0	0	0	0	[171]	[172]	0	2
10	0	0	0	[173], [174]	0	0	[175]	[176]	0	[177]	[178]	6
11	0	[179]	[180]–[184]	[185]–[189]	[47], [190]–[198]	[199]–[202]	[203]–[208]	[209]–[214]	[215]–[223]	[224]–[229]	14[230]–[243]	66
12	0	0	0	0	0	0	[244]	0	[245]	[246]	0	3
13	0	0	0	0	0	0	0	[247], [248]	0	0	0	2
14	[249]	0	0	0	0	0	[250]	0	0	[251], [252]	0	4
15	0	0	0	0	[253], [254]	0	0	[255]–[257]	[258]–[265]	0	0	13
16	0	0	0	0	0	0	[266]	0	0	[267], [268]	0	3
17	0	0	0	[269]	[270]	[271]	0	0	[272]	0	0	4
18	0	0	0	0	[273]	0	0	0	0	0	0	1
19	0	0	0	0	0	[274]	0	0	0	0	0	1
20	0	0	0	0	0	0	[275]	[276]	0	0	0	2
21	0	0	0	0	0	0	0	0	[277]	[278]	0	2
22	0	0	0	0	0	0	0	[279]	0	0	0	1
23	0	0	0	0	0	0	0	0	0	[280]	0	1
0	0	0	0	0	[281]–[286]	[287], [288]	[289], [290]	[291], [292]	[293]–[296]	[297], [298]	[299]–[302]	22
Total	1	1	10	16	35	27	19	25	39	22	27	222

Note:

01 - Health, 02 - Entertainment, 03 - Banking, 04 - Consulting, 05 - Telecommunications, 06 - Media, 07 - Airline, 08 - Retail, 09 - Communications, 10 – Food & Beverage, 11 - IT, 12 - Manufacturing, 13 - Education, 14 - Logistics, 15 - Government, 16 - Insurance, 17 - Real State, 18 – Automotive, 19 - Culture, 20 - Human Capital, 21 - Research & Development, 22 - Space Exploration, 23 - Energy, 0 - N/A.

3.3 Reporting the Review

The final phase of a systematic review involves summarizing the extracted data and writing up the results of the review.

3.3.1. Answer for RQ1 – What are the capabilities, practices, benefits, and challenges identified in the Case Studies in DevOps in the ‘White’ literature and in the ‘Grey’ literature?

To ease the identification of the capabilities, practices, benefits, and challenges present in each of the Case Studies in and about DevOps, which are going to be considered as the test variables of the nominal analysis, a review was done of the literature that enabled to derive:

- A total of 37 capabilities from the article [303] where they were identified and categorized into four major categories:
 1. The cultural category has **seven** capabilities which are “*Cross team collaboration and communication*”, “*Support learning culture and experimentation*”, “*Open-source software adoption*”, “*Transformational leadership*”, “*Performance/ westrum organizational culture*”, “*Blameless postmortems/reduced fear of failure*” and “*Job satisfaction*”.
 2. The measurement category has **five** capabilities which are “*Proactive monitoring, observability and autoscaling*”, “*Emergency response/proactive failure notification*”, “*Monitor systems to inform business decisions*”, “*Working in progress limits*” and “*Visual management capabilities*”.
 3. The process category has **seven** capabilities which are “*Continuous improvement of processes/ workflows*”, “*Focus on people, process, and technology*”, the “*Working in small batches*”, “*Lightweight change approval*”, “*Visibility of work in the value stream*”, “*Customer focus/feedback*” and “*Data-driven approach for improvements*”.
 4. The technical category has **18** capabilities which are “*Continuous Integration*”, “*Continuous delivery/deployment automation*”, “*Test automation and environments*”, “*Version control system*”, “*Empower teams to make decisions/changes*”, “*Configuration management*”, “*Cloud infrastructure and cloud native*”, “*Artifacts versioning and registry*”, “*Loosely coupled architecture*”, “*Database change management*”, “*Infrastructure as code*”, “*Containerization*”, “*Shift left on security*”, “*Trunk based development*”, “*Centralized log*”.

management”, “*Test data management*”, “*Chaos engineering*”, and “*Code maintainability*”.

- A total of **11** practices from the articles [43], [45], [47], [205], [303]–[307] which are “*Communication and collaboration*”, “*Continuous planning*”, “*Continuous development*”, “*Continuous testing*”, “*Continuous integration*”, “*Continuous delivery*”, “*Continuous deployment*”, “*Continuous monitoring and register in log*”, “*Establish measures and metrics*”, “*Microservices*” and “*Infrastructure as code*”.
- A total of **12** benefits from the articles [44], [47], [205], [303], [307] which are “*Faster & better product delivery*”, “*Faster issue resolution & reduced complexity*”, “*Greater scalability & availability*”, “*More stable operating environments*”, “*Better resource utilization*”, “*Greater automation*”, “*Quality and reliability*”, “*Greater visibility into system outcomes*”, “*Improved collaboration*”, “*Greater innovation*”, “*Accountability*” and “*Security*”.
- The challenges were derived from the literature [12], [47], [88], [134], [164], [205], [225], [305], [308]–[313] and discerned in the **222** articles in and about the adoption of DevOps, resulting in a total of **18** different challenges.
- The analysis of the **222** articles revealed the necessity to include:
 - The process capability “*Dev & Ops feedback loops*”, resulting in a total of **eight** process capabilities, leading to have a total of **38** capabilities.
 - The technical capability “*Test-driven development*”, resulting in a total of **19** technical capabilities, leading to have a total of **39** capabilities.
 - The benefit of “*Financial savings*”, resulting in a total of **13** benefits.

Leading to a total of **81** test variables that resulted from the literature and were discerned in the **222** articles, which can be seen in Table 5.

Table 5 - Summary of the 81 test variables

Capabilities (39)				Practices (11)	Benefits (13)	Challenges (18)
Cultural capabilities (7)	Measurement capabilities (5)	Process capabilities (8)	Technical capabilities (19)			

Legend: (total)

In the next pages, the figures will show the average of 0’s (%) (no) and the average of 1’s (%) (yes) this indicates the overall occurrence of the capabilities, practices, benefits, and challenges in the **222** articles. To get this data, a concept-matrix approach was required, which

provided a way to identify and/or perceive the capabilities, practices, benefits, and challenges present in each case study, thus providing nominal data.

The occurrence of the cultural capabilities can be observed in Figure 4, the occurrence of the measurement capabilities can be observed in Figure 5, the occurrence of the process capabilities can be observed in Figure 6 and the occurrence of the technical capabilities can be observed in Figure 7 and these are seen as the requirements, the enablers, and the added value for and of the adoption of DevOps.

The occurrence of the practices can be observed in Figure 8 and are seen as the techniques or methodologies for the adoption of DevOps.

The occurrence of the benefits related to the adoption of DevOps can be observed in Figure 9.

The occurrence of the challenges related to the adoption of DevOps can be observed in Figure 10.

The **three** cultural capabilities with the highest occurrence in the 222 retrieved articles are “Cross team collaboration and communication”, “Support learning culture and experimentation” and “Transformational leadership” as shown in Figure 4.

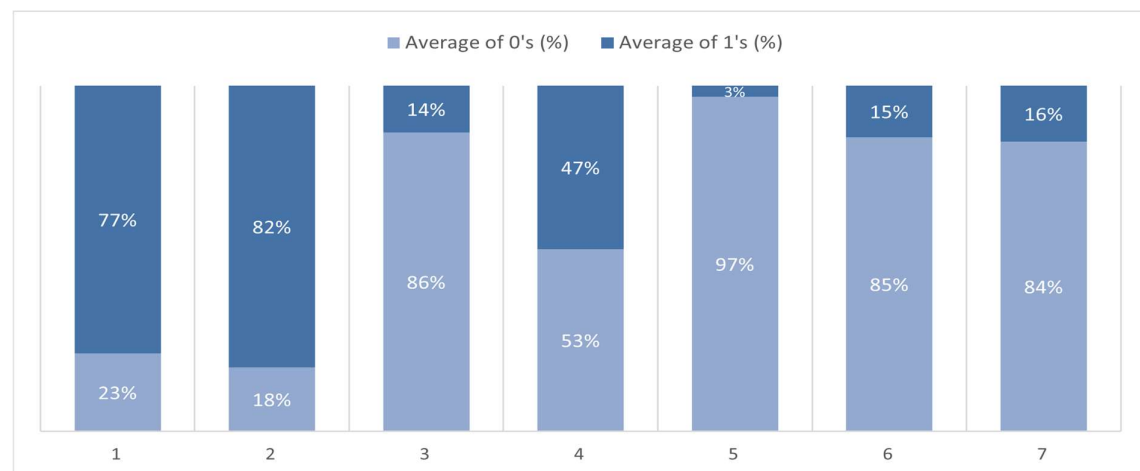


Figure 4 - Descriptive Map of Cultural Capabilities

Legend:

1 - Cross team collaboration and communication; 2 - Support learning culture and experimentation; 3 - Open-source software adoption; 4 - Transformational leadership; 5 - Performance/western organizational culture; 6 - Blameless postmortems/ reduced fear of failure; 7 - Job satisfaction.

The **three** measurement capabilities with the highest occurrence in the 222 retrieved articles are “Proactive monitoring, observability and autoscaling”, “Emergency response/proactive failure notification” and “Monitor systems to inform business decisions” as shown in Figure 5.

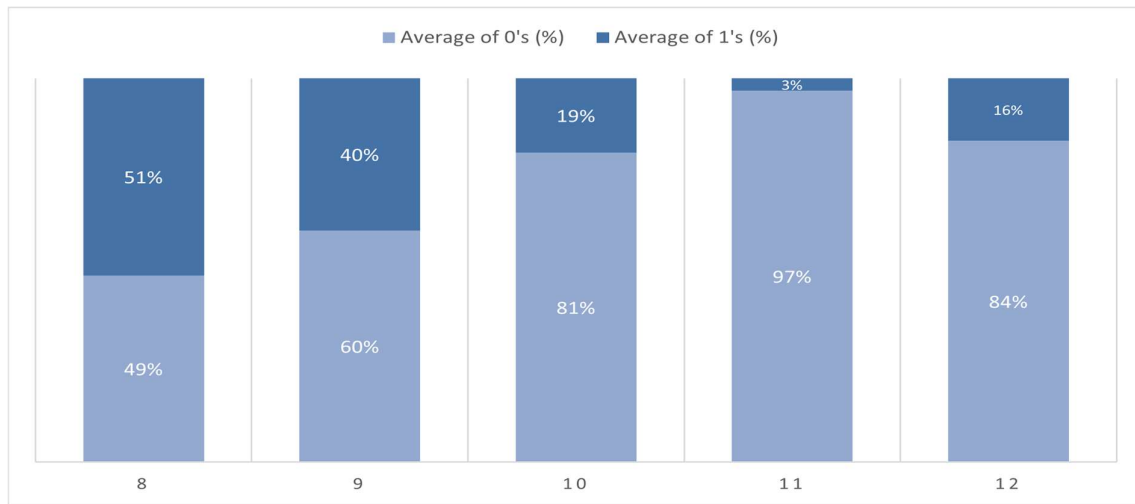


Figure 5 - Descriptive Map of Measurement Capabilities

Legend:

8 - Proactive monitoring, observability and autoscaling; 9 - Emergency response/proactive failure notification; 10 - Monitor systems to inform business decisions; 11 - Working in progress limits; 12 - Visual management capabilities.

The **three** process capabilities with the highest occurrence in the 222 retrieved articles are “Continuous improvement of processes/ workflows”, “Focus on people, process, and technology” and “Working in small batches” as shown in Figure 6.

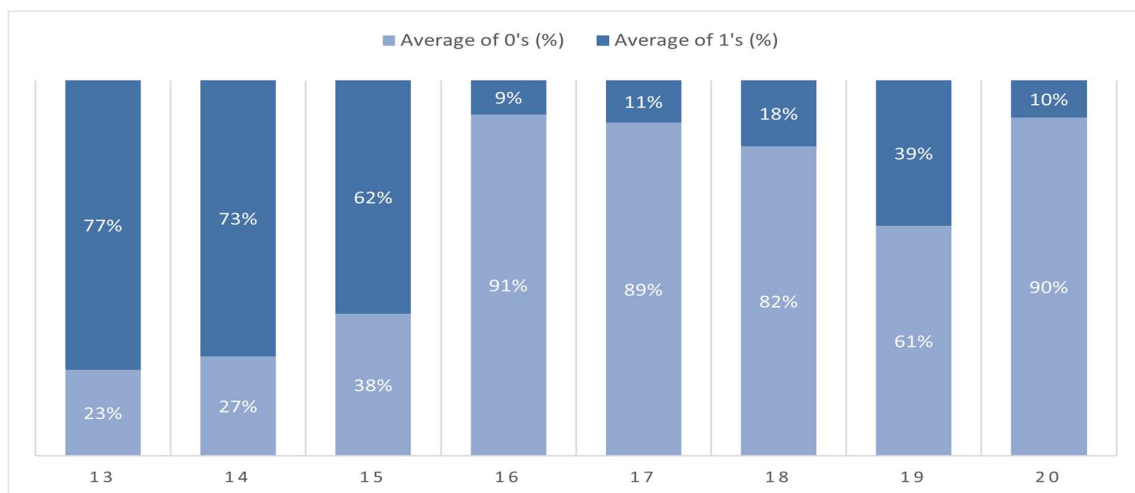


Figure 6 - Descriptive Map of Process Capabilities

Legend:

13 - Continuous improvement of processes/ workflows; 14 - Focus on people, process, and technology; 15 - Working in small batches; 16 - Lightweight change approval; 17 - Visibility of work in the value stream; 18 - Dev & Ops feedback loops; 19 - Customer focus/feedback; 20 - Data-driven approach for improvements.

The **three** technical capabilities with the highest occurrence in the 222 retrieved articles are “*Continuous integration*”, “*Continuous delivery/deployment automation*” and “*Test automation and environments*” as shown in Figure 7.

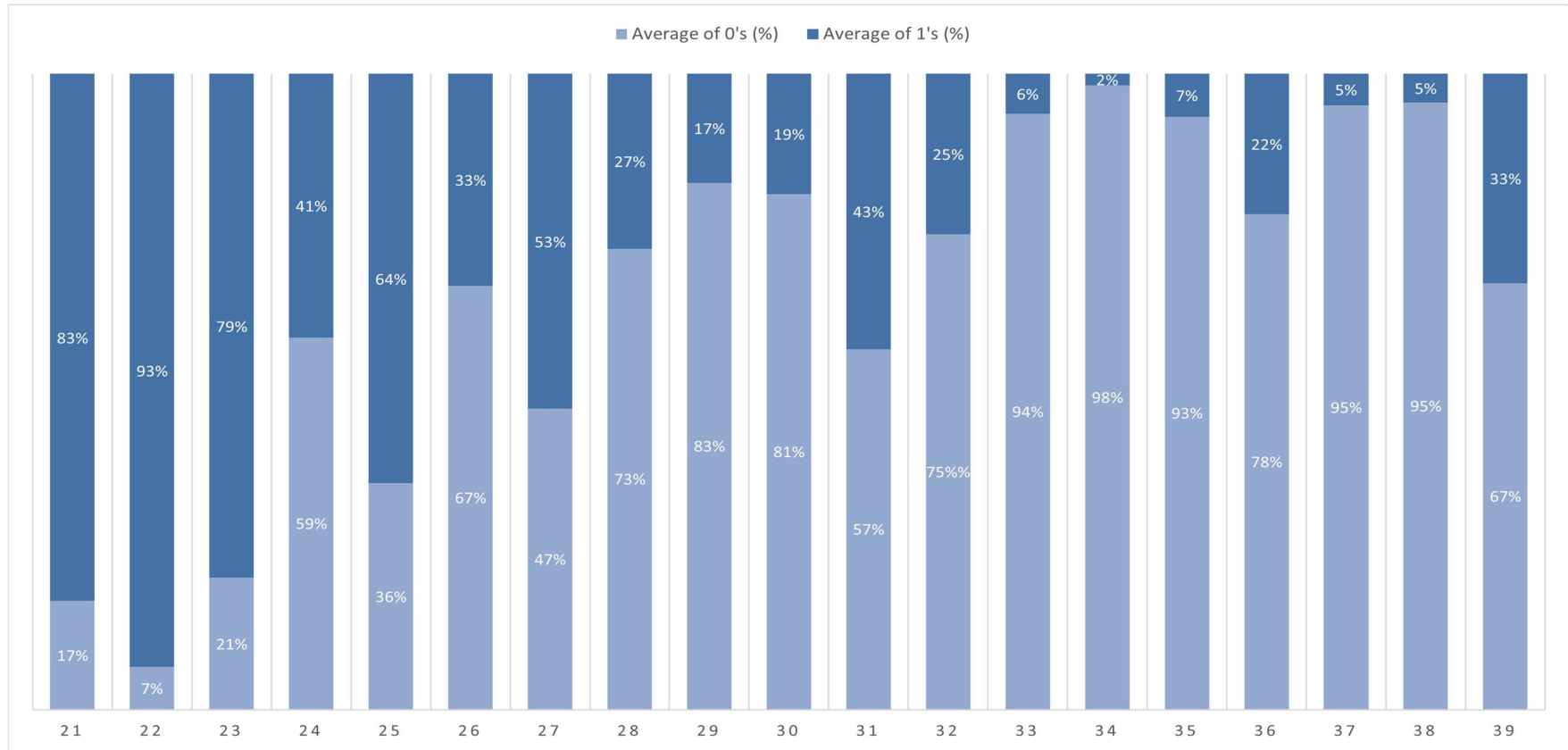


Figure 7 - Descriptive Map of Technical Capabilities

Legend:

21 - Continuous integration; 22 - Continuous delivery/deployment automation; 23 - Test automation and environments; 24 - Version control system; 25 - Empower teams to make decisions/changes; 26 - Configuration management; 27 - Cloud infrastructure and cloud native; 28 - Artifacts versioning and registry; 29 - Loosely coupled architecture; 30 - Database change management; 31 - Infrastructure as Code; 32 - Containerization; 33 - Shift left on security; 34 - Test-driven development; 35 - Trunk based development; 36 - Centralized log management; 37 - Test data management; 38 - Chaos engineering; 39 - Code maintainability.

The **three** practices with the highest occurrence in the 222 retrieved articles are “*Continuous Integration*”, “*Continuous delivery*” and “*Continuous deployment*” as shown in Figure 8.

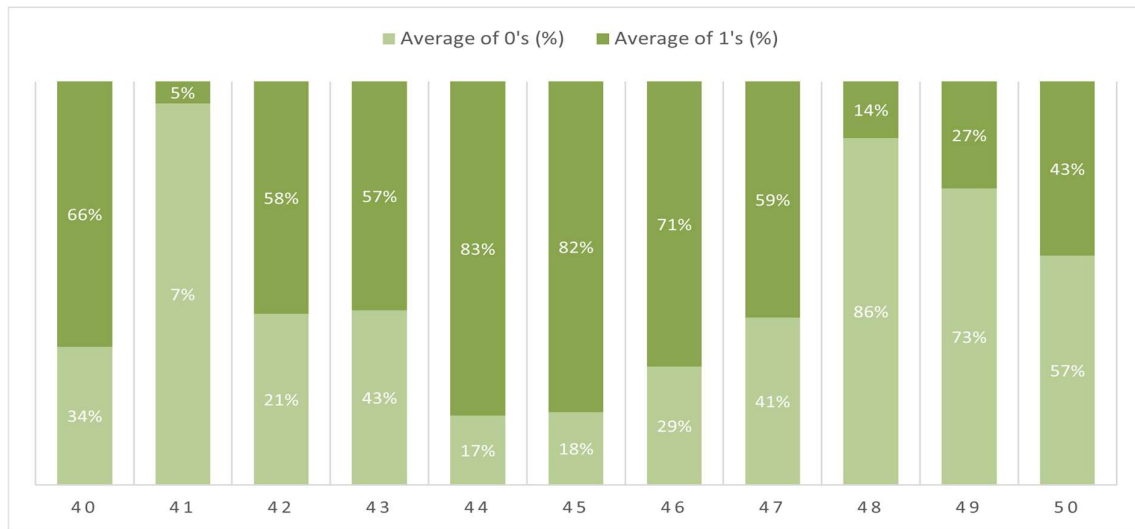


Figure 8 - Descriptive Map of Practices

Legend:

40 - Communication and collaboration; 41 - Continuous planning; 42 - Continuous development; 43 - Continuous testing; 44 - Continuous integration; 45 - Continuous delivery; 46 - Continuous deployment; 47 - Continuous monitoring and register in log; 48 - Establish measures and metrics; 49 - Microservices; 50 - Infrastructure as code.

The **three** benefits with the highest occurrence in the 222 retrieved articles are “*Faster & better product delivery*”, “*Greater automation*” and “*Quality and reliability*” as shown in Figure 9.

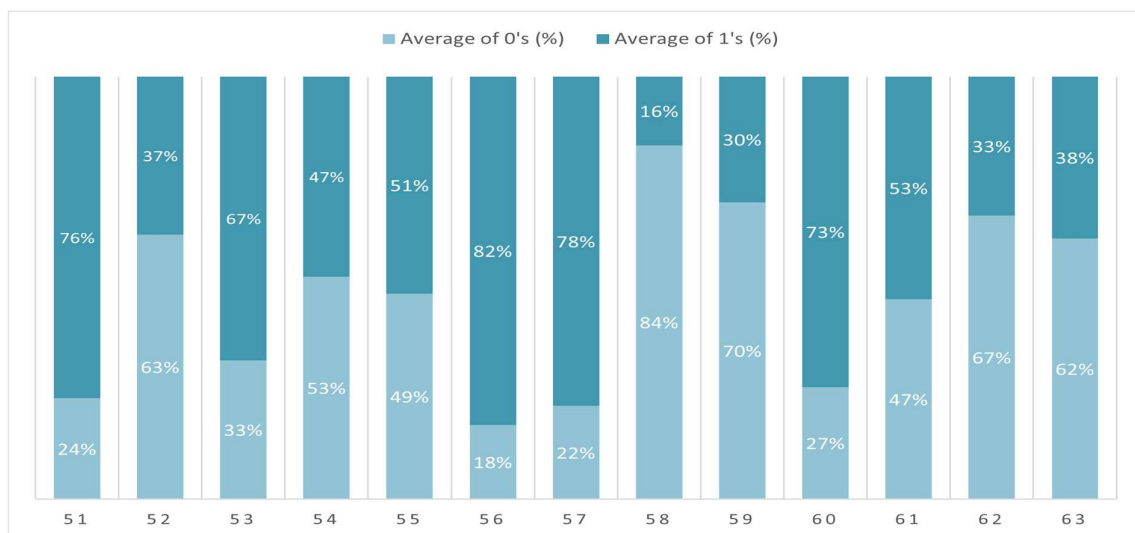


Figure 9 - Descriptive Map of Benefits

Legend:

51 - Faster & better product delivery; 52 - Faster issue resolution & reduced complexity; 53 - Greater scalability & availability; 54 - More stable operating environments; 55 - Better resource utilization; 56 - Greater automation; 57 - Quality and reliability; 58 - Greater visibility into system outcomes; 59 - Financial savings; 60 - Improved collaboration; 61 - Greater innovation; 62 - Accountability; 63 - Security.

The **three** challenges with the highest occurrence in the 222 retrieved articles are “Overcoming the Dev vs Ops mentality”, “Getting started with continuous learning” and “Having staff with the right technical skill” as shown in Figure 10.

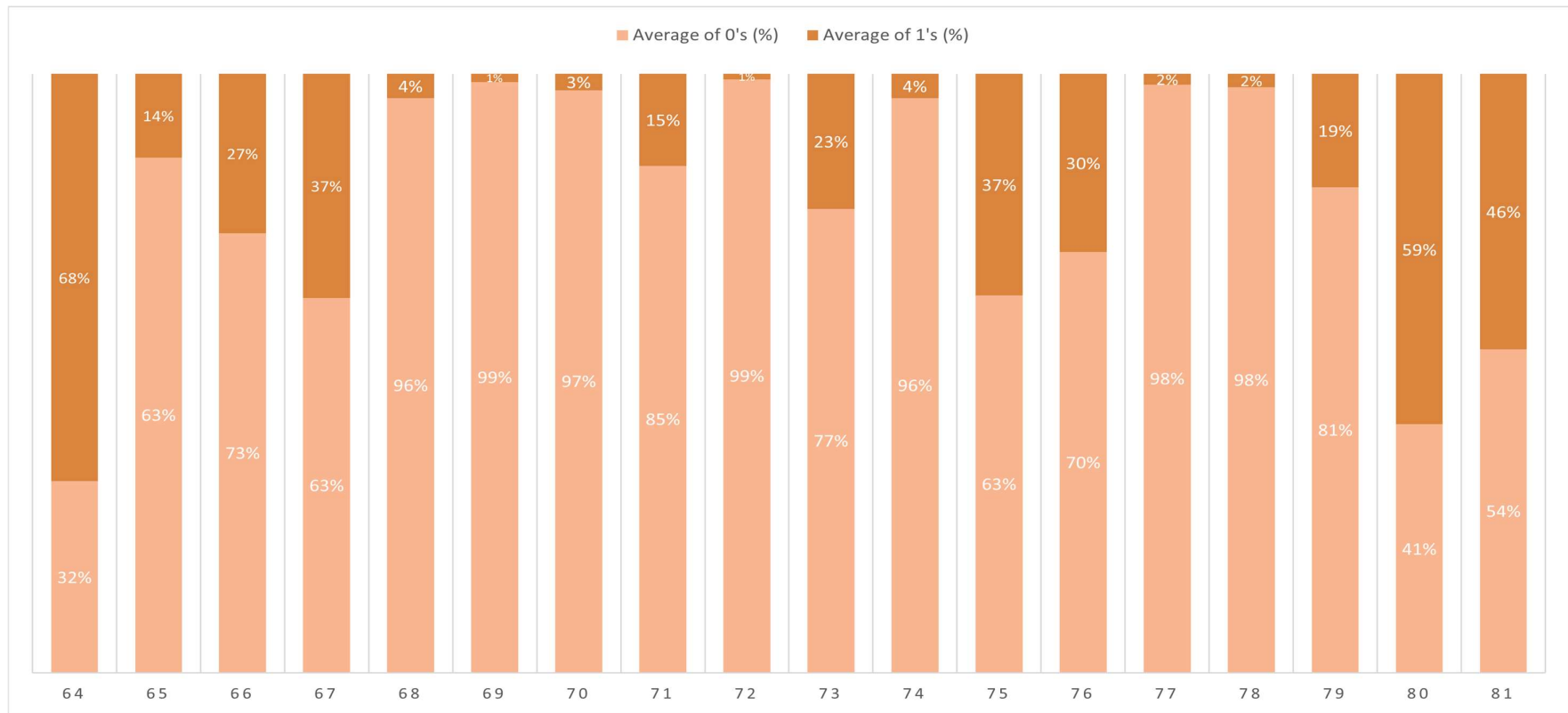


Figure 10 - Descriptive Map of Challenges

Legend:

64 - Overcoming the Dev vs Ops mentality; 65 - Insufficient communication and collaboration issues; 66 - Common understanding of continuous delivery practices; 67 - Moving from legacy infrastructure architecture to IaaS; 68 - Project and resource constraints; 69 - Balancing between speed and quality; 70 - Difficulties in monitoring; 71 - Moving from legacy architecture to microservices; 72 - Lack of organizational support; 73 - Implementing a test automation strategy; 74 - Too much focus on tools; 75 - Team ownership for deployments & releases; 76 - Resistance to change and uncertainty; 77 - Lack of metrics; 78 - Dev and Ops toolset clashes; 79 - Share knowledge; 80 - Getting started with continuous learning; 81 - Having staff with the right technical skill.

3.3.2. Answer for RQ2 – What is the significance that capabilities, practices, and challenges have on the benefits?

The software SPSS Statistics was chosen to analyze the retrieved nominal data. The nominal data with binary values, the 0 (no) and 1(yes) indicate whether the capabilities, practices, benefits, and challenges were discerned and/or identified in each case study.

The analysis examined the significance that each cultural capability, measurement capability, process capability, technical capability, practice, and challenge (1st group), have in each benefit (2nd group).

When testing 2 groups with SPSS Statistics, it is possible to use the Independent Samples T-Test[314] which is more commonly used when the test variables are continuous values and the Two Proportion Test[315] when the test variables are binary values with the Chi-Square Test of Independence[316], [317], therefore the Chi-Square Test of Independence must be utilized. This test requires to have a null hypothesis and an alternative hypothesis defined as:

- Null hypothesis: There are no associations between the groups[318];
- Alternative hypothesis: There are associations between the groups[318].

For the analysis:

- The test variables from the 1st group with an occurrence in the **222** retrieved articles below **10%** will not be considered, due to their association test with each 2nd group variable being a cell count assumption not met.
- Only the test variables that have a relative maximum of common occurrence will be considered.
- The Chi-Square Test of Independence and the Yates' Continuity of Correction significance level $\alpha = .05$ (or p-value of .05) was used to check the statistical significance between the groups[319]–[321]. This means that results with a level lower or equal to .05 reject the Null hypothesis (There are no associations between the groups), therefore confirming the Alternative hypothesis, and that results above .05 accept the Null hypothesis and will not be considered.
- The Cramer's V coefficient [321] is used to better evaluate the strength of a statistically significant association with the classifications in Table 6, and the weak associations will not be considered.

Table 6 – Cramer's V Considered Classifications

Level	Value
weak	< 0.10
moderate	[0.10; 0.25[
strong	> 0.25

3.3.2.1. Benefits Analysis

The following sub-chapters will show the test variables from the 1st group, cultural capabilities, measurement capabilities, process capabilities, technical capabilities, practices, and challenges that show an association and statistical significance to each test variable from the 2nd group (benefit).

3.3.2.1.1. “Faster & better product delivery”

This benefit occurred in **76%** of the **222** retrieved articles as seen in previously in **Figure 9 in chapter 3.3.1 Answer for RQ1**. In the analysis, it was able to discover **14** test variables from the 1st group that showed an association and statistical significance that can be viewed in Table 7.

Of the **14** a total of **10** test variables from the 1st group showed a strong statistical significance which are the process capability “Working in small batches”, the technical capabilities “Continuous integration”, “Continuous delivery/deployment automation” and “Test automation and environments” and the practices “Continuous testing”, “Continuous integration”, “Continuous delivery”, “Continuous deployment”, “Continuous monitoring and register in log” and “Establish measures and metrics”.

Of the **14** a total of **four** test variables from the 1st group showed a moderate statistical significance which are the cultural capability “Support learning culture”, the practice “Continuous development” and the challenges “Getting started with continuous learning” and “Having staff with the right technical skill”.

Table 7 – Association Test Results for the Benefit “Faster & better product delivery”

	Common identifications and/or discernations	Pearson-Chi Square Value	Pearson-Chi Square Sig	Continuity Correction Value	Continuity Correction Sig	Cramer's V
2	65.3%	8,561 ^a	0.003	7,415	0.006	0.196
15	53,6%	20,494 ^a	<0.001	19,051	<0.001	0.304
21	69.4%	33,890 ^a	<0.001	31,500	<0.001	0.391
22	74.3%	21,653 ^a	<0.001	18,833	<0.001	0.312
23	69,4%	22,633 ^a	<0.001	20,601	<0.001	0.319
42	49,1%	13,563 ^a	<0.001	12,415	<0.001	0.247
43	52,2%	16,543 ^a	<0.001	15,198	<0.001	0.273
44	69.4%	33,890 ^a	<0.001	31,500	<0.001	0.391
45	68.5%	30,356 ^a	<0.001	28,141	<0.001	0.370
46	59%	15,780 ^a	<0.001	14,436	<0.001	0.267
47	58,1%	16,148 ^a	<0.001	14,804	<0.001	0.370
48	76,1%	73,958 ^a	<0.001	69,404	<0.001	0.577
80	47.7%	5,056 ^a	0.025	4,363	0.037	0.151
81	38,7%	6,960 ^a	0.008	6,152	0.013	0.177

This table only has test variables with a moderate or strong association

Legend: ^a 0 cells (0,0%) have expected count less than 5.

2 – Support learning culture and experimentation; 15 – Working in small batches; 21 – Continuous integration; 22 – Continuous delivery/deployment automation; 23 – Test automation and environments; 42 – Continuous development; 43 – Continuous testing; 44 – Continuous integration; 45 – Continuous delivery; 46 – Continuous deployment; 47 – Continuous monitoring and register in log; 48 – Establish measures and metrics; 80 – Getting started with continuous learning; 81 – Having staff with the right technical skill.

3.3.2.1.2. “Faster issue resolution & reduced complexity”

This benefit occurred in **37%** of the **222** retrieved articles as seen in previously in **Figure 9 in chapter 3.3.1 Answer for RQ1**. In the analysis, it was able to discover **3** test variables from the 1st group, which are the practices “Continuous testing”, “Continuous deployment” and “Continuous monitoring and register in log”, that show an association and strong statistical significance that can be viewed in Table 8.

Table 8 – Association Test Results for the Benefit “Faster issue resolution & reduced complexity”

	Common identifications and/or discernations	Pearson-Chi Square Value	Pearson-Chi Square Sig	Continuity Correction Value	Continuity Correction Sig	Cramer’s V
43	37.4%	62,330 ^a	<0.001	60,004	<0.001	0.530
46	37.4%	54,882 ^a	<0.001	52,647	<0.001	0.497
47	37.4%	58,533 ^a	<0.001	56,254	<0.001	0.513

This table only has the tests variables with a strong association

Legend: ^a 0 cells (0,0%) have expected count less than 5.

43 – Continuous testing; 46 – Continuous deployment; 47 – Continuous monitoring and register in log.

3.3.2.1.3. “Greater scalability & availability”

This benefit occurred in **67%** of the **222** retrieved articles as seen in previously in **Figure 9 in chapter 3.3.1 Answer for RQ1**. In the analysis, it was able to discover **17** test variables from the 1st group that showed an association and statistical significance that can be viewed in Table 9.

Of the **17** a total of **eight** test variables from the 1st group showed a strong statistical significance which are the measurement capability “Proactive monitoring, observability”, the technical capabilities “Test automation and environments”, “Empower teams to make decisions/changes”, “Cloud infrastructure and cloud native” and “Infrastructure as Code”, the practices “Continuous development” and “Infrastructure as code” and the challenge “Having staff with the right technical skill”.

Of the **17** a total of **nine** test variables from the 1st group showed a moderate statistical significance that are the measurement capability “Emergency response/proactive failure notification”, the process capabilities “Continuous improvement of processes/ workflows” and “Focus on people, process, and technology”, the technical capabilities “Continuous integration” and “Continuous delivery/deployment automation”, the practices “Continuous integration”,

“Continuous delivery” and “Establish measures and metrics” and the challenge “Getting started with continuous learning”.

Table 9 – Association Test Results for the Benefit “Greater scalability & availability”

	Common identifications and/or discernations	Pearson-Chi Square Value	Pearson-Chi Square Sig	Continuity Correction Value	Continuity Correction Sig	Cramer’s V
8	44,6%	41,311 ^a	<0.001	39,494	<0.001	0.431
9	38,3%	12,793 ^a	<0.001	11,791	<0.001	0.240
13	63,1%	10,695 ^a	0.001	9,243	0,002	0.219
14	61,7%	7,160 ^a	0.007	6,038	0,014	0.180
21	59%	8,102 ^a	0.004	7,058	0.008	0.191
22	64,4%	5,360 ^a	0.021	4,123	0.042	0.155
23	61,3%	15,175 ^a	<0.001	13,669	<0.001	0.261
25	50.5%	16,231 ^a	<0.001	15,037	<0.001	0,270
27	41,4%	14,863 ^a	<0.001	13,780	<0.001	0.259
31	35.1%	15,308 ^a	<0.001	14,200	<0.001	0.263
42	47.3%	30,467 ^a	<0.001	28,892	<0.001	0.370
44	59%	8,102 ^a	0.004	7,058	0.008	0.191
45	58,1%	6,477 ^a	0.011	5,566	0.018	0.171
48	64%	11,995 ^a	<0.001	10,364	0.001	0.232
50	35,1%	15,308 ^a	<0.001	14,200	<0.001	0.263
80	44.1%	9,715 ^a	0.002	8,832	0.003	0.209
81	36,9%	15,067 ^a	<0.001	13,975	<0.001	0,261

This table only has test variables with a moderate or strong association

Legend: ^a 0 cells (0,0%) have expected count less than 5.

8 – Proactive monitoring, observability and autoscaling; 9 – Emergency response/proactive failure notification; 13 – Continuous improvement of processes/ workflows; 14 – Focus on people, process, and technology; 21 – Continuous Integration; 22 – Continuous Delivery/Deployment automation; 23 – Test automation and environments; 25 – Empower teams to make decisions/changes; 27 – Cloud infrastructure and cloud native; 31 – Infrastructure as Code; 42 – Continuous development; 44 – Continuous integration; 45 – Continuous delivery; 48 – Establish measures and metrics; 50 – Infrastructure as code; 80 – Getting started with continuous learning; 81 – Having staff with the right technical skill.

3.3.2.1.4. “More stable operating environments”

This benefit occurred in **47%** of the **222** retrieved articles as seen in previously in **Figure 9 in chapter 3.3.1 Answer for RQ1**. In the analysis, it was able to discover **seven** test variables from the 1st group that showed an association and statistical significance that can be viewed in Table 10.

Of the **seven** a total of **two** test variables from the 1st group showed a strong statistical significance which are the technical capabilities “Test automation and environments” and the practice “Continuous monitoring and register in log”.

Of the **seven** a total of **five** test variables from the 1st group showed a moderate statistical significance which are the cultural capability “Cross team collaboration and communication”, the technical capability “Empower teams to make decisions/changes” and “Cloud infrastructure and cloud native”, the practice “Continuous testing” and “Continuous deployment”.

Table 10 – Association Test Results for the Benefit “More stable operating environments”

	Common identifications and/or discernations	Pearson-Chi Square Value	Pearson-Chi Square Sig	Continuity Correction Value	Continuity Correction Sig	Cramer’s V
1	42,8%	5,152 ^a	0.023	4,340	0.037	0.152
23	44,6%	14,160 ^a	<0.001	12,790	<0.001	0.253
25	35,1%	5,799 ^a	0.016	5,135	0.023	0,162
27	31,1%	13,532 ^a	<0.001	12,559	<0.001	0.247
43	36%	6,117 ^a	0.013	5,425	0.020	0.166
46	38,7%	12,035 ^a	<0.001	11,032	<0.001	0.233
47	39,2%	17,057 ^a	<0.001	15,874	<0.001	0.277

This table only has test variables with a moderate or strong association

Legend: ^a 0 cells (0,0%) have expected count less than 5.

1 – Cross team collaboration and communication; 23 – Test automation and environments; 25 – Empower teams to make decisions/changes; 27 – Cloud infrastructure and cloud native; 43 – Continuous testing; 46 – Continuous deployment; 47 – Continuous monitoring and register in log.

3.3.2.1.5. “Better resource utilization”

This benefit occurred in **51%** of the **222** retrieved articles as seen in previously in **Figure 9 in chapter 3.3.1 Answer for RQ1**. In the analysis, it was able to discover **six** test variables from the 1st group that showed an association and statistical significance that can be viewed in Table 11.

Of the **six** a total of **three** test variables from the 1st group showed a strong statistical significance which are the measurement capability “Proactive monitoring, observability and autoscaling”, the technical capabilities “Cloud infrastructure and cloud native” and the practice “Continuous development”.

Of the **six** a total of **three** test variables from the 1st group showed a moderate statistical significance which are the measurement capability “Emergency response/proactive failure notification”, the process capability “Continuous improvement of processes/ workflows” and the technical capability “Test automation and environments”.

Table 11 – Association Test Results for the Benefit “Better resource utilization”

	Common identifications and/or discernations	Pearson-Chi Square Value	Pearson-Chi Square Sig	Continuity Correction Value	Continuity Correction Sig	Cramer’s V
8	37,4%	43,181 ^a	<0.001	41,434	<0.001	0.441
9	29.3%	6,570 ^a	0.010	5,899	0.015	0.172
13	49.1%	10,032 ^a	0.002	8,709	0.003	0.213
23	46,4%	5,801 ^a	0.016	4,938	0.026	0.162
27	35,6%	25,891 ^a	<0.001	24,541	<0.001	0.342
42	31,1%	24,654 ^a	<0.001	23,323	<0.001	0.333

This table only has test variables with a moderate or strong association

Legend: ^a 0 cells (0,0%) have expected count less than 5.

8 – Proactive monitoring, observability and autoscaling; 9 – Emergency response/proactive failure notification; 13 – Continuous improvement of processes/ workflows; 23 – Test automation and environments; 27 – Cloud infrastructure and cloud native; 42 – Continuous development.

3.3.2.1.6. “Greater automation”

This benefit occurred in **82%** of the **222** retrieved articles as seen in previously in **Figure 9** in **chapter 3.3.1 Answer for RQ1**. In the analysis, it was able to discover **seven** test variables from the 1st group that showed an association and statistical significance that can be viewed in Table 12.

Of the **seven** a total of **two** test variables from the 1st group showed a strong statistical significance which are the technical capability “Continuous integration” and the practice “Continuous integration”.

Of the **seven** a total of **five** test variables from the 1st group showed a moderate statistical significance which are the measurement capability “Emergency response/proactive failure notification”, the technical capability “Continuous delivery/deployment automation” and “Test automation and environments”, the practices “Continuous delivery” and “Establish measures and metrics”.

Table 12 – Association Test Results for the Benefit “Greater automation”

	Common identifications and/or discernations	Pearson-Chi Square Value	Pearson-Chi Square Sig	Continuity Correction Value	Continuity Correction Sig	Cramer’s V
9	43,2%	6,054 ^a	0.014	5,217	0.022	0.165
21	72.5%	19,062 ^a	<0.001	17,073	<0.001	0.293
22	78,4%	5,590 ^a	0.018	4,052	0.044	0.159
23	73%	11,843 ^a	<0.001	10,217	0.001	0.231
44	72.5%	19,062 ^a	<0.001	17,073	<0.001	0.293
45	69.8%	5,208 ^a	0.022	4,213	0.040	0.153
48	77%	10,244 ^a	0.001	8,406	0.004	0.216

This table only has test variables with a moderate or strong association

Legend: ^a 0 cells (0,0%) have expected count less than 5.

9 – Emergency response/proactive failure notification; 21 – Continuous integration; 22 – Continuous delivery/deployment automation; 23 – Test automation and environments; 44 – Continuous integration; 45 – Continuous delivery; 48 – Establish measures and metrics.

3.3.2.1.7. “Quality and reliability”

This benefit occurred in **78%** of the **222** retrieved articles as seen in previously in **Figure 9** in **chapter 3.3.1 Answer for RQ1**. In the analysis, it was able to discover **17** test variables from the 1st group that showed an association and statistical significance that can be viewed in Table 13.

Of the **17** a total of **13** test variables from the 1st group showed a strong statistical significance which are the measurement capability “Emergency response/proactive failure notification”, the process capabilities “Continuous improvement of processes/ workflows” and “Working in small batches”, the technical capabilities “Continuous integration”, “Continuous delivery/deployment automation” and “Test automation and environments”, the practices “Continuous development”, “Continuous testing”, “Continuous integration”, “Continuous delivery”, “Continuous deployment”, “Continuous monitoring and register in log” and “Establish measures and metrics”.

Of the **17** a total of **four** test variables from the 1st group showed a moderate statistical significance which are the cultural capability “Support learning culture and experimentation”, the measurement capability “Proactive monitoring, observability and autoscaling”, the process capability “Focus on people, process, and technology” and the technical capability “Empower teams to make decisions/changes”.

Table 13 – Association Test Results for the Benefit “Quality and reliability”

	Common identifications and/or discernations	Pearson-Chi Square Value	Pearson-Chi Square Sig	Continuity Correction Value	Continuity Correction Sig	Cramer’s V
2	66,2%	6,158 ^a	0.013	5,167	0.023	0.167
8	45%	13,061 ^a	<0.001	11,917	<0.001	0.243
9	44,6%	23,080 ^a	<0.001	21,550	<0.001	0.322
13	73%	16,115 ^a	<0.001	14,091	<0.001	0.269
14	70.7%	6,228 ^a	0.013	5,054	0.025	0.167
15	53,6%	14,621 ^a	<0.001	13,373	<0.001	0.257
21	70.7%	34,206 ^a	<0.001	31,739	<0.001	0.393
22	75.7%	18,600 ^a	<0.001	15,923	<0.001	0.289
23	72,1%	36,775 ^a	<0.001	34,101	<0.001	0.407
25	55%	6,490 ^a	0.011	5,638	0.017	0.171
42	50.5%	16,103 ^a	<0.001	14,816	<0.001	0.269
43	59%	21,388 ^a	<0.001	19,813	<0.001	0.310
44	70.7%	34,206 ^a	<0.001	31,739	<0.001	0.393
45	68%	14,912 ^a	<0.001	13,330	<0.001	0.259
46	59.9%	14,354 ^a	<0.001	13,038	<0.001	0.254
47	61.3%	31,516 ^a	<0.001	29,576	<0.001	0.377
48	77.9%	81,889 ^a	<0.001	76,962	<0.001	0.607

This table only has test variables with a moderate or strong association

Legend: ^a 0 cells (0,0%) have expected count less than 5.

2 – Support learning culture and experimentation; 8 – Proactive monitoring, observability and autoscaling; 9 – Emergency response/proactive failure notification; 13 – Continuous improvement of processes/ workflows; 14 – Focus on people, process, and technology; 15 – Working in small batches; 21 – Continuous integration; 22 – Continuous delivery/deployment automation; 23 – Test automation and environments; 25 – Empower teams to make decisions/changes; 42 – Continuous development; 43 – Continuous testing; 44 – Continuous integration; 45 – Continuous delivery; 46 – Continuous deployment; 47 – Continuous monitoring and register in log; 48 – Establish measures and metrics.

3.3.2.1.8. “Improved collaboration”

This benefit occurred in **73%** of the **222** retrieved articles as seen in previously in **Figure 9 in chapter 3.3.1 Answer for RQ1**. In the analysis, it was able to discover **14** test variables from the 1st group that showed an association and statistical significance that can be viewed in Table 14.

Of the **14** a total of **seven** test variables from the 1st group showed a strong statistical significance which are the cultural capabilities “Cross team collaboration and communication”, “Support learning culture and experimentation” and “Transformational leadership”, the technical capabilities “Empower teams to make decisions/changes” and the practices “Communication and collaboration” and “Continuous deployment” and challenge “Overcoming the Dev vs Ops mentality”.

Of the **14** a total of **seven** test variables from the 1st group showed a moderate statistical significance which are the process capabilities “Focus on people, process, and technology” and “Working in small batches”, the technical capability “Continuous integration” and “Continuous delivery/deployment automation” and the practices “Continuous integration”, “Continuous delivery” and “Establish measures and metrics”.

Table 14 – Association Test Results for the Benefit “Improved collaboration”

	Common identifications and/or discernations	Pearson-Chi Square Value	Pearson-Chi Square Sig	Continuity Correction Value	Continuity Correction Sig	Cramer's V
1	68%	29,913 ^a	<0.001	27,650	<0.001	0.367
2	66,7%	34,972 ^a	<0.001	32,695	<0.001	0.397
4	40,5%	15,424 ^a	<0.001	14,252	<0.001	0.264
14	67,1%	7,330 ^a	0.007	6,126	0.013	0.182
15	49,1%	5,782 ^a	0.016	5,053	0.025	0.161
21	64%	7,749 ^a	0.005	6,667	0.010	0.187
22	71.2%	13,250 ^a	<0.001	11,138	<0.001	0.244
25	57,2%	37,517 ^a	<0.001	35,575	<0.001	0.411
40	61,7%	91,062 ^a	<0.001	89,032	<0.001	0.640
44	64%	7,749 ^a	0,005	6,667	0.010	0.187
45	63,1%	6,340 ^a	0.012	5,384	0.020	0,169
46	57,2%	15,377 ^a	<0.001	14,047	<0.001	0.263
48	68.9%	7,915 ^a	0.005	6,521	0.011	0.189
64	55,9%	18,296 ^a	<0.001	16,929	<0.001	0.287

This table only has test variables with a moderate or strong association

Legend: ^a 0 cells (0,0%) have expected count less than 5.

1 – Cross team collaboration and communication; 2 – Support learning culture and experimentation; 4 – Transformational leadership; 14 – Focus on people, process, and technology; 15 – Working in small batches; 21 – Continuous Integration; 22 – Continuous Delivery/Deployment automation; 25 – Empower teams to make decisions/changes; 40 – Communication and collaboration; 44 – Continuous integration; 45 – Continuous delivery; 46 – Continuous deployment; 48 – Establish measures and metrics; 64 – Overcoming the Dev vs Ops mentality.

3.3.2.1.9. “Greater innovation”

This benefit occurred in **53%** of the **222** retrieved articles as seen in previously in **Figure 9 in chapter 3.3.1 Answer for RQ1**. In the analysis, it was able to discover **12** test variables from the 1st group that showed an association and statistical significance that can be viewed in Table 15.

Of the **12** a total of **one** test variable from the 1st group showed a strong statistical significance which are the practice “Continuous development”.

Of the **12** a total of **11** test variables from the 1st group showed a moderate statistical significance which are the cultural capabilities “Cross team collaboration and communication” and “Support learning culture and experimentation”, the process capabilities “Continuous improvement of processes/ workflows” and “Focus on people, process, and technology”, the technical capability “Continuous integration”, “Test automation and environments” and “Empower teams to make decisions/changes” and the practices “Continuous integration”, “Continuous delivery”, “Continuous deployment” and “Continuous monitoring and register in log”.

Table 15 – Association Test Results for the Benefit “Greater innovation”

	Common identifications and/or discernations	Pearson-Chi Square Value	Pearson-Chi Square Sig	Continuity Correction Value	Continuity Correction Sig	Cramer's V
1	47,7%	6,670 ^a	0.010	5,741	0.017	0.173
2	46,4%	6,947 ^a	0.008	6,064	0.014	0.177
13	50%	8,285 ^a	0.004	7,085	0.008	0.193
14	50%	11,457 ^a	<0.001	10,107	0.001	0.227
21	46,8%	6,290 ^a	0.012	5,426	0.020	0.168
23	47,3%	4,881 ^a	0.027	4,091	0.043	0.148
25	40,1%	10,733 ^a	0.001	9,823	0.002	0.220
42	36,9%	15,650 ^a	<0.001	14,592	<0.001	0.266
44	46,8%	6,290 ^a	0,012	5,426	0.020	0.168
45	46,4%	6,134 ^a	0.013	5,298	0.021	0,168
46	41%	5,950 ^a	0.015	5,251	0.022	0.164
47	40,5%	6,643 ^a	0.010	5,912	0.015	0.173

This table only has test variables with a moderate or strong association

Legend: ^a 0 cells (0,0%) have expected count less than 5.

1 – Cross team collaboration and communication; 2 – Support learning culture and experimentation; 13 – Continuous improvement of processes/ workflows; 14 – Focus on people, process, and technology; 21 – Continuous Integration; 23 – Test automation and environments; 25 – Empower teams to make decisions/changes; 42 – Continuous development; 44 – Continuous integration; 45 – Continuous delivery; 46 – Continuous deployment; 47 – Continuous monitoring and register in log.

3.3.2.1.10. “Security”

This benefit occurred in **38%** of the **222** retrieved articles as seen in previously in **Figure 9 in chapter 3.3.1 Answer for RQ1**. In the analysis, it was able to discover **two** test variables from the 1st group, which are the practices “Continuous testing” and “Continuous monitoring and register in log”, that show an association and strong statistical significance that can be viewed in Table 16.

Table 16 – Association Test Results for the Benefit “Security”

	Common identifications and/or discernations	Pearson-Chi Square Value	Pearson-Chi Square Sig	Continuity Correction Value	Continuity Correction Sig	Cramer’s V
43	38,3%	64,764 ^a	<0.001	62,403	<0.001	0.540
47	38,3%	60,819 ^a	<0.001	58,506	<0.001	0.523

This table only has the tests variables with a strong association

Legend: ^a 0 cells (0,0%) have expected count less than 5.

43 – Continuous testing; 47 – Continuous monitoring and register in log.

3.3.2.1.11. Benefits without clear associations

The benefits “*Greater visibility into system outcomes*”, “*Financial savings*” and “*Accountability*” have an occurrence of lower than **33%** of the **222** retrieved articles as seen in previously in Figure 9 in **chapter 3.3.1 Answer for RQ1**.

So, for these benefits, it was not possible to get any association test results with a relative maximum of common occurrence to be considered.

3.3.2.2. Ranking the Test Variables from the 1st Group

As stated previously the 1st group test variables are the cultural capabilities, measurement capabilities, process capabilities, technical capabilities, practices, and challenges which have a total of **68** test variables. The 2nd group test variables have a total of **13** (benefits). So, the analysis has **81** different test variables in total.

After the analysis in **chapter 3.3.2.1**, it was possible to observe that only **26** of the test variables from the 1st group showed a statistical significance and an association with the overall 2nd group test variables of the adoption of DevOps, that can be seen in Table 17.

Table 17 allows to also see the ranking of the **26** test variables, based on the number of times that this variable was identified with a statistical significance and an association, and observe that the 1st, 2nd, and 7th most common test variables, are made up of **11** variables.

Table 17 – Ranking Test Variables from the 1st group

Ranking	1 st	2 nd	2 nd	2 nd	2 nd	2 nd	7 th	7 th	7 th	7 th	7 th	12 th	12 th	14 th	14 th	14 th	14 th	18 th	18 th	20 th	20 th	20 th	20 th	20 th
Times	7	6	6	6	6	6	5	5	5	5	5	4	4	3	3	3	3	2	2	1	1	1	1	1
Test Variable	23	21	44	45	46	47	22	25	42	43	48	2	9	1	8	15	27	80	81	4	31	40	50	64

Legend: Times – Indicate the number of times that this variable was identified as having a moderate or strong association

23 – Test automation and environments; 21 – Continuous Integration; 44 – Continuous integration, 45 – Continuous delivery; 46 – Continuous deployment; 47 – Continuous monitoring and register in log; 22 – Continuous delivery/deployment automation; 25 – Empower teams to make decisions/ changes; 42 – Continuous development; 43 – Continuous testing; 48 – Establish measures and metrics; 2 – Support learning culture and experimentation; 9 – Emergency response/proactive failure notification; 1 – Cross team collaboration and communication; 8 – Proactive monitoring, observability and Autoscaling; 15 – Working in small batches; 27 – Cloud infrastructure and cloud native; 80 – Getting started with continuous learning; 81 – Having staff with the right technical skills; 4 – Transformational leadership; 31 – Infrastructure as Code; 40 – Communication and collaboration; 50 – Infrastructure as code; 64 – Overcoming the dev vs ops mentality.

In Table 18, it is possible to see to which benefit each of the 11 test variables from the 1st group have contributed.

Table 18 – Detailed occurrence of top three Test Variables in the Benefits

Test Variable\Benefits	51	52	53	54	55	56	57	60	61	63	(%) of Y	(%) of N
23	Y	N	Y	Y	Y	Y	Y	N	Y	N	70%	30%
21	Y	N	Y	N	N	Y	Y	Y	Y	N	60%	40%
44	Y	N	Y	N	N	Y	Y	Y	Y	N	60%	40%
45	Y	N	Y	N	N	Y	Y	Y	Y	N	60%	40%
46	Y	Y	N	Y	N	N	Y	Y	Y	N	60%	40%
47	Y	Y	N	Y	N	N	Y	N	Y	Y	60%	40%
22	Y	N	Y	N	N	Y	Y	Y	N	N	50%	50%
25	N	N	Y	Y	N	N	Y	Y	Y	N	50%	50%
42	Y	N	Y	N	Y	N	Y	N	Y	N	50%	50%
43	Y	Y	N	Y	N	N	Y	N	N	Y	50%	50%
48	Y	N	Y	N	N	Y	Y	Y	N	N	50%	50%

Benefits Legend:

51 – Faster & better product delivery; 52 – Faster issue resolution & reduced complexity; 53 – Greater scalability & availability; 54 – More stable operating environments; 55 – Better resource utilization; 56 – Greater automation; 57 – Quality and reliability; 60 – Improved collaboration; 61 – Greater innovation; 63 – Security.

Conclusion

In this research, a MLR was used to obtain the highest number of case studies possible done in and about DevOps **222** articles in total. Which using a concept-matrix approach helped to identify and/or perceive the capabilities, practices, benefits, and challenges present in each case study, as each article was assessed, validated, and registered the presence of each specific capabilities, practices, benefits, and challenges. This approach helped to create nominal data that could be analyzed to check the significance of the capabilities, practices and challenges have on the DevOps benefits in the data gathered. Thus, the data gathered enabled to answer:

- RQ1 – What are the capabilities, practices, benefits, and challenges identified in the Case Studies in DevOps in the ‘White’ literature and in the ‘Grey’ literature?

A total of **39** capabilities (test variables) were found, which can be divided into **four** major categories:

- 1) the cultural capabilities with **seven** capabilities (test variables),
- 2) the measurement capabilities with **five** capabilities (test variables),
- 3) the process capabilities with **eight** capabilities (test variables),
- 4) the technical capabilities with 19 capabilities (test variables).

In addition, a total of **11** practices (test variables), **13** benefits and **18** challenges were found, leading to a total of **81** test variables. Their occurrence figures can be viewed in **chapter 3.3.1 Answer for RQ1**.

- RQ2 - What is the significance that capabilities, practices, and challenges have on the benefits?

The 1st group test variables are cultural capabilities, measurement capabilities, process capabilities, technical capabilities, practices, and challenges which have in total **68** test variables. The 2nd group test variables are only the **13** benefits. After the analysis of the 2nd group in **chapter 3.3.1 Answer for RQ2**, it was possible to find that of the **13** benefits only **10** benefits have test variables from the 1st group with statistical significance and an association. The reason that the other **three** benefits did not register any association to the test variables from the 1st group was their low occurrence in the 222 articles. We can conclude that the main objectives of this research were met.

In Table 19 is possible to observe in which of the benefits the statistical significance was found and their association strength.

Table 19 – Summary of the associations found per Benefit

Benefit	Moderate	Strong	Total	Ranking
“Greater scalability & availability”	8	9	17	01 st
“Quality and reliability”	4	13	17	01 st
“Faster & better product delivery”	4	10	14	03 rd
“Improved collaboration”	7	7	14	03 rd
“Greater innovation”	11	1	12	05 th
“More stable operating environments”	5	2	7	06 th
“Greater automation”	5	2	7	06 th
“Better resource utilization”	3	3	6	08 th
“Faster issue resolution & reduced complexity”	0	3	3	09 th
“Security”	0	2	2	10 th
“Greater visibility into system outcomes”	0	0	0	11 th
“Financial savings”	0	0	0	11 th
“Accountability”	0	0	0	11 th

This table considers the total of moderate and strong test variables, and their associations strength levels

According to the analysis, of the test variables from the 1st group, which had a total of 68 test variables, only 26 show statistical significance and have an association with the overall 10 benefits of the 2nd group of adoption of DevOps as shown in **chapter 3.3.2.2 Ranking the Test Variables from the 1st Group**. Additionally, the ranking in Table 19 shows that the 1st, 3rd, and 5th benefits with the most associations from the 1st group, are “Greater scalability & availability”, “Quality and reliability”, “Faster & better product delivery”, “Improved collaboration” and “Greater innovation”.

Furthermore, the ranking in Table 20 shows that the 1st, 2nd, and 7th most common test variables from the 1st group, are 11 different test variables that have in common at least five benefits that are statistically significant and are associated with the total of 10 benefits.

Table 20 – Ranking Test Variables from the 1st group(Only Top 3°)

Ranking	1 st	2 nd	2 nd	2 nd	2 nd	2 nd	7 th	7 th	7 th	7 th	7 th
Times	7	6	6	6	6	6	5	5	5	5	5
Test Variable	23	21	44	45	46	47	22	25	42	43	48

Legend: Times – Indicate the number of times that this variable was identified as having moderate or strong association

23 - Test automation and environments, 21 – Continuous Integration, 44 – Continuous integration, 45 - Continuous delivery, 46 - Continuous deployment, 47 - Continuous monitoring and register in log, 22 - Continuous delivery/deployment automation, 25 - Empower teams to make decisions/ changes, 42 - Continuous development, 43 - Continuous testing, 48 - Establish measures and metrics.

4.1 Limitations and Threats to validity

Limitations of this study include the fact that it is based on a multivocal literature review. In Table 4, 10% of the literature lacks a proper identification of the sector, this identification is critical in IT Case Studies[322] to draw conclusions about the sector.

This research has two major threats to its validity. The way the capabilities, practices, benefits, and challenges were identified/perceived, and then quantified in nominal binary data cannot fully avoid biases since it depends on what the case study had and on personal perception. The significance that capabilities, practices, and challenges have on the benefits depends on the quality of the data.

However, the results from this study are considered to have value as a basis for further research.

4.2 Future Work

Considering that DevOps is a trending topic, and this is one of the first studies to analyze the nominal data of DevOps Case Studies, future case studies in and on DevOps should provide or annex their data, thus enabling richer analysis of association, correlation, significance, and pattern discovery.

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