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Critical success factors for DevOps adoption in information systems development

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Abstract:
Adopting DevOps is challenging since it makes a significant paradigm shift in the Information Systems Development process. DevOps is a trending approach attached to the Agile Software Development Methodology, which facilitates adaptation to the customers' rapidly-changing requirements. It keeps one front step by introducing software operators who support the transmission between software and implementation into the software development team by confirming faster development, quality assurance, and easy maintenance of Information Systems (IS). However, software development companies reported challenges in adopting DevOps. It is critical to control those challenges while getting hold of the benefits by studying Critical Success Factors (CSF) for adopting DevOps. This study aimed to analyze the use of DevOps approach in IS developments by exploring CSFs of DevOps. A systematic literature review was applied to identify CSFs. These factors were confirmed by interviewing DevOps practitioners while identifying more frequent CSFs in the software development industry. Finally, the research presents a conceptual model for CSFs of DevOps, which is a guide to reap the DevOps benefits while reducing the hurdles for enhancing the success of IS. The conceptual model presents CSFs of DevOps by grouping them into four areas: collaborative culture, DevOps practices, proficient DevOps team, and metrics & measurement.

Keywords:
DevOps; critical success factors; information systems; agile software development methodology.

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1. Introduction

DevOps is a trending approach for increasing the success of Information Systems (IS) development projects. It creates a collaborative culture by combining IS development and operations teams. IS development team is responsible for reacting to market changes and delivering new software assets as soon as possible. The IS operations team is responsible for providing stable, truthful, and secure service to the client [1]. IS distribute information, knowledge, and digital products by collecting, processing, and storing information. Developing high-quality and reliable custom information systems is a challenging project that typically goes through the life cycle called Software Development Life Cycle (SDLC). SDLC involves several stages as; planning, analyzing, designing, building, testing, deploying, and maintenance. The software development methodology is a framework to plan and control this process, and various software development methodologies have been applied over the past decades.

Today, the Agile software development methodology has become more popular in the software development industry since it facilitates adoption with the customers' rapidly changing requirements [2]. The agile Development team comprises both software developers and customer representatives, and they should be well-informed and competent to make the possible adjustments in the development process [3]. Sense of agility in software development is the ability to adapt and react quickly, effectively, and appropriately to environmental changes [4]. Since these Agile methods use fewer instructions when analyzing, designing, and implementing the software requirements, they are easy to use than the traditional heavy-weight methods. Moreover, agile distributes projects into several small projects called sprints. It enables software development teams to provide consumers with certified goods as soon as possible [4].

However, Agile methodology mainly focuses on the customer requirements and maintaining good rapport with the customers rather than on the non-functional requirements of the software, such as maintainability, required resources, portability, and performance. This might cause the process of developing software to fail [4]. Sometimes Agile methodology is unsuccessful when software is developed for customers from diverse backgrounds [4]. Additionally, there are software operating teams' challenges when attempting to deploy software in a real-world setting, emphasizing how crucial communication with the operating team is essential during the development process [5]. The separation of software development and software operations leads to delays in discovering errors and shifts the deadline of projects [6]. Shortcomings of the Agile methodology forced software development teams to include software operating teams in their team. DevOps keeps one front step by introducing software operators who can support the transmission between software and implementation into the software development team [7]. However, only some scientific surveys are available on DevOps [8],[9].

Most researchers have introduced DevOps as a new approach to the Agile software development methodology, while few have discussed it as a new software development methodology [6],[10]. However, according to the common opinion, it is challenging to consider DevOps as a new software development methodology since it uses the same principles as Agile methodology and does not have a standard definition and characteristics. Furthermore, given that DevOps refers to complete automation in the development and delivery of software [11], some scholars have described DevOps adoption as a new paradigm in the software development process [12]. However, this DevOps approach has attracted the attention of software development companies in recent years since it delivers more advantages to them. DevOps confirms the faster development, quality assurance, and easy maintenance of the information systems, dropping the challenges created by the Agile software development methodology [11],[13],[14]. Moreover, it enables software development companies to take faster feedback from customers, reduce deployment costs, and mainly reduce the risk of software failures [15], [16],[17].

Nevertheless, while practicing this approach, the software development team faces some challenges, and recent empirical studies demonstrate the challenges of adopting DevOps. Since the DevOps approach is a novel concept in the software development industry, it is challenging to find DevOps experts [18] and difficult to use DevOps tools and technologies [19]. Furthermore, it is challenging to maintain the software quality while speeding up the development process with DevOps. Similarly, previous research observed that the most critical challenge is the cultural changes [20] leading to effective communication problems. According to a Gartner survey [21] conducted in 2019, the biggest challenge for an organization's expansion of the use of DevOps is recorded as the people issue. Software development projects can fail

again because of the challenges of the DevOps approach. But these industry experiences are not frequently surveyed or reported by researchers [22],[23],[24]. However, it is critical to control the challenges while getting hold of the benefits of DevOps for proper adoption of DevOps. It is required to comply with the critical success factors of DevOps for attaining a victorious DevOps adoption. The critical success factors realize the IS development process's continuous, verified, significant, and measurable success [25]. Even so, software development professionals need to know more about the DevOps success elements [18],[26]. Furthermore, existing evidence indicates that the critical success factors surrounding the adoption of DevOps need to be adequately defined while Information Systems are in the row to success. It is, therefore, essential to study the DevOps critical success factors which help to face the DevOps challenges.

Our study aimed to analyze the use of the DevOps approach in software development by exploring the critical success factors of DevOps. Two research questions were defined:

RQ 1: What are the critical success factors of DevOps reported by other researchers in Information Systems Development?

RQ 2: What factors are considered by experts as the DevOps critical success factors, and do they confirm the success factors listed in the literature?

A systematic literature review (SLR) method was applied to identify the critical success factors of DevOps. The identified success factors compared with the practical software development environment by conducting interviews with DevOps practitioners. Finally, the research presents a conceptual model for the critical success factors of the DevOps approach, which guides the adoption of DevOps and earning benefits. The conceptual model presents critical success factors of DevOps by grouping them into four areas: collaborative culture, DevOps practices, proficient DevOps team, and metrics and measurement. The paper consists of six sections. The first section includes an introduction to the study, while the second section discusses the background and related works. Section three introduces the methodology carried out for the research. Section four presents the findings obtained, while section five discusses the results. Finally, the paper concludes with the last section by summarizing the main findings of the research and presenting several directions for further study in this domain.

2. Background and related works

2.1 DevOps in information systems development

Today, the software development industry trend is DevOps, which is considered the next step of the Agile methodology. It resolves the conflicts between developers and operations staff during the deployment by strengthening communication, integration, and collaboration. According to Mishr and Otaiwi [22], the primary goal of DevOps is to increase development speed, frequency, and quality. DevOps has been defined in many ways by different researchers. Lwakatare [27] discusses the DevOps as “a mindset change substantiated with a set of practices to encourage cross-functional collaboration between teams; especially development and Information Technology (IT) operations; within a software development organization, in order to operate resilient systems and accelerate the delivery of changes”. According to Perera et al. [28] a popular definition is “DevOps is a mix of patterns intended to improve collaboration between software development and operations”. Recently, DevOps has emphasized as “a cultural shift which encourages great collaboration to foster building better quality software more quickly and more reliably” [29]. Senapathi et al. [30] presented DevOps transitional journey as “the period of time where software developers transition from just handing over their completed work to system administrators, to actually taking ownership and responsibility themselves”. By the words of a program manager at Microsoft, “DevOps is the union of people, process and product to enable continuous delivery of value to their end users” [31]. Lately, DevOps is defined by Khan et al. [32] as “set of practices and cultural movements to brake the barrios between development and operation teams to improve communication and collaboration”. There is no standard definition for DevOps.

According to the DevOps model presented by Gartner [21], the DevOps process consists of seven continuous steps for successful DevOps practice. It includes parallel and ongoing seven activities as plan, create, verify, prepare, release, configure, and monitor. Farroha and Farroha [33] have discussed the main objectives of DevOps as delivering measurable business value through continuous and high-quality service delivery, emphasizing agility in all areas, including

technology, process, and human factors, breakdown barriers between development and operations by enabling trust and shared ownership, support innovation and encouraging collaboration, and manage dynamic compliance - access/sharing laws are changing. Similarly, several researchers mention many benefits offered by the DevOps approach. Mainly it reduces project completion time, improves software quality, and improves customer satisfaction. In the words of Senapathi et al. [30], DevOps improve customer experience through quicker innovations, an appetite for experimentation, and more frequent releases [16]. More than those advantages, Batra and Jatain explained that [34] DevOps reduces the software design's complexity, stabilizes the operation environment, and creates goodwill with satisfied customers. Moreover, according to Mohammad [35], DevOps enables software development teams to reduce operational costs, improve productivity, ensure high accessibility, and improve reliability while optimizing software performance. Based on the idea generated by Kalliosaari et al. [16], DevOps also benefit the DevOps team members by improving their well-being because frequent releases reduce their stress level. These research findings prove that DevOps has become a silver bullet to the software development industry since it provides various benefits to software developers, operating teams, and their customers.

2.2 Challenges of DevOps adoption

Adopting DevOps in Information System Development projects provides such benefits as same as it brings challenges [13],[22],[32]. Removing the gap between software developers and the operating team changes the organizational culture [22],[18]. According to Lwakatare [27], other than the company culture, DevOps affects the processes, products, associated technologies, and organizational structures used in software development and operations processes. More than that, lack of (DevOps) experienced and knowledgeable people, lack of management support for DevOps adoption, difficulties in changing habits and mindsets of the team members, increased cost of development, and challenges for making a highly secured development process have been specified as the challenges for DevOps adoption in IS projects by Jayakody and Wijayanayake [18]. Like Lwakatare [27] stated that DevOps is not a silver bullet since it creates challenges such as the accumulation of technical debt and difficulties in achieving full automation in infrastructure management. After confirming those challenges, Lwakatare et al. [36] observed difficulties in balancing the speed and quality of developments, insufficiencies in infrastructure automation, DevOps skills and knowledge, and valuable metrics for measurements as considerable challenges of DevOps. The study's findings by Raj, P., and Sinha, P. indicate that DevOps impacts an organization's scope, quality, and project management [37]. Azad and Hyrynsalmi have recently confirmed the DevOps adoption issues [38]. Their research indicates that issues with pipeline execution, debugging, feature releases, integrating new standards, and collaboration with clients arise with DevOps adoption in the industry. These studies point to the importance of controlling challenges while getting hold of the benefits of DevOps. Formal adoption of DevOps helps software development companies to attain this target. So, it is required to comply with the critical success factors of DevOps to attain a victorious DevOps adoption.

2.3 Critical success factors for DevOps adoption

Ghantous and Gill [33] identified the critical success elements of DevOps [39] as communication and collaboration, continuous delivery, automated pipeline, quality assurance, continuous deployment, continuous planning, and rollback code by a systematic literature review. According to their findings, communication, collaboration, and continuous delivery are the highest reported conceptual elements by the other researchers. According to Lwakatare [27], the critical fields of DevOps include four primary directions: the culture of collaboration, automation, services & quality assurance. Similarly, Erich has discussed [40] other categorizations for the DevOps success factors as: a culture in which development and operations people regularly interact, automating steps required for this collaboration, measurements that span the discipline of development and operations, and metrics that provide development personnel access to measurements used by operations personnel and vice versa, Lean for optimizing the interaction between development and operations people, and sharing opportunity that development and operations personnel interact.

A systematic literature review by Leite et al. [41] presents the CAMS as the most recognized model for enabling DevOps. This model provides an idea about the critical success factors of DevOps as culture, automation, measurement, and sharing. Again CAMS has been presented as the core value of DevOps by Jha and Khan [42], and Aljundi [43]. As same

as the CAMS model, researchers have discussed the CALMS framework, which adds Lean principles to the same CAMS framework. Lean principles motivate continuous improvements by accepting failures as everyday operations.

Furthermore, Amaradri and Nutalapati [9] have explained that software development companies should adopt the principles of culture, automation, collaboration, measurement, and sharing for the success of DevOps practices. In another way, a recent article [29] focused on five critical success factors that help drive DevOps to success. They advised connecting the siloes culturally as the first success factor. The other four considerations are closing the loop between monitoring and planning, measuring the success based on the entire system, keeping practical goals, and leveraging technology to automate and orchestrate. Besides, Yu and Guerra have explained [20] the core requirements for a successful implementation of DevOps practices as: cultural shift, automaton, ability to form multi-skilled groups, top management support, continuous observation, continuous monitoring, start small and iterate. According to them, a cultural shift is the most critical element, and automation is also a key factor for DevOps adoption. Jabbari et al. conducted another literature review [23] to study the DevOps principles. According to their findings, knowledge sharing, automation, shared responsibility, continuous activity, measurement, and composability are essential to achieve the success of DevOps adoption.

Furthermore, Dumoulin has published [44] critical success factors for DevOps adoption: the term DevOps understood by the team, the organizational structure includes the product owner's role, which priories the work based on business value, Cross-functional DevOps team, focus on security in DevOps, the scope expanded with non-functional requirements, continuous integration & deployment, and Use DevOps metrics. Similar to this study, another survey conducted by INTLAND software [45] presented critical success factors for DevOps as service and product ownership, cross-functional team, use of DevOps to bolster security, DevOps Continuous Integration (CI)/Continuous Deployment (CD) of automation toolset, monitoring and Key Performance Indicators (KPIs). Recently, Azad and Hyrynsalmi published nearly 100 DevOps critical success factors as their findings by systematically reviewing 38 research papers [46]. These 100 individual factors are grouped into technical, organizational, and social & cultural factors. Besides, the report published by Akbar et al. [47] identified and prioritized nineteen DevOps access factors and grouped in into three categories as people, business, and change. The people category emphasizes culture more than the tools, empowerment, cross-functional team, skilled DevOps team, and attempt matrix organization and transparency. The next category, business, consists of six success factors; design of a common baseline, sequencing of the DevOps approach, internal DevOps events, demonstration of lean leadership behavior, continuous integration and deployment, measuring progress and planning next improvement. The last category also consists of eight factors; use modeling, integration of changes in operations and support, automated testing, accommodating the legacy system, use of system orchestration, assessment of DevOps strategy, real-time feedback, and DevOps security pipeline. Like most other researchers, this study also ranked cultural changes first. Correspondingly, Ebert and Hochstein explained that according to the perspectives of software operators, culture and discipline are significantly impacted by DevOps practices [11].

Correspondently, Nagarajan and Overbeek [48] have published a DevOps implementation framework for financial organizations. According to them, successful implementation of the DevOps approach in organizations that practice the Agile methodology depends on four factors: organization, people, process, and technology. Organizational factors include organizational structure, large-scale agile practices, leadership commitment, training and guidance, and a trusted environment. People should be competent with cross-functional skills, teamwork ability, communication and collaboration skills, and attitudes to take responsibility. The next factor they presented is the process, which involves continuous process improvement, good knowledge management practices, and operations management practices. Moreover, the last factor identified by this survey is technology. Successful implementation of DevOps depends on continuous software engineering practices and automation. Similarly, Burrell [49] has explained that DevOps adoption capability positively affects organizational agility. Alike, the capability of communication, monitoring, measurement, and automation positively affect the DevOps adoption capability, and the capability of responsiveness, competency, flexibility, and quickness affect organizational agility capability.

According to the majority of explanations by researchers, collaborative culture is the core factor for successful DevOps adoption. Again, different studies have explained diverse ways to attain this collaborative culture within the DevOps team. Luz et al. [50] have presented six main concepts which strengthen the collaborative culture; the development team

should seamlessly perform operations tasks, software development empowerment, product thinking, straightforward communication, shared responsibility, and blameless context. More than the collaborative culture, they have presented two other categories that support DevOps adoption as automation and sharing & transparency. The findings of a survey conducted by Lwakatare et al. [51] explained collaboration and culture as two crucial success factors of DevOps adoption. Rethinking and reorientating roles and teams in software development and operations activities is described as collaboration & empathy, support & a good working environment between development and operation teams described as an excellent cultural practice. Govil et al. [52] have defined DevOps as a cultural change in the software development and operations teams. Masombuka and Mnkandla [53] have developed a DevOps collaborative culture acceptance model to explain the importance of the collaborative culture for the success of DevOps adoption. According to them, four elements are crucial to DevOps's collaborative culture. The first element is open communication, which keeps all the DevOps team members informed about the software product through its life cycle. The second element they reported is responsibility and incentives, which align with four main areas as scope, behavior, performance evaluation, and consequences of not fulfilling responsibilities. Next, an essential element described as trust is the willingness of the group to make themselves vulnerable to other groups based on vulnerability, confidence, benevolence, reliability, competence, honesty, and openness. The final element is respect for each member of the group.

Furthermore, in the way of explanation by Smeds et al. [54], DevOps adoption depends on the flourishing cultural change, which includes shared goals and definition of success, shared ways of working and responsibility, collective ownership, shared values, respect and trust, effortless communication and continuous learning. An empirical study [55] conducted by Rowse and Cohen described cultural changes made by DevOps as: giving the responsibility for the development team to deployment functions, quality assurance functions, and deployment operations, more outstanding communication between development and operational functions, attending operational representatives to the planning and development meetings, and aware development team members about the operational faults.

More than the collaborative culture, "automation" is also highlighted by many researchers as a critical factor for the success of DevOps adoption. Luz et al. [50] explained that automation is vital to ensure the transparency, and responsibility of tasks, reduce the risk of human failures, and increase confidence in the team. They have discussed eight concepts regarding automation as; deployment automation, test automation, infrastructure provisioning automation, infrastructure management, autonomous service, containerization, monitoring automation, and recovery automation. As same as Lwakatare et al. [51] also explained infrastructure and deployment process automation as a success factor for DevOps adoption. Not only that, Smeds et al. [54] presented seven concepts as the technological enablers for DevOps adoption. It consists of build automation, test automation, deployment automation, monitoring automation, recovery automation, infrastructure automation, and configuration management for code and infrastructure.

Based on the research conducted by Luz et al. [50], transparency and sharing are essential to disseminating information among DevOps team members. They have identified three main sharing concepts as; knowledge sharing, activity sharing, and process sharing. According to Lwakatare et al. [51], monitoring and measurement are also vital for the success of DevOps adoption. Not only that, Smeds et al. [54] describe the required capabilities for adopting DevOps successfully. According to their explanation, continuous planning, continuous & collaborative development, continuous integration & testing, continuous release & deployment, continuous infrastructure monitoring & optimization, continuous user behavior monitoring & feedback evaluation, and service failure recovery without delay are essential for the success of DevOps practices.

Similarly, a case study-based research conducted by Trigo et al. [56] mentioned top management support as the most mentioned success factor of DevOps adoption. In total, they presented twelve success factors: applied technology, change management, communication, competencies of the involved human resources, cooperation, implementation process, monitoring and evaluation, organizational culture, project governance, project management, top management support, and training of the involved stakeholders. More than the cultural and technical capabilities, Joby [57] has explained the skills very essential for the ideal DevOps team members as: advisory skills, complete stack development skills, analysis skills, functional skills, social skills, decision-making skills, and testing skills to earn the targeted success of DevOps adoption.

2.4 DevOps frameworks presented by other researchers

Few researchers have published frameworks based on the critical success factors of DevOps. Luz et al. [50] presented a model which provides initial guidance for companies to adopt DevOps. As their findings, the most critical factor in DevOps adoption is 'Collaborative Culture.' 'Automation' and 'Sharing & Transparency' propitiate the foundation of a collaborative culture. 'Agility' and 'Resilience' are the DevOps outcomes that expect this formation's consequences. Finally, 'Continuous Measurement' and 'Quality Assurance' are present as DevOps enablers. Not only that, Wahaballa et al. [58] explained that high collaboration between software developers and the operating team might cause conceptual deficits forced by unimplemented non-functional requirements, bounded rationality, complex and dynamic environment, principle agent problems, and moral hazard. They have introduced a unified DevOps with three sub-models: application and data model, workflow execution model, and infrastructure model. More than that, Lwakatare [27] has grouped DevOps practices into two categories: organizational and socio-technical. The organizational perspective focuses on reorienting responsibilities between software development and operating teams, and the socio-technical perspectives focus on automating the software delivery process.

This explanation indicates that some studies have been published supporting crucial success factors and DevOps frameworks. The majority of studies, however, used the literature review approach to identify best practices and, as a result, did not validate those success factors with the current practices of the industry. Moreover, researchers have observed that DevOps practitioners refrain from engaging with available frameworks since they do not directly focus on all the critical success areas of DevOps adoption. As well as, according to Mohammad et al. [59], usage of those frameworks is minimal and needs to be validated by actual DevOps experts. Accordingly, more research and empirical studies are required to guide the successful DevOps adoption with managing the recorded DevOps challenges. Therefore, the requirement of comparing already published critical success factors with the industry expert's opinion has emerged. Furthermore, it highlights the necessity of a validated conceptual model with improving existing DevOps frameworks which can apply to the successful adoption of DevOps in the software development industry.

3. Research methodology

The grounded theory approach was applied to survey the critical success factors of DevOps, which helped to adopt DevOps in software development companies successfully. This approach is mainly applied in qualitative research using the inductive approach [50]. Based on that, two sequential steps were applied to achieve the aim of this research, as shown in Fig. 1. First, the study used a systematic literature review (SLR) to collect secondary qualitative data. The findings of the SLR were applied to propose a conceptual model which guides DevOps practitioners to earn their success [26]. As the next step, the study applied interviews to discover the experience in DevOps adoption, collecting the primary qualitative data. The results of the interviews were applied to shape the conceptual model developed by the systematic literature review.

Fig. 1. Research methodology

3.1 Identify critical success factors of DevOps through a systematic literature review.

The literature review study was conducted by a systematic mapping research method. It helps to survey the state of the art of research areas that still need to be mature [60]. According to this method, search terms formed as "DevOps", "DevOps" AND "Evolution", "DevOps" AND "Software Development Methodologies", "DevOps" AND "Benefits" OR "Advantages", "DevOps" AND "Challenges" OR "Problems", "DevOps" AND "Overcoming Strategies", and "DevOps" AND "Critical Success Factors". The search resulted in 317 relevant publications such as journals, books, reports, articles,

and conference proceedings from different databases such as Scopus, Google Scholar, Emerald Inside, Web of Science, Science Direct, and Google Search Engine to fulfill the research purpose. Then, the following inclusion and exclusion criteria were applied to select the most relevant publications for this study, and it filtered 223 publications from the downloaded list.

Inclusion Criteria

- Literature discusses the evolution of DevOps.
- Literature discusses Software Development Methodologies.
- Literature discusses the benefits of DevOps adoption in Information Systems.
- Literature discusses the challenges of DevOps adoption in Information Systems.
- Literature discusses the overcoming strategies of DevOps challenges.
- Literature discusses the critical success factors of DevOps.

Exclusion Criteria

- Literature not related to the purpose of the study.
- Inaccessible literature.
- Duplicated literature.

Afterward, the title of downloaded papers was used to filter 201 publications that were more related to the research objectives. As the next step, keywords and abstracts of those selected papers were reviewed, which helped filter the final set of the most relevant 103 studies for the review. Finally, the study was conducted by reading the entire paper of the most relevant 103 studies selected from this systematic approach, as shown in Figure 2.

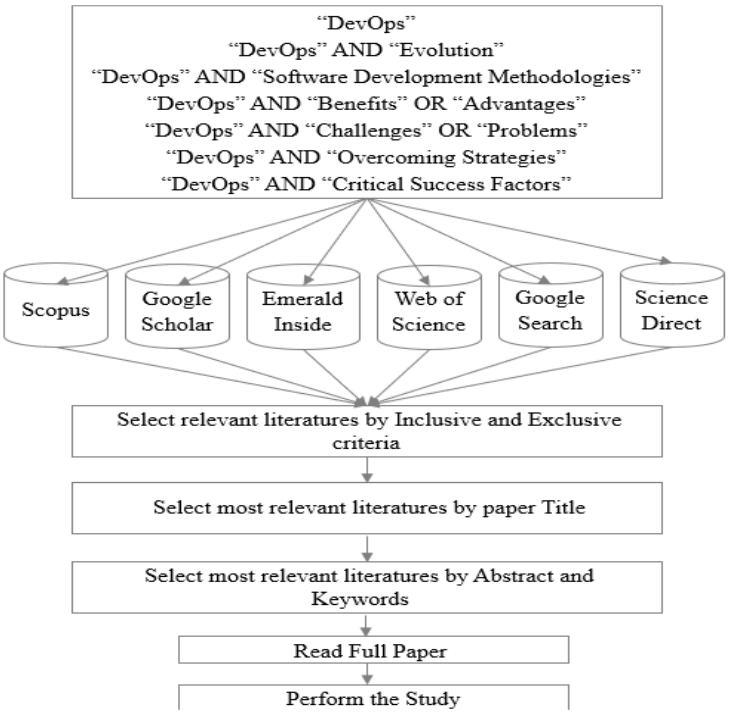

Fig. 2. Approach for the systematic literature review

The systematic literature review study observed background information about DevOps, its evaluation, its advantages compared to the other software development methodologies, and the challenges of adopting DevOps in the software development process. By reading and analyzing this background information, the study identified significant factors to focus on for a successful DevOps adoption in Information Systems. Finally, SLR identified the most frequent critical success factors in studies. This helps to answer the first research question while creating a roadmap to develop a conceptual model for successful DevOps adoption.

3.2 Enhance results of the systematic literature review through the opinion of DevOps practitioners.

As the next step, the research confirmed and identified critical success factors with the actual opinion of software developers by conducting interviews. Semi-structured questions were applied to interview DevOps experts in software development companies. Twelve (12) DevOps experts representing different domains comprised the study sample, as listed in Table 1.

Table 1. Interviewee Details

Interviewee	DevOps Role	DevOps Experience	Age	Gender
A	Senior DevOps engineer	5 Years	35	Male
B	Performance test engineer	3 Years	33	Male
C	Quality assurance engineer	3 Years	31	Male
D	TechOps Engineer	2 Years	30	Female
E	Associate Tech Lead	2 Years	29	Male
F	Automation architect	2 Years	28	Male
G	Software Developer	2 Years	31	Female
H	DevOps Tech lead	1 Year	29	Male
I	Software Developer	1 Year	28	Male
J	Quality assurance engineer	1 Year	27	Female
K	Trainee DevOps	Six months	25	Male
L	Trainee DevOps	Four months	25	Female

Two of the twelve interviews were conducted in person, and the rest online. The findings of the interviews were applied to identify patterns and connections among the collected data. Lastly, an operationalization process used the above-verified results to identify concepts, variables, and indicators of successful DevOps adoption. This helped to answer the second question of this research. Further, the survey results were applied to rank and identify DevOps adoption's most significant critical success factors in Information Systems. In conclusion, the study proposes a conceptual model that helps DevOps practitioners apply DevOps practices and earn benefits by minimizing the challenges.

4. Research findings

Initially, the systematic literature review examined the critical success factors of DevOps adoption identified by the related studies. It was conducted by reading nighty-eight (98) related studies. Among those selected studies, few authors have directly discussed the critical success factors of DevOps and presented these factors in different ways. More than those few studies, other researchers have presented about DevOps practices. The study filtered critical success factors by analyzing their findings and discussions. Finally, this study mapped identified critical success factors and ranked them according to the frequency of each factor identified by previous studies, as shown in Table 2.

Table 2. Critical success factors of DevOps identified by systematic literature review

No	Critical success factors of DevOps adoption	Identifies literature
01	Collaborative culture of the development and operations team supportive and good working environment shared goals and definition of success shared ways of working and responsibility collective ownership and shared values effortless and open communication continuous learning blameless context trust, vulnerability, confidence, benevolence, reliability, competence, honesty, and openness of group members respect for each group member	[1],[9],[14],[11],[23],[27],[36],[39],[40],[41],[42],[43],[47],[46],[48],[49],[50],[51],[52],[53],[56],[57],[61],[62],[63],[64],[65],[66],[67],[68],[69],[70],[71],[72],[73],[74],[75],[76],[77],[78],[79],[80], [81],[82],[83],[84],[85],[86],[87]
02	Automation DevOps CI/CD automation toolset automated testing build automation test automation deployment automation monitoring automation recovery automation infrastructure automation configuration management for code and infrastructure technological enablers	[1],[9],[14],[11],[27],[36],[39],[40],[41],[42],[43],[45],[47],[46],[48],[49],[50],[54],[56],[57],[61],[63],[64],[65],[68],[69],[71],[88],[89],[90],[73],[74],[76],[77],[78],[81],[82],[83],[84],[91],[87]
03	Metrics and Measurements monitoring the progress and planning the next improvement use DevOps metrics use Key Performance Indicators	[1],[9],[14],[23],[40],[41],[42],[43],[44],[45],[47],[49],[56],[57],[61],[63],[69],[71],[81],[82],[86],[88],[92],[93],[94],[95]
04	Continuous Process and Capabilities continuous planning continuous process improvement continuous and collaborative development continuous testing continuous delivery continuous deployment continuous release continuous integration continuous infrastructure monitoring and optimization continuous user behavior monitoring and feedback evaluation service failure recovery without delay	[14],[15],[23],[39],[44],[47],[46],[48],[54],[61],[63],[64],[70],[72],[90],[73],[74],[75],[96],[94],[77],[95],[91],[97],[98]
05	Transparency and Sharing knowledge sharing shared responsibility	[1],[9],[23],[27],[39],[40],[41],[42],[43],[47],[50],[51],[57],[68],[69],[71],[82],[99],[100]

No	Critical success factors of DevOps adoption	Identifies literature
06	Skills of the DevOps team members communication skills advisory skills full stack development skills analysis skills functional skills social skills decision-making skills testing skills cross-functional skills team working ability collaboration skills attitude for taking responsibility. capability of responsiveness competency flexibility	[39],[47],[48],[49],[57],[68],[70],[79],[80],[100], [95],[97],[98],[101],[102],[103]
07	Cross-functional DevOps team	[44],[45],[47],[46],[61],[101],[75],[100],[79],[83], [84],[87]
08	Commitment of the leadership	[48],[56],[66],[67],[69],[76],[80],[85],[86],[102]
09	DevOps knowledge, training, and guidance	[44],[48],[56],[61],[75],[76],[86],[93],[98]
10	Focus on DevOps security	[11],[44],[45],[47],[46],[66],[68],[89]
11	Focus on quality assurance	[27],[39],[46],[64],[92],[95],[98]
13	Real-time customer feedback	[47],[46],[90],[94],[76],[14],[98]
14	Lean and lean leadership behavior	[1],[11],[40],[47],[46],[66]
15	Large-scale agile practices	[14],[11],[48],[63],[95]
16	Organizational structure and scope expanded with non-functional requirements.	[44],[46],[48],[87]
17	Good knowledge management practices	[48]
18	Service and product ownership	[45]

The next and essential part of the research was conducted by analyzing and validating the critical success factors of DevOps adoption using interviews with DevOps experts in the software development industry. Twelve (12) DevOps experts representing different domains comprised the study sample. In numerous respects, as shown in Table 3, they supported the crucial success factors outlined by the SLR.

Table 3. Critical success factors of DevOps identified by interviews

No	Critical success factors of DevOps adoption	Participants
01	Collaborative culture	A,B,C,D,E,F,G,H,I,J,K,L
02	Automation	B,C,D,E,F,G,I,K,L
03	Knowledge about DevOps	A,B,D,F,L
04	Team working skills	C,F,G,J,L
05	Communication	B,H,I,J
06	Continuous delivery	H,I,J,K
07	Continuous integration	H,I,J,K
08	Continuous monitoring	H,I,J,K
09	Continuous testing	I,J,K
10	Knowledge sharing	C,F,L
11	Looking at a problem in a different manner/ Entrepreneurial Ideas	B,G
12	Select the right toolset	A,E
13	Cross-functional team	A, B
14	Multi-functional team	A, B
15	More engagement with the end user	C,K
16	Continuous deployment	I,J

No	Critical success factors of DevOps adoption	Participants
17	Adopting new technologies	B
18	Having the correct idea about the project	A
19	Documenting	C
20	Use DevOps metrics	D
21	Build a good CI/CD pipeline	E
22	Apply security with DevSecOps	E
23	Evolve with project management	E
24	Measurement	F
25	Trusteeship	G
26	Mutual respect	G
27	Integrity	G
28	Security	H
29	Active customer participation	I
30	Integrated configuration management	I
31	Integrated change management	I
32	Automated testing	I
33	Integrated deployment planning	I
34	Improve top-down commitment	K
35	More focus on the KPIs, and it should be transparent	K
36	Soft skills of the team members	L

In the next stage of the research, the critical success factors of DevOps were validated and presented by comparing the literature survey results with the interviews. According to the comparison, most of the success factors have been identified by both literature surveys and interviews, as shown in Table 4. However, interviewees confirmed all the factors identified by the literature survey, and they added two factors that needed to be identified by the literature survey as: applying change-management knowledge and having a clear idea about the project scope. Further, identified critical success factors were mapped into four main areas according to the opinion of DevOps practitioners, as shown in Table 4.

Table 4. Critical success factors of DevOps adoption

No	Critical success factors		Identified in Literature Survey	Identified in Interview
01	Collaborative Culture	I. Transparency and sharing		✓
		i. Knowledge sharing	✓	✓
		ii. Process sharing	✓	
		iii. Activities sharing	✓	
		iv. Shared responsibility	✓	
		v. Shared ownership	✓	
		vi. Shared values	✓	
		II. Effective communication		✓
		i. Effortless communication	✓	
		ii. Frequent communication	✓	
		iii. Open communication	✓	
		III. Management commitment to cultural changes	✓	✓

No	Critical success factors		Identified in Literature Survey	Identified in Interview
02	DevOps practices	I. DevOps technology		
		i. Continuous integration	✓	✓
		ii. Continuous planning	✓	✓
		iii. Continuous & collaborative development	✓	----
		iv. Continuous monitoring	✓	✓
		v. Continuous testing	✓	✓
		vi. Continuous delivery	✓	✓
		vii. Continuous release & deployment	✓	✓
		viii. Continuous process improvement	✓	----
		ix. Continuous infrastructure monitoring and optimization	✓	✓
		x. Continuous user behavior monitoring and feedback evaluation	✓	✓
		xi. Service failure recovery without delay	✓	----
		II. Automation		✓
		i. Automated pipeline	✓	✓
		ii. Build automation	✓	
		iii. Test automation	✓	✓
		iv. Deployment automation	✓	✓
		v. Monitoring automation	✓	
		vi. Recovery automation	✓	
		vii. Infrastructure automation	✓	
		viii. Configuration management for code and infrastructure	✓	
		III. Implement the proper DevOps toolchain	✓	✓
		IV. A balance between human interaction and automation	✓	✓
03	Proficient DevOps Team	I. Multi-functional team	✓	✓
		II. Skills of team members		✓
		i. Communication skills	✓	✓
		ii. Motivational skills		✓
		iii. Organizing skills		✓
		iv. Team working skills	✓	✓
		v. Creativity		✓
		vi. Adaptability	✓	✓
		vii. Cross-functional skills	✓	✓
		viii. Capability of responsiveness	✓	✓
		III. Knowledge and experience in DevOps		✓
		i. The team understands the term DevOps	✓	
		ii. Training and guidance on DevOps	✓	
		iii. Continuous learning	✓	✓
		IV. Lead by a perfect leader		
		i. Leadership skills	✓	----
		ii. Analytical skills	✓	----
		iii. Decision-making skills	✓	----
		iv. Commitment to DevOps changes	✓	✓
		v. Advisory skills	✓	----
		vi. Practice knowledge management experience	✓	----
		vii. Practice change-management knowledge	----	✓
		V. Celebrate success in gaining adoption	✓	----
		VI. Large-scale agile practices	✓	----
		VII. Establish joint accountability for outcomes	✓	----
		VIII. Emphasize culture more than the tools	✓	----
		IX. Respect and trust	✓	✓
		X. Blameless context	✓	✓

No	Critical success factors		Identified in Literature Survey	Identified in Interview
04	Metrics and measurements	I. Clear scope	----	✓
		II. Clear goals	✓	✓
		III. Measure progress and plan the next improvement	✓	✓
		IV. Quality assurance	✓	✓
		V. Security measurements	✓	✓
		VI. Use KPIs	✓	✓
		VII. Develop a roadmap with incremental maturity	✓	✓

5. Results and discussion

The study aimed to analyze the use of DevOps approach in software development by exploring the critical success factors of DevOps in Information Systems. A systematic literature review and interviews with DevOps practitioners were applied to achieve the research purpose. Finally, we proposed a conceptual model, as shown in Fig. 3 for the best practices of DevOps, which help and guide software development companies to earn their victory with a successful DevOps adoption.

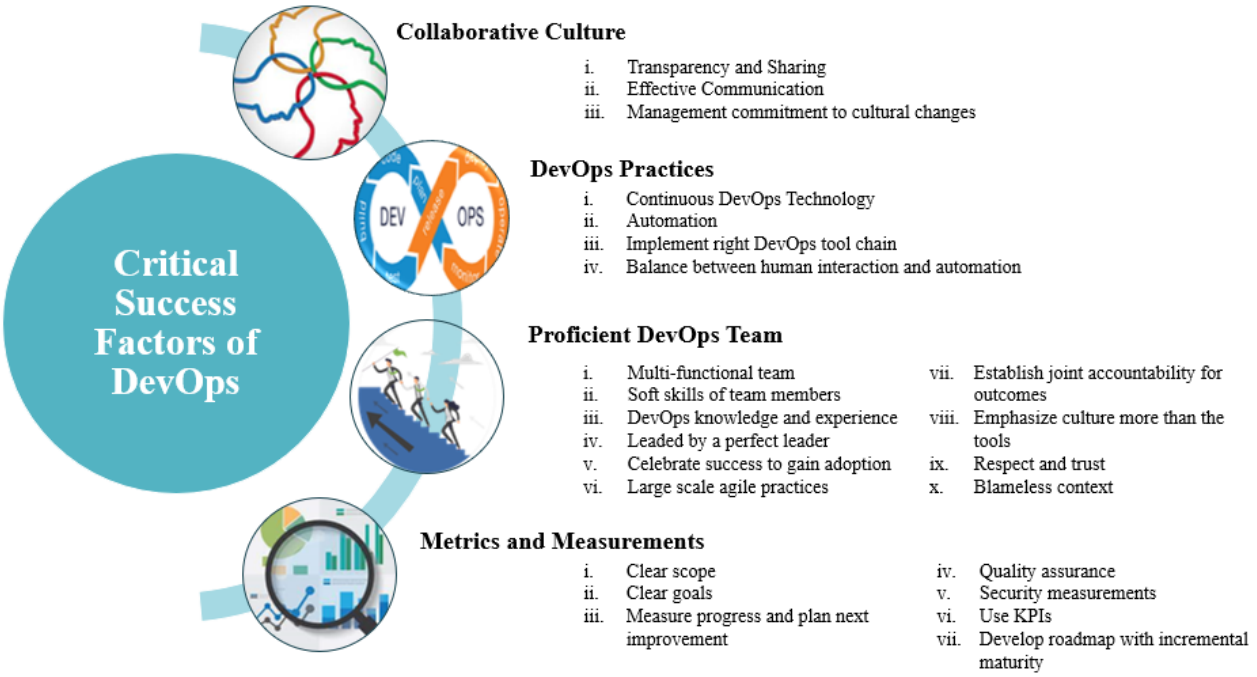

Fig. 3. Conceptual model for the critical success factors of DevOps adoption

According to the literature study and all the DevOps practitioners who participated in the interview, building a collaborative culture is DevOps adoption's main critical success factor. Adoption of a new set of tools is simple when compared to changing the culture of the software development working team [62]. Because culture represents the different opinions of the people, they are different from each other, and the DevOps team combines software developers and operators. Therefore, most related studies discuss enabling collaborative culture as the critical challenge the DevOps teams face, and industry experts confirm it. According to the findings, collaborative culture is related to three success factors: transparency and sharing, effective communication, and management commitment to cultural changes. Both literature surveys and interviews identified these three factors. However, minor aspects were discovered by the SLR and

grouped with professional industry opinions. According to that, transparency and sharing consist of knowledge sharing, process sharing, activity sharing, shared responsibility, shared ownership, and shared values. Effective communication can be enabled by open, effortless, and frequent communication. Management or leaders' commitment to change is also critical for building a collaborative culture.

Good DevOps practices are the next essential group of concepts for a successful DevOps Adoption. It combines DevOps technology, automation, the suitable DevOps toolchain, and a balance between automation and human interaction. DevOps technology explains continuous practices of the software development life cycle [77]. SLR is supported in identifying sub-factors of DevOps technology, and most of those factors are also mentioned by industry experts. It consists of continuous planning, continuous integration, continuous monitoring, continuous testing, continuous delivery, continuous release & deployment, continuous infrastructure monitoring & optimization, continuous user behavior monitoring & feedback evaluation. More than that, three sub-factors as: continuous & collaborative development, continuous process improvement, and Service failure recovery without delay, were identified only by the SLR and validated by interviews. Like DevOps technology, automation is also crucial to effective DevOps adoption [77]. Automation can expand to an automated pipeline, build automation, test automation, deployment automation, monitoring automation, recovery automation, infrastructure automation, and configuration management for code & infrastructure. These eight sub-factors were also identified by the SLR and validated by the interviews. Accordingly, software development companies have to automate the software development process based on their practices, called Automated Pipeline. The success of DevOps operations depends on how they build and operate their automated pipeline. While automation considers as a key DevOps success factor, SLR has been confirmed and validated by experts as it is required to maintain a proper balance between this automation and human interaction. Selecting and implementing a suitable DevOps toolchain is also crucial for successful DevOps operations. Many DevOps tools are available for different purposes, and no researchers or DevOps practitioners defined a specific tool as the best. Selection of the correct tool depends on the context. However, according to the interviewees, commonly used DevOps tools can be listed as; "Jira", a team collaboration tool, "Git", a version control system tool, "Docker", a containerization tool, "Puppet", a configuration management and application deployment tool, "Selenium", a continuous testing tool, and Visual Studio Team Service.

Similar to the collaborative culture and DevOps practices, the Proficient DevOps team is the next critical concept for DevOps adoption. Surveys confirmed that the DevOps team must be multi-functional and combine people from the different functional areas of the Software Development Life Cycle. Team members must be skillful with soft skills such as; communication, motivation, organizing, team working, creativity, adaptability, cross-functional skills, and capability of responsiveness. As with soft skills, team members need to fulfill the knowledge and skills in DevOps. This could be observed from both surveys, and SLR provided three sub-factors as: understanding the DevOps concept, training & guidance on DevOps, and continuous learning. The interviewees also validated them as critical factors for the DevOps team members.

Similarly, industry experts validated an SLR finding; a leader must lead the DevOps team with leadership, analytical, decision-making, advisory, commitment to changes, and knowledge management experience. More than that, interviewees suggested improving the team leader's change management knowledge. As same as, SLR perceived and confirmed by the interviewees to celebrate success to gain adoption, establish joint accountability for outcomes, emphasize culture more than the tools, and large-scale agile practices are essential factors for a proficient DevOps team. Also, both surveys confirmed that it is essential to maintain a respectful, trusting, and blameless environment for sustaining a successful DevOps team.

According to the survey results, metrics and measurements are the next important concept for successful DevOps adoption. Well-communicated goals are grouped under this concept. Like developing a roadmap with incremental maturity, measuring progress and planning the next improvement are also crucial for applying the DevOps approach. Similarly, quality assurance, security measurement, and using Key Performance Indicators (KPIs) to measure performance are also identified as critical factors of DevOps adoption and grouped under the metrics and measurements. Both SLR and interviews identify all these factors. However, industry experts added a clear scope of the software development project to this category. These four concepts presented with the conceptual model of the DevOps critical

success factors provide direction to software developers for earning the benefits of DevOps adoption while managing the challenges created by the DevOps practices.

6. Conclusion

DevOps is a trending approach for increasing the success of IS developments. It combines IS development and operations teams while delivering high quality products early to the customers. Most IS development companies practice Agile software development methodology for developing their software. It has become more popular since it facilitates adapting to rapidly changing customer requirements. However, the difficulties of installing software in the real environment the software operating team faces highlight the importance of communication with the operating team in the development process. DevOps keeps one front step by introducing an operator who can support the transmission between software and implementation into the software development team. Currently, DevOps is introduced as a new approach to the Agile software development methodology while attracting the attention of software development companies since it delivers more advantages to them. DevOps confirms the faster development, quality assurance, and easy maintenance of the information systems, tackling challenges created by the Agile software development methodology. However, software development companies have recently reported the challenges of adopting DevOps. It is critical to control the challenges while getting hold of the benefits of DevOps for proper adoption of DevOps. This can be achieved by focusing on the critical success factors of DevOps. These industry experiences are not frequently surveyed and reported by many researchers. Existing evidence indicates that the critical success factors surrounding adopting DevOps must be defined appropriately. It is, therefore, essential to study the DevOps critical success factors according to the practitioner's point of view, which helps to face the DevOps challenges. The study aimed to analyze the use of DevOps approach in software development by exploring the experimental critical success factors of DevOps for the prosperity of IS.

A systematic literature review method was applied to identify the critical success factors of DevOps. The identified success factors were compared with the practical software development environment by conducting interviews with DevOps practitioners. Finally, the research presents a conceptual model for the critical success factors of DevOps approach. The conceptual model presents critical success factors of DevOps by grouping them into four areas as: collaborative culture, DevOps practices, proficient DevOps team, and Metrics & Measurement. The study contributes to the literature by presenting critical success factors for DevOps adoption by comparing theoretical knowledge with the practical experience of the industry. For practitioners, the study helps to get DevOps benefits while minimizing its barriers through the proper application of DevOps approach in the software development industry. Researchers can continue the study for further comparisons of these findings with industry experts. The study has several limitations, given that DevOps is a new idea in the software development industry. Lack of studies about the best practices of DevOps. Finding DevOps expertise from various fields in the software development sector proved difficult. Twelve DevOps experts were interviewed for the study, and additional interviews with DevOps specialists could further complement the study's conclusions. Furthermore, future studies are recommended to analyze the maturity levels for DevOps critical success factors that occur between software development stages to promote the acceptance of DevOps in IS development processes.

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Appendix A. Interview Protocol

Step 1: Welcome the interviewee

Step 2: Describe the interviewer in detail

Step 3: Give details regarding the study
Purpose of the study
Present state of the research

Step 4: Gather data about the interviewee
Organization of the interviewee
Role of the present position
Experience in the software development
Experience in the DevOps team
Age

Step 5: Gather responses to the structured questions
How would you describe DevOps?
How DevOps is helpful to software developers?
How DevOps is helpful to software operators?
What are the popular tools for DevOps?
What are the key aspects or principles behind the DevOps?
How would you describe the functions of an ideal DevOps team?
How would you take our company’s DevOps strategy to the next level?

Step 6: Dialogue for additional remarks and inquiries
Discuss about the critical success factors gathered from the literature review

Step 7: Appreciation to the interviewee

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