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A theory on human factors in DevOps adoption

Juanjo Pérez-Sánchez [a,*], Saima Rafi [b], Juan Manuel Carrillo de Gea [a], Joaquín Nicolás Ros [a], José Luis Fernández Alemán [a]

[a] University of Murcia, C. Campus Universitario, Edificio 32, 30100, Murcia, Spain
[b] Edinburgh Napier University, Merchiston Campus 10 Coliton Road, EH10 5DB, Edinburgh, United Kingdom

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ABSTRACT

Context: DevOps is a software engineering paradigm that enables faster deliveries and higher quality products. However, DevOps adoption is a complex process that is still insufficiently supported by research. In addition, human factors are the main difficulty for a successful DevOps adoption, although very few studies address this topic.
Objective: This paper addresses two research gaps identified in literature, namely: (1) the characterization of DevOps from the perspective of human factors, i.e. the description of DevOps' human characteristics to better define it, and (2) the identification and analysis of human factors' effect in the adoption of DevOps.
Method: We employed a hybrid methodology that included a Systematic Mapping Study followed by the application of a clustering technique. A questionnaire for DevOps practitioners ($n = 15$) was employed as an evaluation method.
Results: A total of 59 human factors related to DevOps were identified, described, and synthesized. The results were used to build a theory on DevOps human factors.
Conclusion: The main contribution of this paper is a theory proposal regarding human factors in DevOps adoption. The evaluation results show that almost every human factor identified in the mapping study was found relevant in DevOps adoption. The results of the study represent an extension of DevOps characterization and a first approximation to human factors in DevOps adoption.

Contents

* Corresponding author.
E-mail address: juanjose.perez9@um.es (J. Pérez-Sánchez).

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1. Introduction

1.1. Motivation

DevOps is a software engineering paradigm whose objective is to bridge the gap between Development (Dev) and Operations (Ops) teams [1]. Although this was the first broad scope of DevOps employed in scientific literature with this wide definition, more recent studies have linked DevOps with collaboration, automation, and continuous practices [1–3]. Moreover, despite the efforts made to identify exactly what DevOps is, many different definitions of it exist [4]. There is, therefore, no consensus in the scientific literature regarding the definition of DevOps. In fact, some recent studies have reported the lack of agreement between the definitions used in literature [2,5,6]. In this study, we follow Sanchez-Gordon and Colomo-Palacios [7] perspective that DevOps culture should be characterized in order to understand its current state.

DevOps was first introduced in 2009, but the main problem it addresses had already been identified [3,8,9], i.e., the fact that the separation between development and operations teams generates delays in the time required to deliver software products. DevOps focuses on this issue, by enabling faster deliveries and higher quality products [10], and consequently, making companies more competent in the constantly changing industry. High performance DevOps teams deliver code faster, more frequently, recover from downtime faster, and are less likely to fail [11].

Software Engineering literature has not fully responded to the question of how an organization should adopt DevOps [12]. Some effort has been made to understand how to achieve a mature DevOps implementation, although this is still insufficient [13]. Furthermore, a recent study [14] concluded that improving the DevOps maturity level of an organization does not, in itself, increase its performance: organizational performance is increased only when other interventions and strategies are included. Moreover, maturity models involve a set of implicit incorrect assumptions, as the assumption that different SE organizations will reach a similar state if they reach the same level of maturity, that the increase in the maturity level of an organization will positively impact performance without measuring the outcomes, or that the capabilities needed for an organization to be mature will not change over time [11]. DevOps adoption is not a trivial task, as DevOps often requires both technical and cultural change, and cultural change is more difficult to achieve [15].

Although the "soft side", i.e., the human factors, are always present in software development [16], very few DevOps studies address this topic [7]. In fact, Restrepo-Tamayo and Gasca-Hurtado [17] did not identify any research focusing on DevOps human aspects in a recent mapping study regarding human aspects of SE. Conversely, team culture and human factors have been identified as the main difficulty for a successful adoption of DevOps, since they are more complex to deal with than technical and process issues [15]. Moreover, the adoption process can go wrong at all hierarchical levels if human factors are not properly managed [18], and they have been identified as the most significant for a successful DevOps adoption [19]. To the best of the authors' knowledge, no previous work has identified and thoroughly studied the interplay of human factors and DevOps. The adoption of DevOps implies a cultural shift, which also implies that the set of human factors involved is different from other methodologies [7]. This motivates the research of human factors that are present in DevOps culture, in contrast with the existing research on Software Engineering. Furthermore, a recent mapping study regarding human aspects in Software Engineering [20] did not identify any studies focused on the human aspects of DevOps.

Human factors are abstract in nature, and are frequently mentioned in literature as a broad term without a clear definition [21–23]. Throughout this paper, the term "human factors" will be considered as the set of psychological, behavioral, sociological, and contextual aspects of humans that are related to the software process. Human factors have been closely related to the success or failure of software development [21], and are, in fact, the greatest source of opportunity to improve productivity [24–26]. Conversely, the absence of human aspects in the analysis of systems may lead to dissatisfaction with their development [21,27]. The importance of researching human factors in software development has, therefore, been growing steadily in recent years [23], supported by an upward trend in the amount of papers dealing with human factors in Software Engineering [22].

1.2. Research gaps

This paper addresses two research gaps (RGs): (RG1) the characterization of DevOps culture from the perspective of human factors, and (RG2) the identification and analysis of human factors in the adoption of DevOps. This study approaches DevOps human factors through the adaptation of DevOps-related methodologies that could be considered intrinsic or strongly bound [2]. These other methodologies have been subject to research for a longer time and have reached a more mature state (e.g. Agile, Lean or Automation). The approach of adapting knowledge from more mature fields or disciplines has been encouraged and applied successfully in Information Systems research [28]. In contrast, Software Engineering methodologies have suffered from a lack of cumulative research [29]. This paper is an extension of "A taxonomy of human factors that affect DevOps adoption" [30], published in WorldCIST 2024.

1.3. Contributions

A Systematic Mapping Study has been carried out in order to identify the human factors related to DevOps adoption. A DevOps human factor taxonomy has been developed following the described approach, so as to further characterize DevOps culture and improve the adoption process. The resulting taxonomy was validated through a practitioner targeted survey that involved 151 DevOps practitioners from 12 different countries. The taxonomy has been used as the base for a theory proposal on human factors in DevOps adoption.

A theory on DevOps human factors, which are part of DevOps culture (RG1), will help researchers achieve a better understanding of what DevOps is, which could improve the researchers' perception of the state of the art, the identification of RGs in the field, and the opportunities for a further extension of knowledge in the field. From the perspective of organizations in the process of adopting DevOps, the theory (RG2) may additionally facilitate the adoption process, which is a consolidated research problem in literature, and one of the main difficulties in the Software Engineering industry, and improve the engagement and satisfaction of the employees involved.

1.4. Paper structure

This paper is structured as follows: Section 2 compares this study and other field-relevant studies. Section 3 details the methodology designed to carry out the study. Section 4 presents the results drawn by the methodology, Section 5 presents the evaluation of the results, Section 6 shows a discussion of the results of the study and Section 7 presents a theory proposal. Section 8 states the possible threats to the validity of the study and the measures taken to avoid them, and finally, Section 9 presents the final conclusions of the study along with the lines of future work and research gaps.

2. Related work

While, to the extent of our knowledge, no systematic review has been done regarding DevOps human factors, some papers have reviewed the human factors present in broader contexts. The small amount of review studies on human factors suggests that more efforts are required to leverage the benefits of secondary studies, such as synthesizing existing knowledge, identifying research gaps, and informing evidence-based practices. Machuca-Villegas et al. (2020) [31] (RW1) identified and classified which human factors have an effect on team productivity in software development. They concluded in a list of 13 human factors in software development teams. Restrepo-Tamayo et al. (2022) [17] (RW2), through a Systematic Mapping Study, reviewed 99 papers in order to study which human aspects are being measured in the Software Engineering literature. They differentiated the identified aspects between those that were dependent or independent on other variables. They presented 15 independent human aspects and 11 dependent human aspects, 24 in total, as some human aspects were present as both independent and dependent. Restrepo-Tamayo et al. (2024) [32] (RW3), in a continuation of the study by Machuca-Villegas et al. (2020) [31] (RW1) previously mentioned, focus on 3 human factors (i.e., communication, leadership, and teamwork). Restrepo-Tamayo et al. [32] (RW3) analyze these 3 factors in terms of which variables affect the factors, which variables are affected by the factors, and how are these factors being measured. Finally, Restrepo-Tamayo et al. (RW3) propose a model hypothesis that tries to explain how the factors are related with themselves, and the team dynamics where the factors belong to. Table 1 shows the comparison of the number of human factors studied in each paper. Some factors presented in the related work have been found in this section based on the proposed description and not on the factor names, as the factor names may vary between authors. Only one factor was found in the related work that was not included in this study, in particular, the human factor "happiness", in RW2. However, the authors of the study acknowledge that factors such as "happiness" are multidimensional, and may be included in other factors.

As in this paper, every paper listed in this section performed a literature review and identified, synthesized, and described a set of human factors. RW2 and RW3 also include a deeper analysis on the factors, regarding how do they depend on other variables (RW2), and how are they measured (RW3). In comparison, our paper studies human factors in terms of what effect do they have on the organization. Among the related studies identified, only RW3 tried to describe the human factors identified as a part of a bigger system. Our paper, however, goes further by proposing a theory on human factors in DevOps adoption. While RW3 describes how a small set of human factors takes part in a specific system, the theory proposed in our paper provides the fundamental characteristics of human factors. Regarding the proposal validation, no related study validated the set of human factors identified, while, in our paper, the human factors identified and described have been validated through a practitioner targeted questionnaire.

3. Methodology

Fig. 1 depicts the methodology followed in this study. The steps of the methodologies in the figure are a simplification of how the information is extracted and transformed through the use of this process.

The methodology employed to select the primary studies available in literature was Systematic Mapping Study [33]. A Systematic Mapping Study is a method with which to extract an overview from a

Table 1
Related recent papers comparison. Legend: #HF = Number of human factors studied, #UF = Number of human factors that are not included in this study, Context = The field of study where the human factors are identified.

ID	Paper	#HF	#UF	Context
RW1	Machuca-Villegas et al. (2020) [31]	13	0	Software development teams
RW2	Restrepo-Tamayo et al. (2022) [17]	24	1	Software development
RW3	Restrepo-Tamayo et al. (2024) [32]	3	0	Team productivity

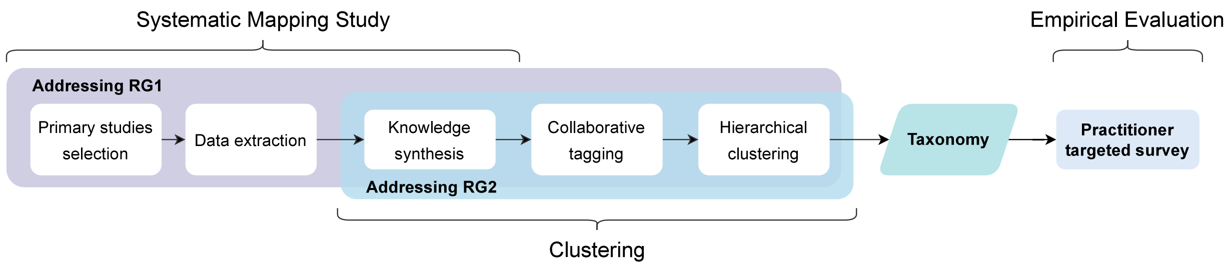

Fig. 1. Hybrid methodology diagram.

research field, and classify the information regarding the topic selected. It shares some commonalities with a Systematic Literature Review, but differs as regards the main purpose, which is the establishment of the structure from a research field, and not the synthesis of evidence, as occurs in systematic literature reviews. After searching in every database reported in Section 3.1.3, no previous systematic mapping studies or systematic literature reviews were found prior the execution of this review. Given the lack of secondary studies in the field, and the lack of structure in the research field, a Systematic Mapping Study was the best fitting methodology. The Systematic Mapping Study guidelines proposed by Petersen et al. [34] were followed in this paper. These guidelines were complemented with the Systematic Literature Review guidelines proposed by Kitchenham and Charters [35], which are also recommended by Petersen et al. [34]. Appendices A and B show the mapping study tasks undertaken, along with the quality evaluation checklist employed during the review process.

Section 3.2 describes the clustering process, which was carried out in order to identify the human factors that are related to each other. The clustering process was carried out after the Systematic Mapping Study, as the clustering process required the information extracted from the primary studies. The clustering process leads to the proposal of a taxonomy. The proposal of a taxonomy based on a secondary study is supported by Ralph's guidelines for process and taxonomy theory proposal [36]. A clustering technique was selected in order to extract the classification of human factors directly from the data, without the need for a previous hypothesis.

3.1. Systematic mapping study

The Systematic Mapping Study was planned and conducted according the information described in the following subsections: Section 3.1.1 shows the research questions addressed in the Systematic Mapping Study, while Section 3.1.2 presents the search strategies selected for the review. Section 3.1.3 shows the databases selected for the automatic search strategy, and Section 3.1.4 details the source of search string terms and the search string used in the automatic search. Section 3.1.5 describes the criteria followed for the primary study selection, while Section 3.1.6 describes the criteria followed in order to assess the quality of the primary studies obtained. Section 3.1.7 reports which data was extracted from the primary studies selected.

3.1.1. Systematic mapping study research questions

The overall objective of our study is to characterize DevOps as regards human factors and to identify the effects of human factors on DevOps adoption. In order to obtain a detailed view of this topic, the systematic mapping study addresses five research questions (Mapping Questions or MQs). Table 2 presents the MQs with their corresponding motivations. These five questions are the first step toward attaining the two main RGs shown in this paper, and MQ3, MQ4 and MQ5 in particular attempt to identify and describe which human factors may be related with DevOps adoption (i.e., RG2), and the effect they might have. Moreover, the information acquired is used in this study as a background with which to characterize DevOps from a human factor perspective.

Table 2
Research questions and motivation.

ID	Research question	Motivation
MQ1	In which years, venues and sources have the selected papers been published?	To identify time tendencies and the different venues and sources (journals, conferences, books)
MQ2	Which research types and methods were used in the selected papers?	To determine the frequency of research strategies and types of empirical studies adopted for evaluation.
MQ3	In which methodologies or practices have human factors been identified?	To identify DevOps-related methodologies or practices (agile, lean, software process improvement, others) that study their human factor.
MQ4	Which human factors affect DevOps adoption?	To extract the human factors that have an impact on DevOps adoption.
MQ5	How do human factors affect DevOps adoption?	To understand the effect of human factors on DevOps adoption.

3.1.2. Search strategy

The principal methodology selected for the review was an automated research, which was complemented with the snowballing technique [37]. The search was carried out on July, 4, 2024.

3.1.3. Database selection

Table 3 shows the digital databases that were used in the search process. Following the guidelines of Petersen et al. [34], two publishing databases and two indexing databases were selected, including ACM Digital Library and IEEE Xplore.

3.1.4. Search string

The keywords in the search string were extracted from PICO(C) (Population, Intervention, Comparison, Outcomes, Context) [38], expert consultation, studies known by the authors, and a thesaurus. In order to achieve the final version of the search string, it was tested and discussed iteratively until the authors of the study reached an

Table 3
Databases selected.

Database	Link
ACM Digital library	https://dl.acm.org/
IEEE Xplore	https://ieeexplore.ieee.org/
Scopus	https://www.scopus.com/
Web of Science	https://www.webofscience.com/

agreement. The search string reflects the approach that this study takes to adapt DevOps-related methodologies to DevOps. Therefore, the search string is not limited to DevOps, but methodologies that can be included in terms as general as "software engineering", that would then be filtered through the selection criteria. The search string used in the study is the following:

("human factor" OR "human behavior" OR "human aspect") AND ("implementation" OR "adoption" OR "acceptance") AND ("software engineering" OR "software development" OR "devops" OR "agile" OR "continuous practices" OR "software process" OR "continuous development" OR "continuous deployment")

The search string was adapted to the syntax of each database, but its content remained the same. The search scope for each database was title, abstract and keywords. Only the time-range filter was applied in the automatic databases.

3.1.5. Selection criteria

The selection criteria was proposed according Kuhrmann et al. guidelines [39]. Most of the criteria are a rephrased form of the standard criteria that are useful in a broad spectrum of studies, and the topic-specific criteria are aligned with the research questions. The selection process was carried out according to the following criteria:

- Inclusion criteria
  - IC1: Studies in the field of software engineering concerning methodologies, techniques, processes, tools or practices used in DevOps contexts.
  - IC2: Studies published in journals or conferences or as book chapters.
  - IC3: Studies written in English.
  - IC4: Studies published from 2010 to the date of the search.
- Exclusion criteria
  - EC1: Papers that did not include any human factors or did not focus on software engineering and the adoption of technology.
  - EC2: Papers available only in the form of abstracts, guidelines, reports, or PowerPoint presentations.
  - EC3: Duplicate papers.
  - EC4: Studies for which the full text was not accessible.

The selection form can be accessed online (https://bit.ly/3vJJiKh). As mentioned in the IC, the selection of papers was restricted to papers published from 2010 to the date of the search in order to avoid papers that were published before DevOps was introduced into scientific literature.

3.1.6. Quality assessment criteria

The quality of the papers selected was assessed by employing the following Quality Criteria (QCs) based on the studies by Khan et al. [40] and Shameem et al. [41]:

- QC1: Are the aims/objectives of the research clearly stated?
- QC2: Are the threats to the validity of the methodology specified?
- QC3: Did the study provide sufficient details for it to be repeatable?
- QC4: Are the results and findings clearly reported?
- QC5: Are the conclusions supported by the results of the study?
- QC6: Is the data analysis clearly described and systematic?

The reviewers (the first two authors of the study) assigned a score to each QC and selected paper after carrying out a full-text review. A score of 0 was assigned if the criteria were not fulfilled, while a score of 0.5 was assigned if the criteria were partially fulfilled, and a score of 1 was assigned if the criteria were completely fulfilled. If the sum of each QC score for a paper was 3 or more, the paper was included in the final papers. The quality criteria assessment form can be accessed online (https://bit.ly/3LpOrh1).

3.1.7. Data extraction

Table 4 shows the data extraction form fields and their motivation. The data extraction form can be accessed online (https://bit.ly/3EUKA9a).

3.2. Clustering

Clustering is a classification technique that uncovers groups (clusters) in data, so that the data in the same group is more similar to each other than to the data in other groups [43]. The clustering technique selected for this study was Hierarchical Clustering, as it is a technique that does not require the number of clusters to be specified in advance, and it is a technique that is frequently used in the field of Software Engineering [44]. The clustering process was carried out according to the following subsections.

3.2.1. Knowledge synthesis

The original information extracted from the selected papers, underwent: (1) a merging process, during which the factors with similar descriptions were merged into the same factor. After two human factors has been merged, the reviewer selected the most descriptive name and the most precise description for the merged human factor. In some cases, the description included parts of more than one paper; and (2) an abstraction level balance process, during which those human factors whose descriptions were (from the reviewer's perspective) too abstract, or too specific, were split into more specific human factors and re-merged, or included in a less-specific human factor that could include the overly-specific human factor. This kind of human factor synthesis has been carried out successfully in another human factor study [45].

3.2.2. Collaborative tagging and folksonomy

This was achieved by employing the collaborative tagging technique. Following the guidelines of Calefato et al. [46], the first and second authors of this paper proposed and freely assigned a set of tags. These were then reviewed by the four first authors of this study in order to reduce bias as regards tag proposals. The tags were assigned so as to synthetically describe the human factors identified, according to the authors' experience. The assignation results can be accessed online (https://bit.ly/37JfvJM).

The result of the axial coding process is denominated as a "Folksonomy". A Folksonomy is a collection of annotations, or "tags", that organize information [46]. The set of annotations used to tag all the human factors was A:

A = {"Personality", "Skills", "Influence", "Management", "Customer", "Support", "Perception", "Empowerment", "Information" }

3.2.3. Hierarchical clustering

The method that the authors of this paper selected for this task was a Hierarchical Clustering analysis, and specifically, the agglomerative complete linkage method [43,44]. A total of 9 annotations were used to tag the human factors (the cardinality of A is: $|A| = 9$). A 9-dimensional binary vector (one dimension per annotation) was then assigned to each human factor, thus enabling each tag to be defined as "1" if present or "0" if not present for each tag. E.g., $F_1 = \{1, 1, 0, 0, 0, 1, 0, 0, 0\}$,

Table 4
Extraction form fields and their definition and purpose.

Field	Definition	Purpose
Authors	The authors of the paper	Identification
Title	The name of the paper	Identification
Publication venue	Journal paper, conference paper, book chapter, technical report, abstract publication, others	Identification, selection, and topic-independent classification
Venue name	Name of the venue of publication	Identification and topic-independent classification
Year of publication	The year in which the paper was published	Identification, selection and topic-independent classification
Research type	Evaluation, validation, solution proposal, philosophical, experience report, opinion paper [42]	Topic-independent classification
Research method	Industrial case study, controlled experiment with practitioners, practitioner targeted survey... [34]	Topic-independent classification
Human factor	Each of the human factors that the paper identifies	Selection and topic-dependent analysis
Factor Description	Description of each of the human factors previously reported	Selection and topic-dependent analysis
Category of factor	Category (if present) in which the human factor has been included in the source paper	Identification

where F_1 represents a human factor, and each dimension of the vector corresponds to a tag in A. The matrix that links the human factors with the annotations was used as the input for the hierarchical clustering analysis.

The clustering process technique employed was Binary Clustering, while the dissimilarity matrix was calculated using the Jaccard distance measure method, as the data source was binary, and the Jaccard distance measure ignores the co-absence of features, which do not provide useful information about the similarity of individuals in this context [43]. In order to obtain the optimum number of clusters, the Silhouette coefficient was calculated for every possible amount of clusters (between 2 and the total amount of human factors minus 1).

3.3. Evaluation method

A practitioner targeted survey was designed to evaluate the results of this study. The survey design followed Kitchenham and Pfleeger guidelines [47]. A non-probabilistic recruitment of participants was conducted. Non-probabilistic data sampling can negatively affect selection bias and undercoverage bias, as the participants selected may not be a good representation of the whole objective population, threatening the generalization of the results. However, non-probabilistic recruitment of participants can be conducted in a shorter span of time compared with probabilistic recruitment. In secondary studies, where the information available is constantly growing, the conclusions extracted might be valid only for a period of time, supporting the use of faster ways of evaluation. In addition, as the participants are volunteers, no tracing or persuasion of non-respondents is required. The participants were invited through direct contact with collaborating software development organizations. As the survey was explicitly designed for DevOps practitioners, and every participant claimed to have experience in DevOps, no participants were rejected. After the collection of responses, a descriptive analysis of the information was performed, which is reported in Section 5.

The survey is divided into three main sections. The first section gathers the respondents' demographic data. The second section focuses on the validation of the human factor categories, where the respondents are asked to evaluate the degree of relation that every human factor has with its category. The third section focuses on the validation of the human factors themselves, whether they are relevant to a successful DevOps adoption or not. The respondents are asked whether they agree or not that each human factor is relevant for DevOps adoption. At the end of the questionnaire, any suggestions that the respondents were willing to provide were gathered. The respondents were provided with the description of each factor as it is shown in Table E.14. The survey's definition can be accessed online (http://bit.ly/3GyB6DD)

3.3.1. Personal data protection

The survey gathered personal data that could be potentially sensitive information. Thus, the survey included an explicit clause where the respondents agree to provide such information, and understand that no sensitive information will be published, having all the non-sensitive information available upon request. By completing the survey, the respondents agreed to participate in the research under the terms stated.

4. Results

4.1. DevOps characterization through the use of literature

The databases shown in Table 3 returned a set of 253 candidate papers. ACM Digital Library returned 4 results, IEEE Xplore returned 31 results, Scopus returned 213 results, and Web of Science returned 48 results, for a total of 274. At this point, 21 duplicated papers (EC3) were removed, giving a total of 253 unique papers. A set of 6 additional papers were included after the use of the snowballing technique, yielding a total of 259 candidate papers. The paper which this paper extends was among the candidate papers, and was consequently excluded before the appliance of the selection criteria, leaving 258 candidate papers. The selection criteria was applied as follows: (1) 90 papers did not fulfill EC1 (168 remaining), (2) 1 paper did not fulfill EC2 (167 remaining), (3) 85 papers did not fulfill IC1 (82 remaining), (4) 40 papers did not fulfill IC2 (42 remaining), (5) 7 papers did not fulfill IC3 (35 remaining), and (6) 1 paper did not fulfill IC4, giving a total of 34 papers that fulfilled every selection criteria, and were considered relevant. This set of relevant papers was then subjected to the quality assessment process reported in Section 3.1.6, which yielded a final amount of 23 papers, listed in Table D.13 in Appendix D. Fig. 2 shows the graphic description of the process.

4.1.1. MQ1. In which years, venues and sources have the selected papers been published?

The purpose of this research question was to trace and detail the publication trends over time. Fig. 3 shows the selected papers divided by venue type from January 2010 to July 2024, when the search was conducted. Table 5 shows the venues at which the selected papers were published, along with the references and the number of papers published at each venue.

Fig. 3 shows a stable publication tendency over the last 11 years, with a maximum of 3 papers published in 2011 and 2017, and a minimum of 0 papers published in 2013 (note that at the time of the search, 2024 was not finished). A 57% of the selected papers (13) were

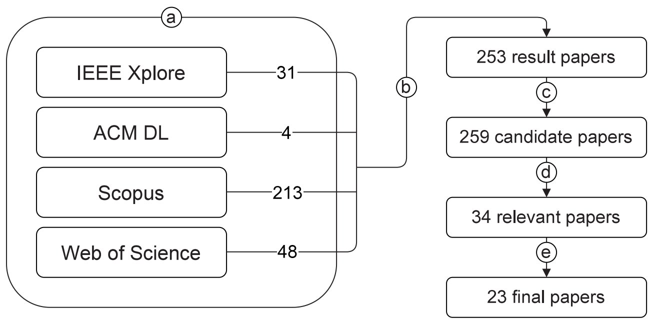

Fig. 2. Systematic mapping study process diagram. Legend: (a) Perform the automatic search using the search string. (b) Collect the results returned by the automatic search. (c) Snowballing. (d) Apply the selection criteria to the candidate papers. (e) Apply the quality criteria to the relevant papers.

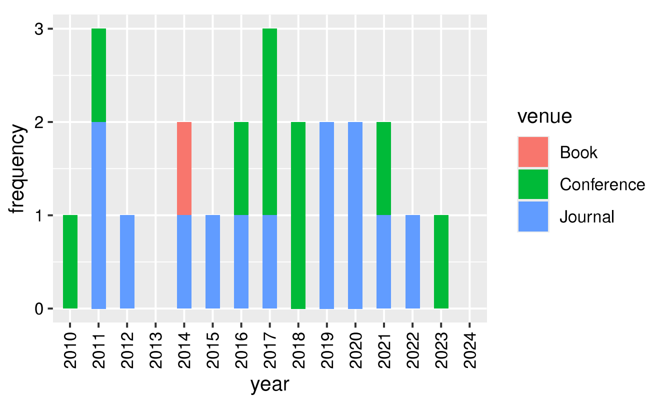

Fig. 3. Publication venues over 14 years tendency.

published in journals, followed by 39% (9) in conferences, and 4% (1) in books. A steady rate of publication can be seen in the last 10 years.

As Table 5 shows, no journal, conference, or book published more than one of the papers selected. Each of the papers selected was published at a different publication venue.

4.1.2. MQ2. Which research types and methods were used in the selected papers?

This research question was proposed in order to identify the methodological trends in the research field. Fig. 4 shows the selected studies research type according the study by Wieringa et al. [42]. Fig. 5 shows the research method tendency according to Petersen et al. [34]. The categories "Practitioner targeted interview" and "Literature review" are not included in the Petersen et al. classification, but we have employed them in order to better categorize the data.

Fig. 4 shows that 51% of the papers contained empirical research types (Evaluation research and Validation research) while 49% did not (Philosophical papers and Solution proposals). However, solution proposal research could be considered as empirical research, and 2 of the papers classified as solution proposals (PS4, PS14) used empirical methods to create their proposals. Therefore, the percentage of empirical research could be considered as 61% of the selected papers (14 papers out of 23).

Fig. 5 shows that a 61% of the selected papers contained research methodologies that are closely related to a validation in industry (Industrial case study, Practitioner targeted interview, Practitioner targeted survey).

4.1.3. MQ3. In which methodologies or practices have human factors been identified?

Table 6 shows the methodologies and practices identified in the selected papers, along with its relationship with DevOps, and a list of

Table 5
Venues at which the selected papers were published.

Venue	Pap.	#Pap.
International Journal of Sociotechnology and Knowledge Development	PS1	1
International Conference on Software Engineering and Knowledge Engineering	PS2	1
Procedia CIRP	PS3	1
Journal of Systems and Software	PS4	1
International Conference on Agile Software Development	PS5	1
IEEE Engineering Management Review	PS6	1
International Conference on Information Technology for Organizations Development (IT4OD)	PS7	1
South African Journal of Industrial Engineering	PS8	1
European Conference on Cognitive Ergonomics (ECCE)	PS9	1
International Journal of Computer and Information Engineering	PS10	1
International Journal of Software Engineering and its Applications	PS11	1
Journal of Product Innovation Management	PS12	1
Journal of Manufacturing Technology Management	PS13	1
ACM/IEEE International Conference on Model Driven Engineering Languages and Systems Companion (MODELS-C)	PS14	1
IEEE International Conference on Requirements Engineering	PS15	1
Overcoming Challenges in Software Engineering Education: Delivering Non-Technical Knowledge and Skills	PS16	1
Journal of technology management & innovation	PS17	1
International Conference on Research Challenges in Information Science (RCIS)	PS18	1
International Journal of Information Technologies and Systems Approach	PS19	1
America's Conference on Information Systems (AMCIS)	PS20	1
Journal of Software Maintenance and Evolution	PS21	1
RISKS	PS22	1
Journal of Enterprise Information Management	PS23	1

Fig. 4. Research type tendency.

selected papers that focus on that particular methodology or practice. The methodologies and practices were identified by reviewing the title and abstract, and if necessary, reading the full text of the selected papers. All the selected papers state explicitly in which methodology or practice they focus, i.e., the methodology or practice to which the human factors identified belong.

Regarding the methodologies and practices where the factors were identified, 33% of the papers (7) identified human factors in the methodology of Agile software development, followed by 24% of papers (5), which were related to Lean Management. Only one paper directly addressed DevOps.

Table 6
DevOps-related methodologies and practices identified in the selected studies.

Methodology/Practice	Relation with DevOps	Papers
Agile methodology	DevOps extends the agile methodology in terms of the principles involved, as DevOps can provide a pragmatic extension of current agile activities [2]. Hosono [48] mentioned that agile methods can be considered as enablers for the adoption of DevOps thinking. Agile can support DevOps by encouraging collaboration among team members, the automation of building, deployment and testing, measurement and cost metrics, value and processes, and knowledge sharing and tools [49]. DevOps is the new software process that extends the agility practices within the collaborative culture in order to enhance the process of software development and delivery [50].	PS1, PS4, PS5, PS11, PS12, PS17, PS21, PS22
Lean Management (LM)	Lean software development principles and practices inform DevOps implementation [51]. DevOps and lean methodology share similar goals and can effectively complement each other. DevOps and lean are key elements that achieve rapid software development and validated learning [52].	PS3, PS6, PS7, PS8, PS13
Software Process Improvement (SPI)	Software process improvement (SPI) will help DevOps to enhance quality of software product [50]. This program will assist DevOps organizations to successfully manage and improve their processes so as to achieve the actual benefits of DevOps [53].	PS2, PS10
Software development teams	DevOps practices have improved the performance of software development teams by establishing cross-functional teams and providing closer collaboration with customers [54]. DevOps is promoting collaboration between development and operation teams [55].	PS14, PS16
Technology adoption	The adoption of DevOps is an initiative toward the adoption of new technology [56]. According to Koilada [57], DevOps has led to an innovation from a technology perspective, by fostering the collaboration among diverse teams, eliminating cultural disparities and transforming business models for the new adoption of technology.	PS18, PS23
Process management	Process management helps in DevOps adoption. Challenges as regards managing current changes and DevOps adoption can be resolved by managing the DevOps process [58].	PS19
Automation	DevOps is related to end-to-end automation through software development and delivery [59]. DevOps and automation can improve software quality by removing accidental mistakes through the incorporation of tools of the trade in order to leave precious time for the most essential manual effort requiring tasks, such as design [60]. DevOps encourages automation, which has been seen to help improve the quality of releases [61]. DevOps has attempted to use automated systems to bridge the information gap between project team entities and to enforce rigorous processes to ensure real-time communications [62].	PS9
Software modeling	Software modeling helps share information about the system being developed, achieving a unified source of truth, and is a DevOps enabler, and potential requirement [63].	PS14
DevOps	The focus of this paper is DevOps human factors.	PS20

Fig. 5. Research method frequency.

4.1.4. MQ4. Which human factors affect DevOps adoption?

Appendix E shows the human factors identified by means of the mapping study. The names and descriptions have been slightly modified from the data extracted in order to improve legibility. The unmodified synthesized data can be accessed online (https://bit.ly/3OGZVi9). The data shown in Appendix E is the result of the synthesis of the data extracted.

A total of 59 human factors were identified. The most frequently identified factor was “Support of senior management” (8 times), followed by “Technical and methodological skills” (7 times), “Motivation for change” (5 times), “Team work” (5 times), “Lack of evidence of benefits” (5 times), “Communication” (5 times), “Resistance to change” (4 times), “Personal skills (behavioral skills, attitudes and behaviors)” (4 times), “Customer involvement” (4 times), “Team size and project organization” (4 times), “Education and learning” (3 times), “Negative experiences” (3 times), “Autonomous workers” (3 times), and “Commitment” (3 times). A 54% of the human factors (32) were identified at least twice, while a 46% of the human factors (27) were identified only once.

4.1.5. MQ5. How do human factors affect DevOps adoption?

The definitions in Appendix E show how human factors are relevant to a set of components related to DevOps. The human factors identified can be separated into those that are positive if present, and negative if absent (positive human factors), those that are negative if present, and positive if absent (negative human factors), and those that can be positive if applied correctly, or negative if not (ambivalent human factors). Table 7 presents the classification of the effect of human factors. These factors have been classified on the basis of the descriptions shown in Appendix E.

In relation with the effect of the factors identified, 42% of the human factors identified (25) are positive human factors, followed by a 39% of ambivalent human factors (23), and a 19% of negative human factors (11).

Table 7
Classification of effects of human factors.

Positive	Negative	Ambivalent
Technical and methodological skills	Negative experiences	Education and learning
Motivation for change	Resistance to change	Personal skills (behavioral skills, attitudes and behaviors)
Creativity and innovation	Indifferent to change	Cultural Adaptation Aspects
Responsibility and decision skills	Exhaustion from high autonomy and responsibility	Effort expectancy
Leadership	Resistance to lead	Perceived ease of use
Multitask workers	Lack of evidence of benefits	Perceived usefulness
Autonomous workers	Optimism bias	Social influence
Role understanding	Conscientiousness	Satisfaction
Commitment	Neuroticism	Perceived risk
Trust	Time/commercial pressures	Voluntariness
Trust belief	Imposition	Computer self-efficacy
Team spirit		Perceived enjoyment
Teamwork		Compatibility
Recognition and rewards		Relative advantage
Extraversion		Knowledge transfer
Agreeableness		Organizational structure
Support of senior management		Performance Aspects
Respect from management		Customer risk factors
Communication		Financial resources
Collaboration		Team size and project organization
Supporters		The clarity of the goal
Experienced and specialized members		Recruitment
Customer involvement		Self-efficacy
Humane orientation		
Continuous improvement culture		

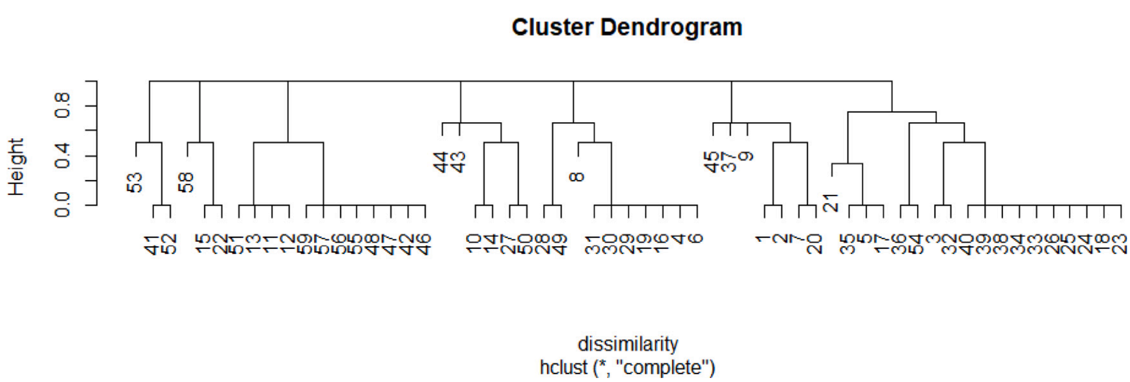

Fig. 6. Binary tree clustering dendrogram. The numbers in the leaves represent the human factors identified (1–59). The lines in the dendrogram merge upwards until the root of the tree is reached, where more similar human factors are grouped together at a lower height, while less similar human factors are grouped together at a higher height.

4.2. Taxonomy proposal

After carrying out the bottom-up analysis described in Section 3.2, a final set of 59 human factors was established and annotated. The annotated human factors were classified in a total of 8 clusters, as this was the configuration that achieved a maximum Silhouette coefficient of 0.52 without one-element clusters. The outcome of the analysis can be seen in Fig. 6, which shows a dendrogram in which the relation among the 59 human factors identified is depicted.

Table 8 shows the list of clusters and the factors that belong to each one. The clusters can be defined as follows: **SKI**, human factors related to DevOps skills, including social skills (e.g. responsibility) and technical skills. **PRC**, human factors related to the perception that a person has of a particular aspect. **PRS**, human factors related to aspects of one person's personality, including human factors that describe how a person reacts in a specific situation. **PAP**, human factors that combine perception (PRC) and personality (PRS). **SUP**, human factors related to the influence of the external or internal support that a person or an organization receives. **MNG**, human factors that rely on an organization management of a process, workforce, culture or resources. **INF**, human factors that focus on the importance of information regarding a process. **CUS**, human factors that depend on, or can be influenced by, an organization's customers.

5. Empirical evaluation

A questionnaire (https://bit.ly/3QPPsnw) was designed to empirically evaluate the proposal included in this paper, as defined in Section 3.3. When the period of collecting answers finished (2024/03/09 to 2024/05/10), the total number of valid answers was 15. The following subsections detail the questionnaire results obtained.

5.1. Respondents demographic analysis

This section presents the demographic information that was collected from the respondents of the questionnaire. Fig. 7 show the geolocation of the participants, Fig. 8 shows the participants' DevOps experience in years, and Fig. 9 presents the respondents' organization number of employees. Fig. 10 reports the respondents' occupation. Finally, Fig. 11 presents whether the respondent's organization is thought to deal with human factor management. The data shown in Figs. 7 and 10 is the result of the normalization of the original data, which was collected in a free-text format.

Table 8
Human factor clusters.

Human factor	Cluster
Technical and methodological skills Team work Responsibility and decision skills Personal skills (behavioral skills, attitudes and behaviors) Knowledge transfer Education and learning Computer self-efficacy	SKI
Voluntariness Trust belief Social influence Self-efficacy Satisfaction Relative advantage Perceived usefulness Perceived enjoyment Perceived ease of use Optimism bias Negative experiences Humane orientation Effort expectancy Compatibility	PRC
Team spirit Performance Aspects Neuroticism Motivation for change Indifferent to change Extraversion Creativity and innovation Conscientiousness Commitment Agreeableness	PRS
Trust Resistance to change Perceived risk Cultural Adaptation Aspects	PAP
Supporters Support of senior management Respect from management Resistance to lead Recognition and rewards Leadership	SUP
Team size and project organization Recruitment Organizational structure Multitask workers Imposition Financial resources Experienced and specialized members Exhaustion from high autonomy and responsibility Continuous improvement culture Communication Collaboration Autonomous workers	MNG
The clarity of the goal Role understanding Lack of evidence of benefits	INF
Time/commercial pressures Customer risk factors Customer involvement	CUS

5.2. Human factor relevance evaluation

This section evaluates whether the factors identified are relevant from a practitioner's perspective or not. A symmetrical Likert scale of 5 points was used. Likert scales are mainly designed to assess construct validity [64], and are a convenient way to measure unobservable constructs [65], such as the relevance of human factors in DevOps adoption. Each survey's respondent was asked to evaluate each human factor identified with one of the following options, regarding its relevance towards a good DevOps adoption: Strongly agree (Dark green),

Fig. 7. Country distribution of the respondents.

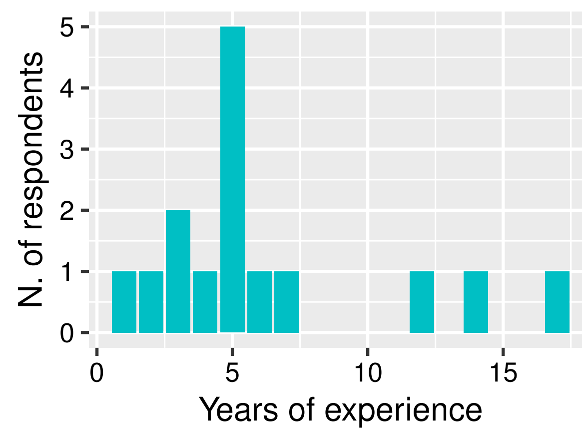

Fig. 8. Respondents' DevOps experience distribution.

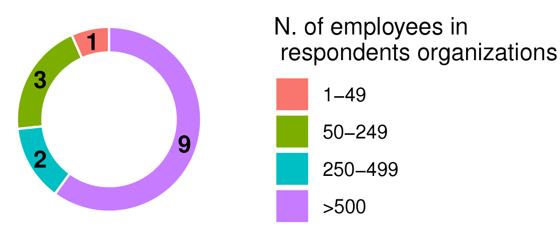

Fig. 9. Respondents' organization size distribution.

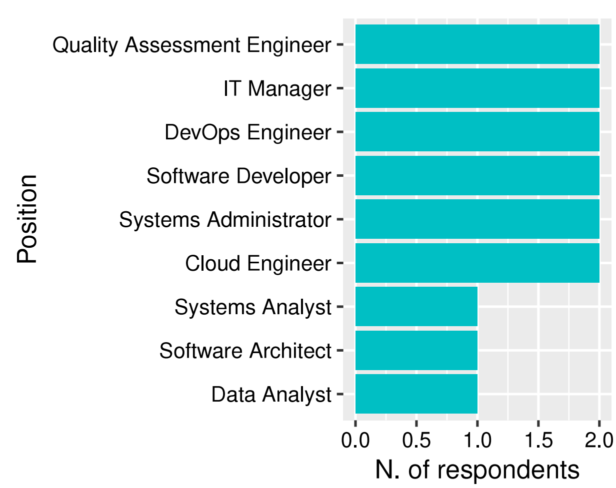

Fig. 10. Respondents' occupation in industry distribution.

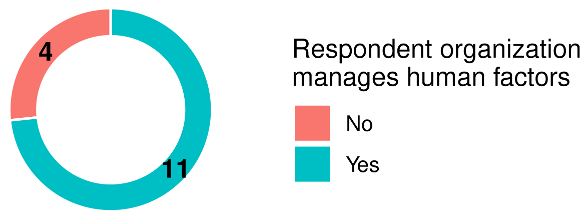

Fig. 11. Human factor management in respondents' organizations.

Agree (Light green), Neutral (Yellow), Disagree (Orange), Strongly disagree (Red). Fig. 12 show the results of the empirical evaluation for each human factor in each category. The X axis represents the number of respondents (15).

The results of the evaluation show that almost every human factor identified was found relevant in DevOps adoption, strongly supporting the validity of the set. In order to analyze the results, the textual Likert scale was replaced by a numeric one where "Strongly irrelevant" was replaced with the value 1, and "Strongly relevant" was replaced with the value 5 (including the rest of the options). In order to assess the agreement between respondents, the Fleiss Kappa value was calculated, and a Kappa value of 0.0599 was obtained. Only "Neuroticism" was found irrelevant for DevOps adoption by the majority of the respondents (mean = 2.93, median = 3, s.d. = 0.704). When clusters are considered, the skill-related human factors were found the most relevant by the respondents (mean = 4.15), while the personality-related human factors were found the least relevant (mean = 3.61). However, a clear distinction between the evaluation of the clusters was not perceived.

Fig. 13 show the average value of the responses for each human factor. A total of 18 human factors were found between "Relevant" and "Strongly relevant" (values 4 and 5), and the bast majority of human factors (48 out of 59, 81%) have an average response above 3.5 (being 3 "Neutral" and 4 "Relevant").

6. Discussion

6.1. DevOps characterization (RG1)

The number of publications found regarding human factors in DevOps-related methodologies and practices has been relatively low for the last 14 years, with a maximum of 3 papers published in one year. The study of the human factors in DevOps is carried out in this paper from the perspective of different methodologies and practices that can be related to DevOps, shown in Table 6, which includes the relation between the methodology/practice and DevOps. Some researchers have reported the need to adapt knowledge, methodologies, and perspectives, from other fields in order to extend Software Engineering research [22], which is supported by the lack of studies from the perspective of human factors. The application of a literature review methodology, such as a systematic mapping study, has been particularly suitable for this adaptation of knowledge from other fields, which have more extensive research on human factors. Although some of the research fields that have been adapted can be considered as being mature, e.g. Agile, the low number of publications suggest that the field is still immature regarding the study of human factors. Moreover, the fact that all the papers selected were published at different publication venues suggests that no publication venues have specialized in this field, or if they do exist, that they are not attractive to researchers. Both scenarios support the claim that the research field is immature.

With regard to the research type of the selected studies, almost half of them (39%, 9 out of 23) presented research types without empirical evaluations, while 24% of them (5) proposed and evaluated a solution, and 33% of them (7) validated a solution proposed in other studies. From another perspective, the number of studies that proposed a new solution (with or without validating it) is high (43%, Evaluation research and Solution proposal), which also suggests that the research field is not mature. However, only 26% of the papers (Philosophical paper) presented a theoretical approach to the subject.

The research methodology results show a trend in research methods related to validation in industry. This is the natural conclusion in a field that combines software development methodologies, which are mostly present in industry, and human factors, which require to be in contact with practitioners. Of the research methodologies found, there is a non-negligible amount of studies that do not show a research method (17%, 4 out of 23).

With regard to the relationship between the selected studies and DevOps, only one of the 23 papers selected directly addressed human factors in DevOps. There is a clear difference in comparison with the papers found regarding Agile methodologies or Lean methodologies, since more papers address these aspects (8 in the case of Agile, and 6 in that of Lean). While some definitions of DevOps consider some methodologies in question as an intrinsic part of DevOps [2], DevOps is always related to a wider range of aspects that are not completely covered by any other individual methodology or practice. To the best of our knowledge, there is, therefore, an RG in that field, as papers that address it are almost nonexistent. Since DevOps is closely related to more mature methodologies, and as Table 6 shows, there is consequently a research opportunity to adapt well-established studies in DevOps-related methodologies, in order to characterize DevOps. Furthermore, in our previous study concerning the DevOps certifications available in industry [66], we reviewed the list of competencies of the main certifications available for DevOps as a methodology or for DevOps-oriented practices. Every certification focused on the technical part of DevOps, and no certification acknowledged any competency regarding human factors. This fact might indicate the absence of knowledge on this subject in industry, thus further motivating its study.

6.2. DevOps adoption (RG2)

The final contribution of this paper is a human factor theory for DevOps adoption, based on a human factor taxonomy. The taxonomy is the combination of the human factors identified, together with their descriptions, which are shown in Appendix C, and the classification provided in Table 8. The taxonomy addresses both of the main objectives of this paper, the characterization of DevOps, and guidance through DevOps adoption. The results of the human factor classification show a set of clusters that are closely linked with human behavior, such as personality and perception. However, the results also show that the human factors related to DevOps include: (1) the stakeholders' skills; (2) the support the stakeholders receive and offer; (3) the management of the organization; (4) the information flow; and (5) the relationship with the customers of the process. This proves that human factors have an effect on a wide range of DevOps aspects.

As Table 7 shows, the majority of the human factors found are of a positive nature (25, 42%), followed by those that are ambivalent (23, 39%), and finally, those of a negative nature (11, 19%). The classification of human factors regarding their effect could improve our knowledge regarding what to pursue, what to avoid, and what to take into account in the process of adopting DevOps.

With regard to human factors that have a positive effect, the PRS cluster, which is related to the personality of one person, contains the highest absolute percentage of positive factors (60% relative percentage, 24% absolute percentage). The high relative percentage suggests that the successful personality management during the DevOps adoption process depends on the identification and fostering of positive personality traits in stakeholders. Moreover, the SUP cluster, which consists of human factors related to the influence of the support given to a person or an organization, contains the highest relative percentage of positive factors (83% relative percentage, 20% absolute percentage).

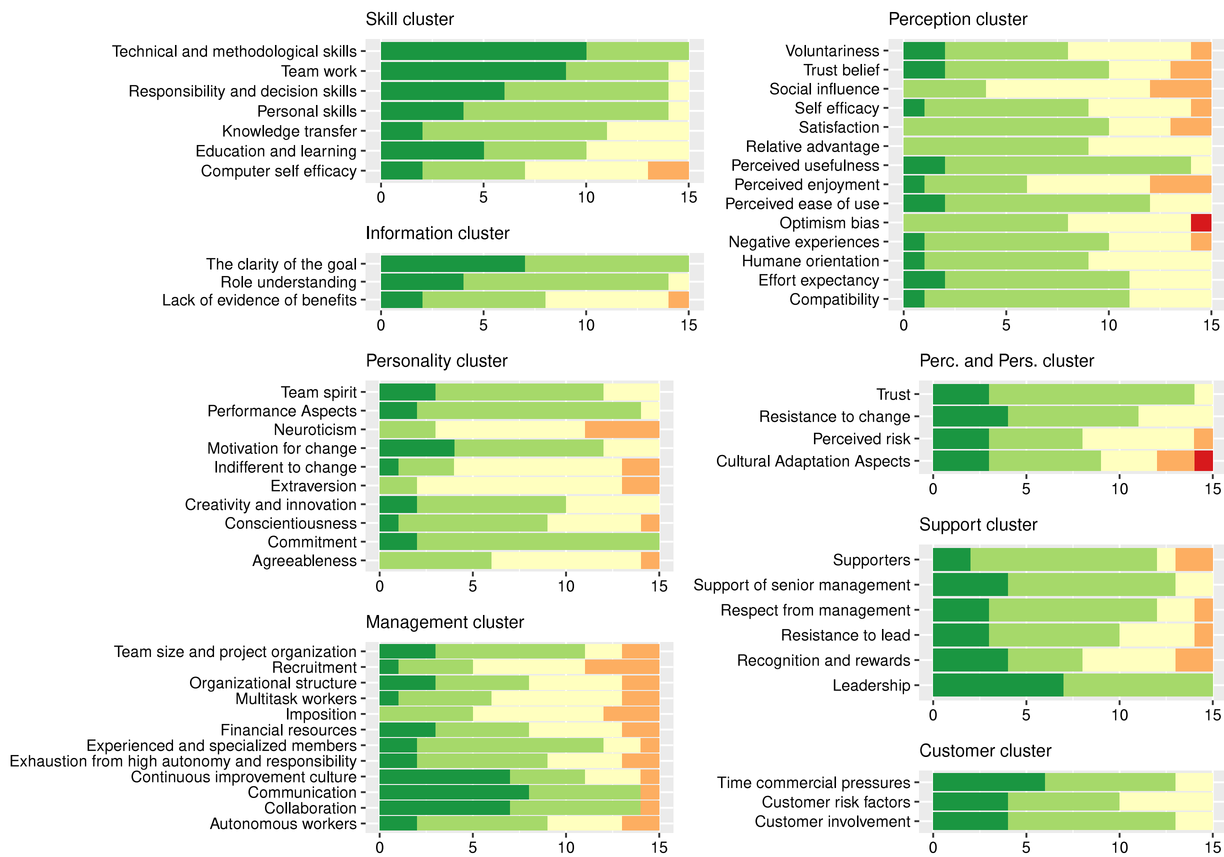

Fig. 12. Human factor relevance evaluation assessed by the respondents, grouped by human factor cluster. Legend: Strongly agree (Dark green), Agree (Light green), Neutral (Yellow), Disagree (Orange), Strongly disagree (Red). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

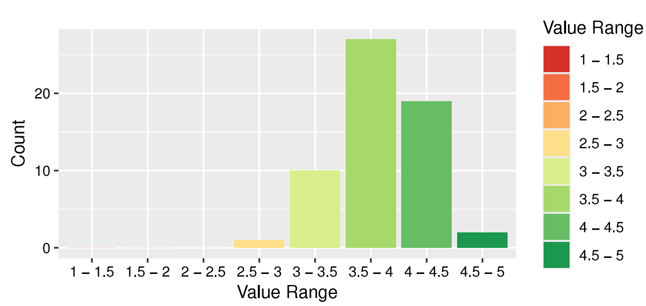

Fig. 13. Human factors average responses.

Out of the 6 factors identified in this cluster, 5 are of a positive nature. This suggests that the nature of the whole cluster is mainly positive. In other words, the human factors that are related to support will most probably have a positive effect in DevOps adoption. The MNG cluster, which consists of human factors related to the organizational management, contains the third highest relative percentage (50% relative percentage, 24% absolute percentage). The fact that half of the factors identified by this cluster are of a positive nature implies that the presence or absence of specific management measures and conditions might be of great importance in DevOps adoption. The three aforementioned clusters (PRS, SUP, and MNG) add up to 68% of the total number of positive factors identified. This indicates that personality, support and management may be the largest source of opportunity to positively improve the effect of human factors on DevOps adoption.

In contrast, the factors of a negative nature did not have any clear tendency among the clusters identified. However, in the case of those of an ambivalent nature, the PRC cluster, which consists of human factors that are related to human perception of a particular aspect, contains the highest relative and absolute percentage of ambivalent factors (71% relative percentage, 43% absolute percentage). The fact that the PRC cluster is composed mainly of ambivalent factors is logical, as it is very difficult to predict human perception, which can mostly affect a process either positively or negatively. Nevertheless, the high absolute percentage implies that human perception might have the greatest range of effects on DevOps adoption, varying from a very negative effect to a very positive one. This possibility makes human perception the greatest risk of all the human factors involved in DevOps adoption.

Fig. 14 shows a bubble chart that visually depicts the effect of each cluster. The y axis, *positivity*, is the difference between the relative percentage of positive factors and the relative percentage of negative factors in a cluster. The x axis, *relative ambivalence*, is the relative percentage of ambivalent factors in a cluster. The size of the bubbles represents the percentage of factors that one cluster has with regard to the total amount of factors. The bubbles are colored in order to help differentiate between clusters, and a slight jitter was applied to increase readability of overlapping bubbles. In particular, the INF cluster has been moved slightly to the left in order to assist with legibility, as its position and size coincide exactly with those of the CUS cluster (which has not been modified). The additional axes have been added with the mean values of positivity and relative ambivalence in order to split the chart into four quadrants. The vertical axis separates those clusters with a lower relative ambivalence from those with a higher relative ambivalence. The horizontal axis separates those clusters with a higher positivity from those clusters with a lower positivity. The clusters in the upper quadrants are, therefore, composed principally of factors that should be supported, while those in the lower quadrants contain a higher amount of factors that should be avoided. Note that no negative values of positivity are shown, meaning that no cluster has more negative factors than positive ones. Similarly, the quadrants

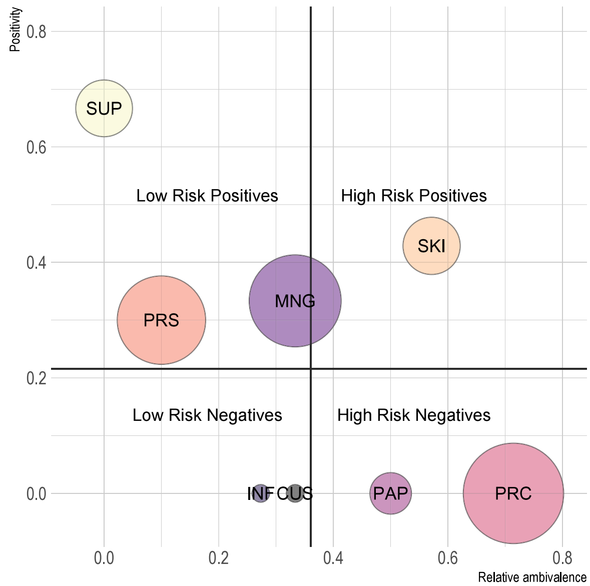

Fig. 14. Bubble diagram showing Effect.

on the left represent a lower risk, as they have a lower percentage of ambivalent factors, whereas those on the right represent a higher risk, as they have a higher percentage of ambivalent factors. Moreover, the larger clusters in the chart represent areas that might require special attention and effort during the adoption process, as they include a higher number of factors. From this perspective, the PRC cluster is of special importance as its size and relative ambivalence are both the highest of all the clusters identified. The second and third largest clusters identified were the PRS and MNG clusters. These two clusters are included in the Low Risk Positives quadrant, therefore, in contrast with the PRC cluster, they might require less attention as their relative ambivalence is lower.

The differentiation between positive and negative human factors is present explicitly in some selected papers [67,68], and is present implicitly in almost every selected paper (as they describe them as something to look for/avoid). In fact, the identification of human factors in the selected studies was always motivated by the impact of each factor on the adoption process. Therefore, human factors with no impact on the adoption process would be considered as irrelevant and would not be identified. However, the human factor descriptions offered in the selected studies, in particular, the description of their impact on the adoption process, bring a wide range of different perspectives of analysis. Namely, the effects identified among those descriptions are: (1) The human factor is a requirement for the adoption process as a whole; (2) The human factor is a requirement for one or more parts of the adoption process; (3) The human factor is positive/negative for the adoption process; (4) The human factor has a direct positive or negative effect on one or more human factors; (5) The human factor has a moderator effect on one or more human factors; and (6) The human factor is a requirement for the presence or absence of one or more human factors. While the set of identified effects is relatively exhaustive, the selected studies, individually, only analyzed a small subset of them. This suggests a lack of a common framework for the analysis of human factors in DevOps-related methodologies adoption, and could be particularly relevant for methodologies that are considered mature as Lean and Agile.

From another perspective, the selected studies did not describe any effects on any technical aspects of the methodologies, only on cultural and organizational aspects. However, the selected studies did identify technical aspects with effects on human factors, for example, the technical changes required for DevOps adoption increase stakeholder's uncertainty [69]. While no human factors addressed technical aspects individually, one of the selected studies, PS21 [70], focuses on the human aspects of technology acceptance and technology adoption. The study identifies and describes the human factors that affect behavioral intention, and finally, use behavior. In the same way that technology cannot be used by itself, the technical aspects of a development methodology cannot be adopted by themselves. Therefore, we believe that use behavior is strongly related to the technological changes in development methodologies. Nevertheless, we would like to highlight that individual use behavior most probably cannot be used directly to predict changes in technical aspects of a methodology, since the decision to change a technical aspect depends on a much wider range of factors.

Despite the fact that no cluster includes any human factor that is explicitly related to sustainability, the need to study human factors in order to address the human dimension of sustainability has been reported in literature [71]. In this respect, human factors are a key aspect of production sustainability [72], as motivated workers are more likely to continue producing quality products than are unmotivated workers [71]. Since the good management of every human factor identified in this study is beneficial for the well-being of humans as individuals in software development, every cluster is also indirectly yet closely related to the sustainability of the development process.

7. Human factors in DevOps adoption theory

The information gathered and validated has been used to propose a theory in human factors in DevOps adoption. The theory proposal follows Gregor's study regarding theories in information systems [73]. The theory proposed classifies as a Type I theory, that is, a theory for analyzing or for "what is", as described by Gregor. Gregor states that this type of theory is needed when nothing or very little is known about the phenomenon in question. In fact, the results of the mapping study carried out show that only one study directly addressed human factors for DevOps adoption. Also, Gregor affirms that variants of this theory type are referred to as classification schema, frameworks, or taxonomies, which is the overall result of our mapping study, and supports its use as the base of the theory. The purpose of this theory proposal is to provide a framework for the analysis of human factors, given the lack of homogeneity provided in the mapping study's selected papers. The rest of this subsection describes the two main components of the theory, primary constructs and statements of relationship, as proposed by Gregor. The central construct, which serves as the center of orbit for other constructs in this theory, is the human factor. Nonetheless, we have identified "surrounding" primary constructs that are directly or indirectly related to the central construct. Table 9 provides an overview of the theory proposal.

As stated in Section 1, in this paper we considered "human factors" to be the set of psychological, behavioral, sociological, and contextual aspects of humans that are related to the software process. The results of the mapping study performed did not yield any evidence refuting this definition. Section 4.1.4 reported the list of human factors that are related to DevOps adoption, and Section 4.1.5 provided a positive/ambivalent/negative classification based on their effect. Also, Section 6.2 showed a human factor clustering that provided structure to the previously unstructured data, and thoroughly discussed what effect human factors have on DevOps adoption. Depending on the way they are defined, human factors can be present or absent (e.g. a person has "negative experiences" or not), or they always have a certain degree of "presence" (e.g. a person partially "trusts" another). We believe that this difference between human factors is exclusively dependent on how they are defined. For example, "negative experiences" (present or absent type) could also be defined as "negativity", or "negativity level" (degree of presence type). Therefore, every human factor should be considered present to a certain degree, which includes total absence or presence, and therefore, can also contain the disappearing type.

Table 9
Theory overview table.
Source: (adapted from Gregor [73]).

Theory overview	
The theory on DevOps human factors identify which human factors affect a DevOps adoption, how can they affect the organization, how are they related to people, and how can they be affected by people or by other human factors.	
Theory Component	**Instantiation**
Means of representation	Textual description, diagrams, tables, and figures.
Primary constructs	Human factor, Actor, Action, Resources, Priority level, Organizational performance.
Statements of relationship	An example: *Human factors can, in most cases, be affected voluntarily by the actions of an actor.*
Scope	The relationships between the primary constructs are always present, or depend on the particular primary construct.
Causal explanations	Not present
Testable propositions	Not present
Prescriptive statements	Not present

Based on this logic, every human factor measurement should be a value between 0% and 100%.

Besides human factors, we were able to identify other constructs that were implicitly used in the selected papers and that are strongly related to human factors:

- **Actor**: Human factors are, naturally, always regarding at least one "human", or "actor". This actor is the person or group of people whose behavior is measured by the human factor. The actor is always a stakeholder (including the customer of the software product) or group of stakeholders such as the team, or the organization as a whole. For example, the human factor "motivation for change" regards to the person which is more or less motivated for change, who would be the actor.
- **Action**: Human factors can, in most cases, be affected voluntarily by the actions of an actor. In a scenario where a software developer is "resistant to change", the team manager can improve the knowledge the software developer has about the change, reducing the resistance to change that the software developer experiences [74]. In this case, the action is the improvement of the knowledge of a software developer, the actor is the team manager, and the human factor is the resistance to change. Note that, as in this example, one actor (the team manager) can affect the human factor measurement of another actor (the software developer). We could identify two different types of actions based on the actor that performs them:
  - Actions that can be taken by any actor.
  - Actions that can only be taken by an actor with a management role in the organization.

  This distinction is based on the need to make organizational changes to impact a human factor, for example, to change the responsibility of employees in the organization to improve having "autonomous workers". In order for the effect of the action to be permanent, we could also distinguish, with regard to the duration of the effects of the actions:
  - Actions that need to be taken once.
  - Actions that need to be taken continuously to be effective.

  For some human factors, e.g. personality traits (conscientiousness, extraversion, neuroticism, agreeableness), they cannot be affected by any action.
- **Resources**: Actions require resources in order to be performed. Examples of resources required for some actions are: time, financial resources and human resources. For example, the action of improving the knowledge of a software developer requires time (spent providing and acquiring the knowledge) and human resources (as the software developer and the actor providing the knowledge are not available during the process). While some actions require a negligible amount of resources, such as providing feedback to developers, they could still be considered to require time (even if almost insignificant) to be performed.
- **Priority level**: Based on their impact on the organization, and in their relationships with other human factors, human factors have a priority level, i.e. some human factors should be addressed before others. For example, one of the selected studies [75] states that the "leadership" human factor should be addressed before the "autonomous workers" human factor, as the last requires the first to be present. The human factor "leadership" has, therefore, a higher priority level than the human factor "autonomous workers".
- **Organizational performance**: Human factors affect the ability of an organization to develop software. The term "performance" does not only refer to how fast software can be developed, but also the ability to attract and maintain skilled professionals in the organization (employee turnover rate), software quality, and customer satisfaction.

A graphical description of the relationships between the constructs defined before is shown in Fig. 15. As seen in Fig. 15, human factors are also related to themselves. This relationship is based on the fact that the presence of one human factor can affect the presence of another human factor. This relationship is bidirectional, as one human factor can affect another human factor or be affected by it. One example of this is the negative effect that "negative experiences" has over "resistance to change" [76]. The descriptions on the selected studies suggest that the human factors form a deeply interconnected network, where one human factor can be affected by many other human factors, and at the same time affect many others. However, very few selected studies measured the impact of these relationships. Besides, the existence of these relationships suggest that the study of the set of human factors that affect DevOps adoption as a whole might be beneficial, in order to fully understand how human factors affect each other, and the extent of this effect.

7.1. Practical applicability

Software engineering literature holds a number of proposals aimed to improve DevOps adoption process [13,77,78], but none includes a descriptive analysis of human factors in the process, while mentioned indirectly.

The ultimate purpose of this research is the improvement of DevOps application in industry organizations. Human factors play a key role in

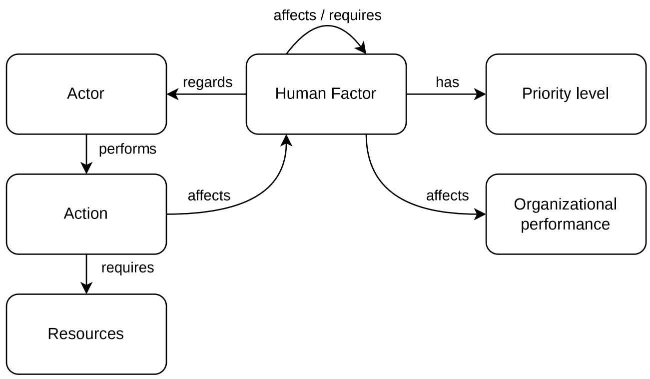

Fig. 15. Conceptual model for human factors relationships.

DevOps adoption and application. However, DevOps adoption depends on a bigger set of dimensions that should be studied in depth from different perspectives.

A recent study by Amaro et al. [79] thoroughly reviewed and structured DevOps practices and capabilities through a general perspective. The study divided DevOps into four different categories that included a set of capabilities, which could enable or are needed for a set of practices, generating a set of outcomes. The study tries to describe DevOps completely, and while it does not include a "human factors" category, some of the human factors that are identified in this paper are included among the capabilities, practices, and desired outcomes that are reported in Amaro et al. study.

To the best of our knowledge, we presented the biggest set of human factors that affect DevOps adoption. This set of human factors, and their categorization, represent the most complete perspective on effect on DevOps adoption. For researchers, this set of human factors can be used as a starting point for further research, and the taxonomy can be used as a framework for the analysis of human factors in DevOps adoption. In addition, the theory proposed improves the knowledge we previously had regarding what human factors are, and can be used in the future to extract a structure from empirical data. For practitioners, the set of human factors can be used as a checklist to ensure that all human factors that have an effect on DevOps adoption are taken into account.

In order to exploit the theory proposed, we found the following requirements:

- Data collection. The theory requires that the secondary constructs that depend on the organization (e.g., the actors) are identified properly, and that the human factors are measured, optimally in a quantitative and continuous way. While this could be performed through data collection instruments in physical format, automatic digital tools may be more efficient and less error-prone.
- Data anonymization. The collected data should be anonymized. The human factors included in the theory are related to highly sensitive information, which poses two different problems. First, privacy and security should be guaranteed. Second, participants might fear that the data collected could be used against them, as many human factors pertain to sensitive topics such as their abilities, personality, perspectives on the organization, or relationships with other members of the organization, among others. This fear could lead participants to refuse to provide data, or provide false or inaccurate data.
- Organizational support. As any other strategies to improve an organization, the theory requires that the organization supports it at all management levels in order to be applied. This includes the allocation of resources to make measurements and improvement actions possible.

8. Threats to validity

The threats to validity have been assessed in accordance with the validity dimensions identified by Wohlin et al. [80]:

8.1. Construct validity

Construct validity threats are those that affect the relationship between the methodology design and the theoretical background. This relationship includes the design of the methodology based on the theoretical background, and the interpretation of the results to generalize and extend the theoretical background.

8.1.1. Systematic mapping study

The construct threats to validity in a systematic mapping study are related to how the primary studies were identified [81,82]. As occurs with any systematic literature review, one of the possible limitations is the low sensitivity of the search, or biased selection processes. In order to deal with these limitations, the search string was defined iteratively with each author's agreement. The search string was built by including the PICO(C) strategy, consultation with experts in the field, numerous iterations in order to allow the authors to reach an agreement, keywords from known studies, and the use of a thesaurus. The iterations were also tested in database searches. The online databases were selected according to the quality measures suggested by Petersen et al. [34]. The selection criteria were defined after the first two authors had reached an agreement, and the selection process was carried out by these same two authors in order to reduce bias. Moreover, the primary studies were selected by following an explicit quality criteria assessment. No gray literature was included. These details are listed in Appendices A and B.

8.1.2. Practitioner targeted survey

The construct validity threats in a survey are related to which the survey measures a target construct (DevOps human factors). The survey methodology was selected as it successfully measured human factors in plenty literature studies [69,83], which supports its use based on the theoretical background. In addition, the survey was evaluated according to Molléri et al. checklist [84] Appendix C.

8.2. Internal validity

Internal validity threats concern any possible threats that could affect the independent variable without the knowledge of the researcher. They affect the relationship between the treatment and the outcome [81,82].

8.2.1. Systematic mapping study

In order to deal with author bias in the extraction and analysis process, the data were extracted by the first two authors of this paper, and the data extracted were then reviewed by the remaining authors. The data were extracted according to the specific fields of a previously defined form. The data extracted were synthesized by the first author and reviewed by the others.

8.2.2. Practitioner targeted survey

The definition of the questionnaire itself is also a potential validity threat, as a poorly defined questionnaire could affect how the respondents answer the questions, and finally affecting the outcome. In order to deal with this limitation, the questionnaire was designed strictly based on the human factors identified and the defined categories, and the survey process was evaluated according Molléri et al. checklist [84] Appendix C.

8.3. Conclusion validity

The threats to the validity of the conclusion are those that affect the ability to concur the correct conclusion regarding the treatment and the outcome of an experiment.

8.3.1. Systematic mapping study

The threats to the conclusions obtained in a systematic mapping study include factors such as missing studies and incorrect data extraction [81,82]. If a study has a low conclusion validity, this signifies that other researchers may reach different conclusions when repeating the study. In order to deal with this threat, every step of the methodology was reported and discussed, and the data have been published. The series of steps followed by the data, and the transformations that were applied to the data, have been described carefully in order to make them traceable. A questionnaire was used to confirm the results obtained through the application of the SMS, supporting conclusion validity.

8.3.2. Practitioner targeted survey

Regarding the questionnaire methodology, to deal with the possibility of "fishing" data to achieve a desired (biased) result, in the development of the questionnaire, no data was modified, and no data was selected or removed from the data obtained. Concerning the threat of data being incorrectly measured, in our case, the respondent's information being incorrectly gathered, the questionnaire was designed, as it was mentioned previously, to be clear and straightforward, in order to allow respondents to easily understand the questions and answer them as precisely as possible.

8.4. External validity

The threats that affect external validity are those that limit the ability to generalize the results of the study, so they can be applied in a practical industrial environment [85]. This paper focuses on a DevOps context, which is a methodology that has gained interest in the last years. While DevOps has been interpreted differently in different industry contexts, the organization cultural change remains being its key component. Different DevOps adoptions may vary in technical implementations as well as in organizational implementation, however, this study does not focus on a specific way to adopt DevOps, in other words, the knowledge acquired from this study affects transversely to any DevOps adoption. The particular differences in industrial scenarios should not affect our generalization as it is based on an extremely basic organizational structure, i.e., an organization that employs software developers, that work in teams, that have responsibilities and roles, and that involves a customer in any way.

The results of the systematic mapping study were validated through a survey. The amount of responses gathered with the survey are limited, and geographically almost all of them belong to Spanish professionals. This could limit the generalization of the results. However, the results of the survey were consistent with the results of the systematic mapping study, which supports the generalization of the results.

Although we do not claim that this study can be generalized for any software development scenario, this basic organizational structure is shared by most of them. Moreover, the study of human factors can be generalized to other parallel methodologies, such as BizDevOps, DevDocOps, or DevSecOps, that are based on the same principles as DevOps.

9. Conclusions and future work

This paper makes two main contributions to the DevOps state of the art regarding the two RGs introduced in Section 1. The first contribution is the characterization of DevOps (RG1). The research shown in scientific literature has reached no consensus as to what DevOps is [4], despite the considerable amount of studies that have attempted to describe it [2,86,87]. Some studies have consequently highlighted the need to characterize DevOps from different perspectives [7]. DevOps, like any software development methodology, is carried out in a complex context that includes technical knowledge, infrastructure, organization, resources and human factors, among others. This paper aims to fill this RG by providing a detailed description of the characteristics of DevOps from the perspective of human factors. The human factors identified have been analyzed and categorized in terms of their similarity and effect, and the possible impact of each category has been measured and reported. The list of human factors and their effect constitute a set of aspects that improve or hinder DevOps adoption. The human factor descriptions, and the effect-based categorization, provide a previously unexplored perspective of what DevOps is based on which human factors help or hinder its adoption.

The second contribution of this paper is the research on DevOps adoption from the perspective of human factors (RG2). The adoption of DevOps has proven to be difficult, and the lack of guidance throughout the adoption process has been reported in literature [88]. While literature does contain some studies focusing on DevOps adoption, they are not sufficient, as the methodologies employed are only partially described, and the impact they have had on industry has not been as expected [13]. Moreover, to the best of our knowledge, all the studies on DevOps adoption have approached the research problem from a general perspective, in an attempt to include guidelines in order to adopt every aspect of DevOps. This paper extends the knowledge contained in literature with a more specific and descriptive approach supported by a systematic mapping study and a proposal regarding a taxonomy focused on human factors.

The contributions provided in this paper have implications for both the future of the research field and practitioners in industry. With regard to researchers in the field, this work further improves the known characteristics of DevOps identified in literature, and adapts the existing knowledge from related research fields, e.g. human factors in Agile, or human factors in Lean. This study builds the first theoretical background on DevOps human factors. To the best of our knowledge, the set of human factors identified outsizes any other proposals in the literature, making it the most complete set of human factors. This set and its categorization, provide a wider perspective on how humans aspects affect DevOps adoption. In addition, a theory that conceptualized what human factors are, and how are they related to other constructs, has been proposed. As a descriptive theory, it can be used as a framework to explicitly identify abstract concepts that were previously identified only implicitly, and remained unexplored. With regard to practitioners, this paper provides a detailed list of human factors that have been reported to be relevant in at least one component of DevOps, including an effect-based characterization of these human factors. This information is of particular importance as human factors play a key role in the software development industry. The ability to know which human factors affect the development process in an organization is not only a great enhancer for DevOps adoption, but also for human-related sustainability. In addition, the results of this study have implications for software engineering education, as they can help to develop a training syllabus, to improve practitioners knowledge regarding human factors, which is currently scarce and insufficient [16].

The authors of this paper found the following lines of future work: (1) the extension on the empirical validation of the theory proposed. The human factors identified have been validated individually and categorically, however, the impact of human factors in the development process and their relation to each DevOps component remain unstudied. In this respect, (2) the extension of the human factors identified in studies focused on DevOps would be of benefit to the research field, as only one selected study addressed this topic. With regard to sustainability, (3) the study of human factors and their effect on sustainability is a relatively young and unknown research field in Software Engineering research. In parallel with this, (4) the research

Table A.10
Mapping study tasks conducted in accordance with the guidelines of Petersen et al. [34].

Phase	Activities	Applied
Need for map	Motivate the need and relevance	✓
	Define objectives and questions	✓
	Consult with target audience to define questions	✓
Study ident.	**Choosing search strategy**	
	Snowballing	✓
	Manual	•
	Conduct database search	✓
	Develop the search	
	PICO(C)	✓
	Consult librarians or experts	✓
	Iteratively try finding more relevant papers	✓
	Keywords from known papers	✓
	Use standards, encyclopedias, and thesaurus	✓
	Evaluate the search	
	Test-set of known papers	•
	Expert evaluates result	•
	Search web-pages of key authors	•
	Test-retest	•
	Inclusion and Exclusion	
	Identify objective criteria for decision	✓
	Add additional reviewer, resolve disagreements between them when needed	✓
	Decision rules	•
Data extraction and classification	**Extraction process**	
	Identify objective criteria for decision	✓
	Obscuring information that could bias	•
	Add additional reviewer, resolve disagreements between them when needed	✓
	Test-retest	•
	Classification scheme	
	Research type	✓
	Research method	✓
	Venue type	✓
Validity discussion	Validity discussion/limitations provided	✓

area of Software Engineering may also benefit from the adaptation of other disciplines, as the study of human behavior is addressed to a much greater extent in disciplines such as Psychology. These other disciplines may provide a much deeper understanding of the information that computer science researchers gather regarding human factors. In addition, (5) the proposal of specific adoption guidelines that take into account the human factors identified may help organizations throughout the adoption process. In practice, (6) the amount of human factors identified, and the complex relationships between the constructs presented in the theory proposed in Section 7, could benefit from a tool that helps to visualize and manage the state of human factors in a DevOps team. Finally, (7) the theory proposed in this paper could be developed to be able to offer testable hypothesis, and to be able to analyze the theory in terms of accuracy and reliability.

CRediT authorship contribution statement

Juanjo Pérez-Sánchez: Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Saima Rafi:** Writing – review & editing, Writing – original draft, Validation, Investigation, Formal analysis, Data curation. **Juan Manuel Carrillo de Gea:** Writing – review & editing, Validation, Supervision, Conceptualization. **Joaquín Nicolás Ros:** Writing – review & editing, Validation, Supervision, Funding acquisition, Conceptualization. **José Luis Fernández Alemán:** Writing – review & editing, Validation, Supervision.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Juanjo Perez-Sanchez reports financial support was provided by Spain Ministry of Science and Innovation. Juanjo Perez-Sanchez reports financial support was provided by European Regional Development Fund. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Mapping study tasks

Table A.10 presents the mapping study tasks conducted according the guidelines proposed by Petersen et al. [34].

Appendix B. Systematic literature review evaluation checklist

Table B.11 presents the systematic literature review evaluation checklist proposed by Ali et al. [85].

Appendix C. Survey evaluation checklist

Table C.12 presents the survey evaluation checklist proposed by Molléri et al. [84].

Appendix D. Selected studies

Table D.13 show the primary studies selected after the application of the inclusion and exclusion criteria and the quality assessment.

Table B.11
Systematic literature review evaluation checklist proposed by Ali et al. [85]. ✓: the answer to the evaluation question is yes, and the information related to it is at least available from the corresponding author upon request. - : the evaluation question cannot be answered because the subject that the question addresses was not included in the review. •: the answer to the evaluation question is no, or the information which the question requires is not available.

Step	Checklist	At least accessible upon request
Choosing search strategy	[E1] Is the choice of search strategy (automated-search, manual-search, snowballing, contacting key authors or a combination) clearly described?	✓
	[E2] Is the search strategy appropriate for the given topic (search approach and justification)?	✓
	[E3] Is an appropriate combination of search strategies used to improve coverage?	✓
Identifying known-set	[E4] Are the papers in the known-set reported?	•
	[E5] Is the approach used to identify the known-set likely to identify a good set?	–
Search-string construction	[E6] Are the keywords aligned/derived from the research questions?	✓
	[E7] Are the keywords and their sources described?	✓
	[E8] Is the choice of keywords appropriate for the topic i.e. likely to ensure coverage?	✓
	[E9] Is the general search string reported?	✓
	[E10] Is the search string (the terms used and their combination using operators like Boolean operations) appropriate?	✓
	[E11] Is the time span of search documented?	✓
	[E12] Is the chosen time span for search appropriate for the topic?	✓
	[E13] Is the chosen level of search (e.g. title, metadata or full-text) documented?	✓
	[E14] Is the chosen search level (title, metadata and/or full-text) appropriate for the topic?	✓
	[E15] Is the level of recall acceptable and appropriate for the topic (reflecting on how important is completeness)?	–
Source selection	[E16] Are the databases described that were used in the search?	✓
	[E17] Were an appropriate number of databases (both publisher and indexing databases) used?	✓
	[E18] In case of manual-search as a supplementary strategy, are the names and years of the selected venues reported?	–
	[E19] Are the selected sources (e.g., databases, venues) appropriate for the topic?	✓
	[E20] If gray literature is used, is it reported?	–
	[E21] Were the measures undertaken to reduce publication bias sufficient?	✓
SLR protocol validation	[E22] Was the protocol validated by an independent reviewer?	✓
Conducting search	[E23] Are the database specific search strings reported?	✓
	[E24] Are the additional filters used in the search reported?	✓
	[E25] Are the additional filters used in the search appropriate?	✓
	[E26] Are the deviations from the general search string documented?	✓
	[E27] Are the deviations from the general search string acceptable?	✓
	[E28] Are the database specific search hits documented?	✓
	[E29] Are database specific search results made available online?	•

Table C.12
Survey evaluation checklist proposed by Molléri et al. (tailored version focused on reviewing aspects of evidence and reporting) [84]. ✓: the answer to the evaluation question is yes, and the information related to it is at least available from the corresponding author upon request. - : the evaluation question cannot be answered because the subject that the question addresses was not included in the survey. •: the answer to the evaluation question is no, or the information which the question requires is not available.

Checklist item	Applied
Research Objectives	
Are the research objective expressed in measurable terms? E.g. as research questions, or using the goal-question-metric approach.	✓
Identify the population	
Is the population or the survey's target audience characterized (e.g. through audience analysis)?	✓
Is the size of the population stated? If it is not possible to gather this data, are statistic estimates of the population drawn?	•
Sampling plan and participant recruitment	
Is the kind of sample (i.e. probabilistic, non-probabilistic) defined? Obs. impact for data analysis, its representativeness and/or generalization should be discussed.	✓
Is the sampling process described, and the resulting sample size presented?	✓
Are the sources of sampling (e.g. particular databases or directories, open or restricted) defined? E.g. through a search plan.	✓
Are the strategies to select participants stated and implemented? E.g. through a sampling frame, as well as invitations, authorizations codes, self-recruitment, or snowballing.	✓
Response management	
Are the responses monitored? E.g. response rate, non-responsiveness, and drop-out questions. In case of inadequate response rate, the reasons for non-responses and drop-out items were investigated?	✓
Data analysis	
Is the data validated prior to analysis? E.g. through checking inconsistent, incomplete and missing values.	✓
Is the method for data analysis specified? Are the steps of the analysis process described? Are they suitable for the response formats collected?	•

(continued on next page)

Table C.12 (*continued*).

Checklist item	Applied
If statistical analysis is employed, is the hypothesis testing process documented and the standardized responses (i.e. nominal, ordinal, interval or ratio) stated? Appropriate scales should be assigned according to the mapped variables.	-
Are the demographic questions formulated according to the audience? If a stratified sample is defined, are the data analyzed according to demographics? Are there meaningful comparisons drawn from them?	✓
Reporting	
Are the instrument and ancillary documents accessible (e.g. URL link, external reference, appendix) to readers? If not, are the reasons for that discussed and convincing? If data resulting from the survey were disclosure, were anonymity and confidentially of data discussed?	✓
Has a discussion of both positive and negative findings been demonstrated? Are the discussion addressing the research question(s) or hypothesis? Does the discussion take into consideration the generalization of the findings	✓
Are the results of the assessment checklist reported? Are the limitations of the study (e.g. threats to validity) discussed?	✓
Are the conclusions justified by the results? Furthermore, are the implications and potential use of the results discussed?	✓

Table D.13
List of final papers.

ID	Title	Reference
PS1	Understanding Conflicts in Agile Adoption through Technological Frames	Abdelnour-Nocera J, Sharp H [89]
PS2	Software Process Improvement Programs: What happens after the official appraisal?	Albuquerque R, Malucelli A, Reinehr S [67]
PS3	A conceptual lean implementation framework based on change management theory	AlManei M, Salonitis K,Tsinopoulos C [90]
PS4	Factors affecting Agile adoption: An industry research study of the mobile app sector in Saudi Arabia	Altuwaijri FS, Ferrario MA [91]
PS5	Empirical Investigation on Agile Methods Usage: Issues Identified from Early Adopters in Malaysia	Asnawi AL, Gravell AM, Wills GB [68]
PS6	How to Make Lean Cellular Manufacturing Work? Integrating Human Factors in the Design and Improvement Process	Ayough A, Farhadi F [92]
PS7	Lean continuous improvement to information technology service management implementation: Projection of ITIL framework	Berrahal W, Marghoubi R [93]
PS8	Lean Implementation Strategies: How are the Toyota Way Principles addressed?	Coetzee R, Van der Merwe K, Van Dyk L [94]
PS9	Scared, frustrated and quietly proud: Testers' lived experience of tools and automation	Evans I, Porter C, Micallef M [95]
PS10	Software process improvement: An organizational change that needs to be managed and motivated	Ferreira MG, Wazlawick RS [76]
PS11	How human aspects impress Agile software development transition and adoption	Gandomani TJ, Zulzalil H, Abdul Ghani AA, Sultan AB, Sharif KY [96]
PS12	From Empowerment Dynamics to Team Adaptability: Exploring and Conceptualizing the Continuous Agile Team Innovation Process	Grass A, Backmann J, Hoegl M [97]
PS13	Lean manufacturing and operational performance	Hernandez-Matias JC, Ocampo JR, Hidalgo A, Vizan A [83]
PS14	Unveiling Developers' Mindset Barriers to Software Modeling Adoption	Kalantari R, Lethbridge TC [98]
PS15	Persuading Software Development Teams to Document Inspections: Success Factors and Challenges in Practice	Komssi M, Kauppinen M, Pyhajarvi M, Talvio J, Mannisto T [99]
PS16	Controlled Experiments as Means to Teach Soft Skills in Software Engineering	Kuhrmann M, Femmer H, Eckhardt J [100]
PS17	Human Aspects of Agile Transition in Traditional Organizations	Pinton M, Torres Junior AS [74]
PS18	Gamification solutions for software acceptance: A comparative study of Requirements Engineering and Organizational Behavior techniques	Piras L, Paja E, Giorgini P, Mylopoulos J, Cuel R, Ponte D [101]
PS19	Getting the Best out of People in Small Software Companies	Sanchez-Gordon ML [75]
PS20	Uncertainty, personality, and attitudes toward DevOps	Shropshire J, Menard P, Sweeney B [69]
PS21	Agile methods and organizational culture: Reflections about cultural levels	Tolfo C, Wazlawick RS, Ferreira MG, Forcellini FA [102]
PS22	Sustainable Risk Management in IT Enterprises	Trzeciak M [103]
PS23	The unified theory of acceptance and use of technology (UTAUT): A literature review	Williams M, Rana N, Dwivedi Y [70]

Table E.14
Human factors identified by means of the systematic mapping study.

Human factor name	Definition	Ref.
Technical and methodological skills	The implementation of Lean Management implies changes on the level of skills of the workforce due to the increased complexity of the tasks and routines required. This compels employees and managers to increase their training and skills. These increments are associated with technological changes and changes in working strategies due to the Lean Management implementation.	[67,70,76,83,89,91,92,98,101]
Education and learning	Common challenges tend to be around education and understanding. Lack of deep understanding of Agile approach, makes people's reactions unpredictable and often ineffective.	[75,83,91,96]
Negative experiences	Negative emotional language used in responses included: painful; struggling; fear; frustration; infuriating; distrust, uncertainty. Whether impediments are technical and usability, [...] the feelings of powerlessness and personal failure that result enhance the impediments by increasing a desire to delay, or even quit.	[67,76,95]
Motivation for change	Mindset is equally important for the adoption factor of Agile methods. The mindset should be from the stakeholders' perspective (for example, team members, customers, project managers and management). Agile is different in terms of its way of working and thus requires a change in mindset. In other words, those involved must be willing to change the way they work, especially those who have been using different methods for a long time.	[67,68,70,75,96]
Resistance to change	Those are the problems pointed by literature as the biggest obstacles to Software Process Improvement. They happen when practitioners are unwilling to leave the practices they are comfortable with. They resist to the new practices sometimes because they are accustomed to the current ones, because they had a bad previous experience, or they feel insecure about the new way of working, among other factors.	[74,76,93,96,98]
Indifferent to change	While some people were enthusiastic or worried about change, as was reported by the participants, some others were indifferent to the change process. It seemed that lack of knowledge and motivation was the hidden reason for this human aspect during the change process.	[96]
Personal skills (behavioral skills, attitudes and behaviors)	Person's evaluation of a specified behavior. The agile values and principles represent a new working philosophy that includes behavior and attitudes that could lead to better results along the implementation process.	[67,69,70,102]
Creativity and innovation	Likewise, creativity and innovation results from a high degree of people involvement based on networking, teamwork and collaboration. Additionally, allowing creativity creates a higher sense of personal fulfillment and consequently enhances involvement.	[70,75]
Responsibility and decision skills	Lack of skills regarding responsibility-bearing and decision-making can cause team members to refuse empowerment. Train team members to take on more responsibility both in training and on the job by gradually granting them more responsibility; staff teams with a mix of experienced and new team members to foster on-the-job learning.	[75,97]
Leadership	Similarly, leadership is an enabler or inhibitor of successful Lean Management implementations. When management influences and enables employees to reach their goals by providing them with the required resources, ensuring their continuous learning, helping them understand their responsibility of improving actual operations and helping them change their attitudes, beliefs and values, it empowers them and motivates them to produce exceptional performance.	[75,83]
Multitask workers	Developing multitask workers means increased productivity by having the same worker with the ability to perform multiple operations. A policy of multitask workers not only empowers employees to remove waste right at the moment and place where it occurs, but it also has the potential of increasing the employees' sense of worth.	[83,101]
Autonomous workers	It means to delegate power and authority to employees by increasing the abilities, responsibilities, formal authority, effective capacity and involvement of broadly skilled frontline workers in problem-solving, decision-making and continuous improvement. An empowered employee is autonomous and can make his own decisions.	[74,75,83]
Exhaustion from high autonomy and responsibility	Feeling exhausted from high autonomy and responsibility can cause team members to refuse empowerment. Let team members participate in development programs that train them in coping with agile and its challenges.	[97]
Resistance to lead	Resistance to execute agile leader roles and engaging in agile-destructive behavior. Inform and train leaders with regard to agile and the adaptation of their leader role.	[97]
Role understanding	We need to make sure that the product owners understand their role, so everybody in the team has to understand their role first. I think if they understand their roles, it will be easier because they understand the responsibility that they have, so that is very important.	[68,91,101]
Commitment	What do you need in your people in Scrum? You need them to be committed, to be skilled in what they bring to the table [...]. Today you need people who are very committed [...].	[67,68,83]
Trust	Willingness of one party to be vulnerable to the actions of another party based on the expectations that the other party will perform a particular action important to the trustor.	[70,94]
Trust belief	The perception that the trustworthiness of the vendor consists of a set of specific beliefs about integrity, benevolence, and competence.	[70]
Team spirit	When asked what factors made the project manager in company B chose Agile methods, he replied: "I think first thing comes to mind is team spirit. Scrum really encourages team work together and whole team commitment, that really helps team spirit, kind of like bringing everyone closer, because working in IT is more like, yeah, you deliver something, and have a fun environment, it is very important to me."	[68]

(continued on next page)

Table E.14 (*continued*).

Human factor name	Definition	Ref.
Teamwork	Teamwork results from the ability of people to work together in a creative and productive relationship within a process, leading to enhanced and assured quality in products and services. Teamwork is encouraged by rewarding the team rather than the individual, by recognizing positive influences and by creating incentives for collaboration in the group. This is a way of organizing workload which strongly contributes to people involvement.	[75,83,94,102,103]
Cultural adaptation aspects	Understanding the new work environment requires a cultural change in two aspects. First, human resources including the managers and operators require external changes in their work methods, and communication skills, and second, an intrinsic change is necessary within their commitment levels and belief systems.	[91,92,96]
Lack of evidence of benefits	Practitioners will not use the new methods if the benefits are not been clarified, having as a consequence their lack of commitment.	[69,70,75,76,98,101]
Optimism bias	A systematic error in perception of an individual's own standing relative to group averages, in which negative events are seen as less likely to occur to the individual than average compared with the group, and positive events as more likely to occur than average compared with the group.	[70,96]
Effort expectancy	(Extracted from [104]) Effort expectancy is defined as the degree of ease associated with the use of the system.	[70,101]
Perceived ease of use	The extent to which a user believes that using a particular system will be effortless.	[70,98,101]
Perceived usefulness	The user's perception to the extent that the system will improve the user's workplace performance.	[70,98]
Recognition and rewards	Recognition and reward reinforce people's behavior and their understanding of the value their efforts have provided for the organization. This leads to positive feelings towards the job - i.e. job satisfaction. The key benefits of positive attitudes and motivation are that they foster a work environment that is conducive to achieving planned results.	[75]
Conscientiousness	The second personality dimension, conscientiousness, entails a strong sense of purpose and high aspiration levels. Individuals with high conscientiousness prefer order and planning to spontaneity. They thrive in highly-structured environments with clear lines of responsibility and authority. Applying the extant literature to the present scenario, it is expected that individuals with high levels of conscientiousness will have aversion to DevOps because it breaks down traditional organizational boundaries. Even if a high-conscientiousness individual see potential benefits in DevOps, his or her inherent tendency to avoid all types of change will result in a negative attitude toward DevOps.	[69]
Extraversion	This is a preference for communication, companionship, and social interaction. Individuals who rate highly in extraversion gain energy and satisfaction from interacting with others. They are less shy around strangers and are open to meeting new people. It should be noted that a core DevOps principle espouses increased communication between traditionally-isolated departments. Based on related studies it is expected that extraversion will moderate the relationship between uncertainty and attitude toward DevOps such that those with high levels of extraversion will have more favorable opinions of DevOps. The inclination toward communication matches positively with the DevOps requirement for coordination.	[69]
Neuroticism	Individuals with high levels of neuroticism are more inclined to feel depressed, stressed, anxious, and tense. Those with lower levels are considered to be more emotionally stable. Uncertainty is known to correlate with feelings of stress, anxiety, and tension — major tenants of neuroticism. Individuals with high levels of uncertainty and neuroticism feelings are expected to have even more negative impressions toward DevOps.	[69,70]
Agreeableness	Agreeableness is the degree to which the individual is compassionate and cooperative rather than suspicious and antagonistic. Adjectives commonly associated with agreeableness include appreciative, forgiving, generous, kind, sympathetic, non-critical, and trusting. Those with a low degree of agreeableness are seen as competitive or challenging people. High agreeableness individuals are often seen as naïve or submissive.	[69]
Social influence	(Extracted from [104]) Social influence is defined as the degree to which an individual perceives that important others believe he or she should use the new system.	[70]
Self-efficacy	The belief that one has the capability to perform a particular behavior.	[70]
Perceived risk	A combination of uncertainty and plus seriousness of outcome involved.	[70,98]
Satisfaction	The attitude that a user has toward an information system.	[70]
Voluntariness	The degree to which the use of the innovation is perceived as being voluntary.	[70]
Computer self-efficacy	An individual judgment of one's capability to use a computer.	[70]
Perceived enjoyment	The extent to which the activity of using a specific system is perceived to be enjoyable in its own right, aside from any performance consequences resulting from system usage.	[70]
Compatibility	The degree to which an innovation is perceived as being consistent with the existing values, needs, and past experiences of potential adopters.	[70]
Relative advantage	The degree to which an innovation is perceived as being better than its precursor.	[70]
Time/commercial pressures	It happens when the projects commitments and customers interests are over the Software Process Improvement initiatives needs, resulting in heavy workload, for example.	[67,76]
Imposition	Sometimes the Software Process Improvement initiatives are conducted as new rules that practitioners must follow, without the right to disagree.	[67,76]

(*continued on next page*)

Table E.14 (*continued*).

Human factor name	Definition	Ref.
Support of senior management	In most organizations, choosing a method to use is based on the decision of the management. This is particularly common in large organizations.	[67,68,75,76,83,91,95–98]
Respect from management	Most managers are under the impression that if employees are treated fairly, given clear goals, trusted to achieve them in the best way, and held to account for results, they receive respect.	[94]
Knowledge transfer	Using Agile, retention of knowledge is questioned when people leave the group. This could occur due to the nature of Agile methods which does not rely on documentation. Therefore, when a person or several people move out from a group, they must ensure the next person is able to continue the work.	[68]
Organizational structure	It is not only the company that should provide the culture; the people or team members in the organization should also embrace it. [...] the mindset of people practicing Agile must be changed first then the environment will adapt to that culture.	[68,91,97]
Communication	Usually developers will make assumptions when they do not have enough information about the requirements, and wrong assumptions create problems later on. Therefore, the emphasis on communication in Agile helps to solve the problem.	[68,75,83,91,98,101,103]
Collaboration	When project teams cannot achieve a collaborative mindset, the transition becomes much more difficult. All team members must act collaboratively and share project ownership.	[74,91,96]
Performance aspects	Human factors that impact performance include learning, forgetting, and boredom (often referred to as motivation level). Productivity is higher if learning and forgetting are integrated into job assignment and selection processes and boredom is associated with negative individual and organizational outcomes.	[92]
Supporters	Supporters, regardless of their roles, were addressed as those who support Agile teams and help them in change process. [...] such people not only motivate others, but also help them to overcome their problems during transformation process.	[96]
Experienced and specialized members	Experienced and specialized team members and teams are suitable for being empowered. Make leaders aware that they should not use a one-size-fits-all strategy but that the degree of empowerment they grant should depend on the experience and skills of the respective agile team (members).	[97]
Customer involvement	Customers should be regarded as team members and take responsibility over project scope decisions and prioritization. Lack of customer proximity and engagement may lead to late decision-making.	[74,83,91,93,97]
Customer risk factors	The main factors belonging to this area include the definition of responsibility between the customer and the project team, underestimation of the time required for product integration on the customer side, multitasking of the team within the customer organization, verification and decision-making time on the customer side, knowledge of the product logic by the implementation team on the customer side, commitment and availability of the customer, etc.	[103]
Humane orientation	Another such critical factor is to possess a humane orientation. Companies with high humane orientation are formed by individuals who perceive each other as a valuable resource for their organizations and that encourage and reward individuals for being fair, altruistic, friendly, generous, caring and kind to others.	[83,91]
Financial resources	Since having an expert workforce increases employees' involvement and empowerment, it is necessary that management allocates financial resources that may be used to hire consultants, train people and assume the temporary deceleration of production sometimes experienced.	[83]
Continuous improvement culture	To foster this type of behavior, it is necessary that a company experiences a cultural shift where change is accepted, where employees and managers feel empowered to seek out and apply new ways to improve things and where there is courage to keep going when setbacks occur. The characteristics of this type of culture are: free flow of information which allows managers to obtain and combine very creative ideas, close and frequent contact between vertical and horizontal work groups and a tradition of teamwork and sharing credit.	[83]
Team size and project organization	Team size and project organization influences the performance. Strategies that work for one-person teams often do not work for teams of larger size. This situation gets even worse if the members are under stress or if a bottleneck arises.	[74,83,100,100]
The clarity of the goal	This element identifies whether and to what extent the goal to achieve is clear to the actors.	[101]
Recruitment	Recruitment is certainly the beginning of the people involvement process due to engagement is the outcome of effective recruitment, followed by an introduction to the workforce through an awareness process.	[75]

Appendix E. Human factors identified

Table E.14 show the human factors identified with a merge of the description provided in the reference papers.

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