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Exploring the Profiles of Software Testing Jobs in the United States

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ABSTRACT There is an indisputable industrial need for highly skilled individuals in the role of software testers. However, little is known about what activities under testers' responsibilities, competencies, and experiences sought after from employers' perspectives. For the purpose of this research, a data set of 1000 job ads related to software testing role in the United States was collected and analyzed. Specifically, a thorough analysis was conducted to find the industrial demand for competencies for the software testing role in terms of (i) Level of education, training, and experience; (ii) Testing skills; (iii) Technical skills; and (iv) Soft-skills. Relevant correlated skills that may influence shaping the profile of the software tester were also analyzed. Also, the essential duties that a software tester is expected to perform were investigated. The results from the subsequent quantitative and qualitative analysis are reported.

INDEX TERMS Software testing, industry practices, survey, job ad, testing career, exploratory study.

I. INTRODUCTION

Inadequate software testing amplifies the chances of generating low-quality software with consequences that may include developer complications, bad consumer experiences, brand credibility dilution, and financial losses. A report by the American National Institute of Standards and Technology (NIST) shows that insufficient software testing in the United States alone has negative economic impacts, which amount to $62 billion USD annually [56]. Software failures due to lack of testing have wreaked havoc at almost every domain of business [8] with cases including even loss of people's lives as in the recent events involving Boeing 737 Max aeroplanes [17]. A detailed review investigating a representative set of 59 recent catastrophic accidents due to undiscovered software bugs was recently presented in [62] along with lessons learned and implications for future software systems.

Until recently, testing was considered a secondary activity, with testers and maintainers being among the least popular software development roles. Studies have portrayed testers as second-class citizens within development teams. Capretz *et al.* [6] found that the majority of software engineers would not choose to be involved in software testing activities and regarded testers as entry-level positions. The findings from a second study by Stray *et al.* [54] reveal that Scrum Masters within agile environments pay more attention to developers than testers during daily meetings as they view developers' received information as more relevant. An observation from a study by Weyuker *et al.* [59] indicates that the most skilled software testers are likely to change their jobs to analysts, programmers, or architects because a career in software testing was not considered advantageous enough for most professionals. Despite that, recent counter-arguments indicate that the tester's role has been changing in the recent years as this role started being perceived as a quality leader who also motivates other team members to adopt quality practices (e.g., [23], [51], [58]).

In the last decade, the subject of software testers' roles has become the focus of discussion of both testing scholars and practitioners. These communities have been elaborating on software testing roles from the perspectives of: (i) bodies of knowledge (e.g. [4], [24], [25], [53]), (ii) certifications (e.g. [26], [57]), and (iii) analysis of the testing competencies

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(e.g. [12], [18], [22]). However, the consensus from these communities is that there is still a significant incongruity concerning the perceptions of the software tester role, responsibilities, and required competencies in the marketplace. Consequently, it is important to study the landscape of job profiling for software testers.

Another motivation to investigate software testers' job profiles is that previous studies on the state of practice of software testing indicate that software testing professionals do more than just testing [32]. Hence, it is necessary to explore the other activities under testers' responsibilities and the qualifications and experiences sought after from employers' perspectives.

Scholars in software engineering research and sociology treat job postings as an artefact to analyze the area of occupational research. This is because the job postings are contended to be representations of occupations and carry occupational terminology, making them occupational artefacts [48]. Typical information that can be found in a job ad include: position, essential duties and responsibilities, skills and competence, experience, and education/training/certificate/security clearances.

For the purpose of this research, 1000 job ads related to software testing role in the United States were collected. This data was analyzed to find the industrial demand for competencies for the software testing role in terms of (i) Level of education, training, and experience; (ii) Testing skills; (iii) Technical skills; and (iv) Soft-skills. Whether any correlated skills that may impact the role of the software tester were also identified. The study also sought the essential duties that a software tester is expected to perform.

The remainder of this paper is structured as follows: Background and related work is summarized in Section 2. In Section 3 research questions and the research process are described. The research results are presented in Section 4, while Section 5 provides a discussion on the implications of the findings on research, practice, and teaching. Section 6 discusses the validity of the results, and finally, Section 7 presents conclusions derived from the research.

II. BACKGROUND AND RELATED WORK

Previous survey studies we conducted on the state of practices of Requirements Engineering (RE) [34], Software Architecture [33], and Software Testing [32] suggest a strong correlation between the skills of a software development team from one side and the success of a project from another. The skills of software developers, in particular, were a subject of attention from the industry [5], [6], [15], and software engineering research community [38] for many years. However, little research has surveyed software testing professionals.

While Jussi Kasurinen and his colleagues [35] found that more effective testing might reduce testing time, they also found that software professionals often underestimate testing effort and cost. This is despite results from the same study showing that testing constitutes approximately 25% of the total development effort.

A good discussion with useful examples on staffing test engineers, managing the test teams, and motivating testers can be found in Chapter 9 of the book by Craig and Jaskiel [10], Chapter 8 of the book by Black [3], Chapter 5 of the book by Dustin, Rashka, and Paul [13], and Chapter 16 of the book by Naik and Tripathy [44]. While these discussions reflect the context when waterfall dominated the landscape of Software Development Life Cycles (SDLCs); other studies suggest that testers are becoming more recognized as integrated team members, especially in Agile development environments (e.g., [9], [23], [51]). This situation is a shift from few years ago when testers were perceived to be "the development team's worst enemies" as they are perceived to carry the news of defects to developers [1].

In [30], Kanij *et al.* surveyed practitioners to determine the factors that influence building successful testing teams. The results suggested that software testing skills make more of an impact on the project than interpersonal skills. This result is consistent with the findings from the survey study by Florea and Stray [18] which suggests that 97.7% of job ads are seeking software testers with software testing skills, while 82.5% of the ads have a demand for technical skills, and 64.2% for interpersonal skills. The same survey reports that the highest-in-demand testing skills are related to test planning and design, progress reporting, test automation, functional and performance testing.

There does not seem to be a dedicated study providing a thorough quantitative analysis on skills requirements for software testers for the United States market. The lack of such quantitiave data motivates the present study.

III. METHODOLOGY

A. WORKING DEFINITIONS

Software Testing is one of the 15 knowledge areas (KAs) defined by the Software Engineering Body of Knowledge (SWEBOK) [4] as consisting of "dynamic verification that a program provides about the expected behaviors on a finite set of test cases, suitably selected from the usually infinite execution domain".

While "software tester" is a frequently used term, existing definitions (Table 1) do not provide an agreement on what this role entitles. Since testing is considered to be a part of the Quality Assurance (QA) process [42], a significant proportion of employers also portrays testers as QA professionals [18].

In this paper a distinction is made between a "position" and "role". While the two may overlap functionally, there are differences [52]. The position has a title which is a label the employer uses to describe an employee. The role, on other hand, is the actual function an employee fill within an organization. In this study, we used a collection of publicly available job postings from employers searching for talents to fill positions that include software testing / QA "roles". These job posts had the "position" titles and included a list of qualifications and skills that the employers deemed important to fill this position.

TABLE 1. Existing definitions for software testers role.

ISO-29119:1 [27]	"One who spontaneously designs and executes tests based on the existing relevant knowledge, prior exploration of the test item, and heuristic "rules of thumb" regarding common software behaviours and types of failure."
ISTQB [26]	"Skilled professional involved in the testing of a component or a system."
Mathur & Malik, 2010 [41]	"One who is responsible for carrying out software testing using various strategies building up the test cases and test plans for the project."
Davidov et al., 2010 [11]	"Professional who discovers new defects from failed test cases, conducts analysis on the defects, and reports them in a bug-tracking system."

B. RESEARCH QUESTIONS

The goal of this research is to scrutinize the state-of-the-practice of Software Testing / QA roles in the U.S. job market. The goal has been further refined into the following four research questions (RQs):

- *RQ1:* What "positions" titles are posted for Software Testing / QA "roles" in the U.S. job market?
- *RQ2:* What are the expected tasks from Software Testing / QA roles?
- *RQ3:* What skills (testing, technical, and soft) do software testers need to possess for the job demand? Are there correlated skills?
- *RQ4:* What educational attainment (e.g. degree and/or certification) and experience level requirements do employers demand of software testers?

C. DATA COLLECTION

As per [19] and [55], a data collection strategy based on job posts is appropriate for the context when the qualitative data is publicly available to analyze, and when a researcher needs to establish a balance between the study execution effort on one hand and breadth and depth of the study on another hand.

Accordingly, and to analyze the state-of-the-practice of Software Testing / QA roles in the U.S., this study utilized one of the most popular jobs search tools "indeed.com". According to Alexa Ranking by Amazon and many other sources (e.g., [43]), "indeed.com" is the most significant engine among its competitors in terms of the traffic volume and the number of jobs posted.

A quasi-systematic process of data collection / extraction was used as defined in [47]. The data collection included the following steps:

1) The search string to be used for this review was defined as ("Software Tester" OR "Software QA"). One of the job search engine amenities includes interpreting the search string which results in a range of relevant jobs related to the search term. Accordingly, a wide range of positions titles using the defined search string was obtained, including: QA Analysts, Test Automation Engineers, User-Acceptance Testers, Cybersecurity Test Engineers, Performance Testers, Functional Testers, Mobile Testers, etc. The initial search was performed in April 2020 using the above string for each of the 50 United States of America. The initial search retrieved 94,848 job ads.
2) Since it is a quite laborious activity to manually analyze such a huge amount of online job ads, and in order to execute our exploratory study within a reasonable time, we used a sample size calculator (https://www.qualtrics.com/blog/calculating-sample-size/) to calculate how many job ads are representative for our exploration. The results shows that at least 1056 job ads should be included in the sample if the margin of error is set as 3% where the confidence level is 95% [28]. To simplify the selection criteria and minimize the requested sample size, we selected the first 22 job ads collected by each search applied on each state using the above string, according to their posting time in a descending order. In this way, 1100 job ads formed the initial data set of our exploration. This set reflects the most recently posted ads at the time of search. Using this set is a pragmatic choice also because we are interested in the most recent software testing / QA jobs in the marketplace and not on job ads published long ago. While signed in to "indeed.com" using an account created specifically for this study, each of 1100 job ads was saved to that account.
3) Each retrieved and saved job post from the 1100 ads sample was assessed manually on the basis of the following inclusion and exclusion criteria: (a) the job post had software testing / QA as one of its core tasks; (b) the job post included at least one software testing activity where the description of this activity included details of specific task and skills set; and (c) the job post assumes a full-time position in software testing. These criteria were used on the text of the entire post (e.g. job title, and descriptions of the responsibilities, tasks, skill set, education, and experience). This assessment process was executed between April and May 2020, and was carried in three steps:
   a) The first, third and fourth authors conducted a pilot study on a subsample of 200 out of 1100 job ads (4 job ads × 50 states). They checked the relevance of each job ad to the inclusion / exclusion criteria and made the selection independently, resulting in 90% agreement on the exclusion of testing relevant job ads. After discussing and

resolving all the disagreements, they got a consensus on the inclusion of 185 job ads out of the 200 subsample for code extraction.

b) Next, the first author completed independently the selection from the remaining 900 ads and retained 815 ads based on the above criteria.

c) Finally, both the first and the third authors participated in the random validation of the included 815 job ads, and they had 100% agreement on the retained selection.

4) One thousand job ads from 50 states retained in the final set for analysis and synthesis for the purpose of this paper.

D. DATA EXTRACTION

To answer the 4 research questions, 14 items of information were extracted from each of the final 1000 job postings included in this study, as shown in Table 2. A survey form was built using the "Qualtrics XM Platform" to enter manually the extracted data from each ad to be able to analyze them later. The online form is available through the link https://bit.ly/340WqxZ.

TABLE 2. Extracted information from the job posts.

What we extracted	Relevant RQ	Data analysis method
General Information		
1. Company name	RQ1	GT
2. Company Domain of Business	RQ1	GT
3. Position Location	RQ1	GT
4. Suggested Salary	RQ1	GT
Job Responsibilities		
5. Testing Activities to be performed	RQ2	GT + Predefined classification
Competencies		
6. Experiences with Testing Techniques	RQ3	GT + Predefined classification
7. Experiences with Levels of testing	RQ3	GT + Predefined classification
8. Testing Automation	RQ3	GT
9. Work Experience	RQ3	GT
10. Technical Competencies	RQ3	GT
11. Experience in tools tools	RQ3	GT
12. Soft-skills Competencies	RQ3	GT + Predefined classification
13. Educational Attainment	RQ4	GT
14. Certifications	RQ4	GT

Because the job posts detail the tasks and responsibilities, qualitative coding techniques from the Grounded theory (GT) approach [2] were applied to the text descriptions that referred to competencies and tasks. Drawing upon Saldana's qualitative data coding process [50], the analysis of each post granularly distinguished between tasks and competencies, and among the different types of competencies (Testing, Technical, and Soft-skills).

Through a qualitative analysis of the **job responsibilities** (items 5 from Table 2), the Software Testing Knowledge Areas (KA) were also used as defined in the SWEBOK [4]. In particular, after reading and analyzing each job ad, they were mapped to one or more corresponding responsibilities; as defined under "Testing Activities" topic in Software Testing KA: "test planning, test case generation, test environment development, execution, test results evaluation, problem reporting/test log, and defect tracking".

The second topic of "Software Testing" KA in SWEBOK recommends competencies in different "Testing Levels", the fifth topic recommends the competencies in "Testing Techniques", while the sixth topic recommends competencies in "Software Testing Tools". To analyze the **testing competencies**, each ad was mapped to its corresponding required experiences or knowledge in testing levels and techniques as defined in SWEBOK. All testing tools required for the job were also extracted.

In order to analyze the **technical and soft skills competencies**, a free-text analysis was executed using "Text-iQ" feature provided by "Qualtrics". This feature employs a natural language processing (NLP) technique that allowed us to conduct "topic analysis" on the extracted technical and soft skills competencies by automatically assigning pre-defined tags to each competency in order to classify them into pre-defined topics. For example, using the pre-defined tags from the Soft Skills Taxonomy by Mahasneh and Thabet [39], and presented in Section IV, "Text-iQ" will automatically classify a required soft skill competency: "Very effective oral, written, and presentation skills" into a "communication-related skill".

The code extraction process in this subsection was conducted between May and August 2020 and executed in three steps:

1) The first and third authors conducted a pilot extraction and mapping independently on a subsample of 200 out of 1000 job ads. Both authors have extensive years of industrial and academic experience in software testing, and they are very well knowledgeable with applying SWEBOK. The results from the mapping was reviewed through a workshop meeting resulting in 95% agreement on the mapping results. After discussing and resolving all the disagreements, they got a full consensus on the mapping.
2) The remaining 800 job ads were split between the first and third authors. Each conducted the process independently on 400 ads.
3) Finally, the second and forth authors (both are very well experts in software testing) conducted a random inspection on a selected subsample from the mapped ads. There was no change requests raised from the inspection.

For the quantitative assessment, "Stats iQ", which is supplied with the "Qualtrics platform", was used. This feature performs a statistical analysis of the extracted data numerical parameters. This resulted in the percentage of job posts that advertised each category of responsibilities and competencies. The extracted data file is available online for access and download through the link https://bit.ly/3lPcDfx.

Moreover, this study aimed at discovering any patterns and themes from the subcategories of skills advertised in the posts. If a strong correlation of skills emerged from the analysis this would have indicated the existence of particular tester profiles that employers are hunting for. Conversely, a lack of this type of pattern would indicate no clear software tester profiles from the job market. To perform this analysis, we reviewed all of the subcategories of skills in the job posts and constructed cross-tables using the "Crosstabs" feature from Qualtrics.

IV. FINDINGS

A. ANSWERS TO RQ1 : POSITION TITLES FOR SOFTWARE TESTER ROLE

At a first glance, it can be observed that the diversity in position titles used to describe the tester role. Out of all the 1000 job posts, the top-ranked position name was testing / QA "engineer" (39%), followed by "tester" (28.5%), and "analyst" (24%).

The majority of the ads (79.4%) didn't specify the seniority level of the role. Only 2.8% ads asked for entry/junior level, 11.6% asked for senior-level, and 6.1% asked specifically for management/supervision/lead role (see Table 3).

Seventy-seven ads used "Automation" keyword in the job title. More than half of these ads were associated with the "Engineer" title (e.g., QA Automation Engineer), while 23% of these ads were associated with the "Tester" title.

TABLE 3. Distribution of the 1000 jobs titles per category and seniority levels.

	Entry Level	Senior Level	Lead	Not Specified	Total
Engineer	4	63	9	318	394
Tester	12	19	2	255	288
Analyst	11	22	5	204	242
Other Roles	2	13	46	25	76
Total					1000

Note that among the 1000 job posts, the majority (31.5%) came from companies which its main business domain is directly related to Information Technology (IT). Nevertheless, a wide range of business domains is still being reflected in the extracted set (see Figure 1), such as Consultancy and Logistics, Health, Finance, and Aerospace and Defense.

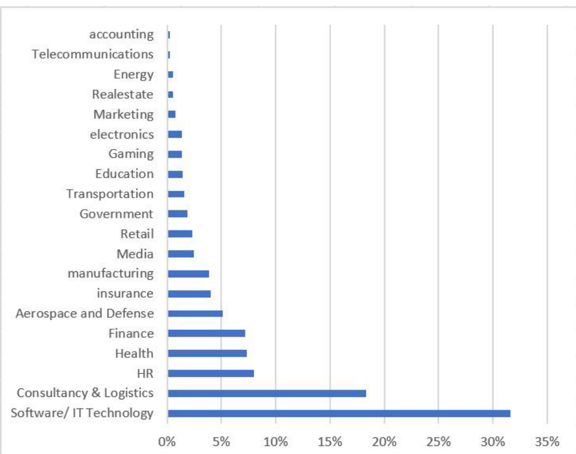

FIGURE 1. Distributions of extracted ads across business domains.

B. ANSWERS TO RQ2 : SOFTWARE TESTING/QA TASKS AND SUBTASKS

After analyzing the job description and required tasks in each job post, these features where mapped to one or more

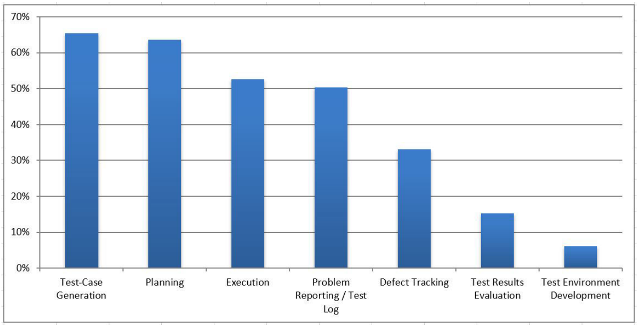

FIGURE 2. Distribution of job ads across software testing tasks.

TABLE 4. Distribution of software testing tasks over categories of position titles.

	Tester	Engineer	Analyst	Others
Planning	51.6%	66.5%	68.9%	72.1%
Test-case Generation	64.0%	70.3%	62.2%	58.2%
Test Environment Development	4.0%	7.0%	7.7%	4.9%
Execution	57.8%	50.5%	55.5%	42.6%
Test Results Evaluation	18.9%	13.8%	13.9%	13.9%
Problem Reporting / Test log	50.5%	45.8%	59.8%	48.4%
Defect Tracking	37.5%	28%	40.7%	28.7%

TABLE 5. Distribution of software testing tasks over seniority levels.

	Entry	Senior	Management
Planning	37.9%	70.3%	79.4%
Test-case Generation	62.1%	62.4%	52.4%
Test Environment Development	0%	8.9%	11.1%
Execution	62.1%	49.5%	38.1%
Test Results Evaluation	10.3%	12.9%	9.5%
Problem Reporting / Test log	34.5%	44.6%	44.4%
Defect Tracking	27.6%	26.7%	31.7%

"Testing Activities" defined in Software Testing KA in SWEBOK [4] (See Figure 2).

The data indicates that employers are mostly interested in professionals with a grip on the whole testing process, with test cases generation coming first in terms of required tasks, and test planning coming in second place and ahead of the typical testing task of executing tests, which comes third. Test planning outlines and tracks an orderly schedule of testing events and milestones. Planning activities also specify the required personnel, equipment, financial and facility resources to support the testing portion within a software project.

Despite being one of the most obvious responsibilities of a tester's job, fewer job postings explicitly include detecting bugs as a responsibility. An explanation is that this responsibility is implied and is therefore not explicitly advertised. Marginal requests were for the software testers to be able to setup and maintain their testing environments.

An examination of how these activities are distributed per the advertised position categories (Table 4) and the levels of seniority (Table 5) was also conducted. The data in Table 4 indicate that holding a position of "Tester" or "QA Engineer" or "QA Analyst" won't significantly impact the

TABLE 6. Distributions of the top testing competencies across business domains (e.g., 84.1% of job ads by finance companies require testing automation skills).

	Automation Required	Regressing Testing	Acceptance Testing	Performance Testing	Usability Testing	Security Testing
Software / IT Technology	73.6%	35.4%	23.2%	24.9%	8.8%	7.4%
Consultancy and Logistics	74.7%	30.3%	21.2%	24.2%	7.3%	8.5%
HR	57.6%	31.9%	30.6%	16.7%	11.1%	4.2%
Healthcare	75%	34.8%	28.8%	27.3%	10.6%	3%
Finance	84.1%	40%	29.2%	30.8%	9.2%	10.8%
Aerospace and Defense	60.5%	15.2%	10.9%	8.7%	4.3%	15.2%
Insurance	77.1%	38.9%	19.4%	19.4%	0%	5.6%
Manufacturing	79.4%	34.3%	5.7%	8.6%	11.4%	8.6%
Media	77.3%	31.8%	13.6%	27.3%	9.1%	9.1%
Retail	78.9%	33.3%	28.6%	4.8%	4.8%	4.8%
Government	68.8%	35.3%	29.4%	23.5%	11.8%	11.8%
Transportation	78.6%	14.3%	28.6%	28.6%	7.1%	7.1%
Education	61.5%	38.5%	38.5%	38.5%	7.7%	7.7%
Gaming	50%	16.7%	16.7%	25%	8.3%	16.7%
Electronics	66.7%	25%	25%	16.7%	0%	0%
Marketing	83.3%	42.9%	42.9%	14.3%	100%	14.3%
Realestate	100%	44.4%	0%	55.6%	0%	11.1%
Energy	60.0%	20%	20%	40%	20%	0%
Telecommunications	100%	50%	50%	50%	50%	0%
Accounting	100%	100%	0%	50%	0%	50%

expected duties. For example, 64.0% of "Testers" is expected to be engaged in test-case generation, and this value is 70.3% for "QA engineers" and 62.2% for "Test Analysts".

Conversely, Table 5 indicates that the change of seniority may have more impact in terms of testing duties. For example, while only "37.9%" of entry positions are asked to be engaged in test planning, "79.4%" of the management level positions are expected to be engaged in planning activities.

C. ANSWERS TO RQ3: REQUIRED COMPETENCIES

1) REQUIRED COMPETENCIES IN TESTING

A focus of Testing can be aimed at verifying various attributes. Test cases can be designed to verify the correctness of functional requirements, but also several quality requirements can be a target for the testing activities. SWEBOK [4] lists 13 subtopics for the "objectives of Testing" as most often cited in the literature. A mapping was conducted of the required testing competencies from each job ad to these subtopics (see Figure 3). The data indicates that high-level testing is the core focus for the industry with regression testing is the most prevalent type of testing competency requested by employers, followed by acceptance/qualification testing, followed by performance testing. The distributions of the testing activities across business domains is also examined (see Table 6).

This study also shows a high demand for skills related to test automation with 72.6% of the overall ads explicitly request experience with test automation. In fact, automation was the most requested skill for each of the business domains. While conducting manual testing can be less expensive in the short term, automated testing tends to reduce the cost of testing over time. Further, automation is less error-prone than manual testing [49], and can be conducted at any time, often, without an operator being present.

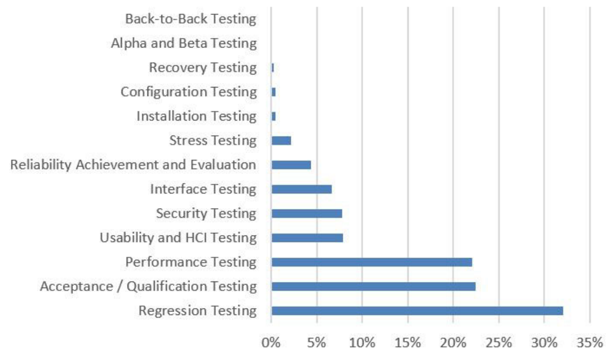

FIGURE 3. Distributions of job ads across testing competencies.

Automating the regression tests is leading the demand when automation is required, with 85.4% of the job posts that request "regression testing" also pointed out that "automation" is required. This is a desirable skill because automation can improve the efficiency of regression testing while decreasing some of the unpredictability associated with tedious execution of a manual test plan. Nevertheless, automation alone will not improve the effectiveness and quality of testing. Testing is only as good as the test plan and test cases; automated test plans can improve efficiency but not the effectiveness of the testing outcome [40]. Automation is not a human replacement. Therefore, employers need to confirm if the people performing the tests have the time and skillset to develop and maintain an effective automated test process. This skill is important, as Karlström *et al.* report that the main impediments to the adoption of software test automation are management issues - not technical issues [31].

Automation is a tool-assisted activity, and competencies with mastering testing tools are another sought-after competency, with 56% of the ads ask for testing-tool skills as a requirement or as a preference. Most of the job posts advertised for software testers who had mastered at least one testing tool, and less than half ask for at least specific two tools. Only 14% of the overall ads ask for competency in five or more tools. The average number of tools per ad among those asking for tools is 3.

The testing tool the employers are most interested in is Selenium (Table 7). This is not surprising considering the high demand for automation and that Selenium doesn't require sophisticated technical skills. Selenium provides a playback to authored functional tests for web applications without the need to program using a test scripting language. Cucumber is the second on-demand in the automating testing tools category. This tool executes automated acceptance tests written in a behavior-driven development. This allows specifying expected software behaviors in a logical language that is more understandable to customers. QTP is another functional testing automation tool on-demand by employers [29].

The tools in the test management category were slightly less in demand than the test execution tools. Jira is the most frequently demanded tool for this category [46] and it incorporates a variety of add-ons features for bug-tracking, management and integration, and time tracking for projects.

A previous survey study shows that performance was the most tested quality attribute [32]. The results from this study on the demand for performance-testing tools confirm the technical component sought in the profile of software testers. JMeter and LoadRunner are on-demand in this category and are both performance-measurement tools that were previously under the responsibility of developers but are currently reaching the territory of testers' competencies as well.

Although significant number of companies employ bug-tracking tools, only a few job posts explicitly require competency in these tools as shown in Table 7.

TABLE 7. Demands for tools used in testing.

Selenium	Automated test execution	43.2%
Jira	Test management, bug tracking	38%
Cucumber	Automated test execution	9.5%
SoapUI	Automated test execution, API testing	8.5%
Jmeter	Performance Testing	7.8%
Team Foundation Server	Test management	7.2%
HP QC / ALM	Test management	6.3%
LoadRunner	Performance Testing	6.2%
Confluence	Test management	5.8%
TestNG	Automated test execution, unit testing	5.8%
HP QTP	Automated test execution	5.5%
TestRail	Test management	5.5%
JUnit	Unit testing	4.4%
Katalon Studio	Automated test execution	2.65%
Bugzilla	Bug tracking	1.94%
TestComplete	Automated test execution	1.94%
Microsoft Test Manager	Test management	1.76%
Ranorex	Automated test execution	1.41%
Tosca	Automated test execution	1.23%

It is natural not to see a demand for competency in static testing tools. Even though it is complementary to dynamic testing, static testing is conducted directly on the code using dedicated tools by developers or architects, and not by the testers.

2) REQUIRED TECHNICAL SKILLS

A finding from a study on the agility and testing processes in software organizations [36] indicates that employers value testers' technical skills more than domain knowledge. This is in line with other findings in this study as most employers are asking testers a variety of technical skills that are not specialized in narrow aspects. These skills vary from project management, development tools and frameworks, programming languages, integration skills, and many more.

The majority of the ads (56.8%) require some level of programming skills, which implies that there is a clear demand for testers with programming and scripting capabilities. Our results show that SQL takes first place with 18.3% of the ads ask for it. The second most demanded skill in development languages is Java (11%). Third in line is having a competency of C# or C++ with (8.1%) for each of them. It is also noteworthy that 13.1% of the ads ask for skills in scripting languages. Javascript was the most demanded in this category, and Python lagging. Table 8 shows the distribution of the ads sample across the most demanded programming languages.

TABLE 8. Demands for technical skills.

Software Development Phases	
Requirements Engineering	15.5%
Software Architecture	2.8%
Software Design	2.5%
Programming	56.8%
Programming Languages	
SQL	18.3%
Java	11.2%
C++	8.1%
C	8.1%
Javascript	7%
Python	6%
XML	2.6%
XML	2.4%
CSS	1.6%
Ruby	1.2%
Perl	1.1%
Operating Systems	
LINUX	2.9%
WINDOWS	2.8%
Android	1.8%
iOS	1.6%

The data from the extracted ads shows that 11.8% of the explicitly ask for working knowledge of software development. Regarding various software development life cycles, expert knowledge in the area of agile processes is in demand by some software companies (6%). We further analyzed the demands to master knowledge in the different development phases. Working skills related to Requirements Engineering was sought after by 15.5% of employers. There was less demand for skills related to Software Design or Architecture.

Only 6.7% of employers are interested in testers / QA with specialized competence related to a particular operating system (Table 8). And only a small fraction (3.2%) ask for software engineering skills relate to continuous integration, continuous development, continuous delivery, or DevOps. Notwithstanding that, and focusing on software development tools and frameworks (Table 9), it can be noted that there is some demand for tools supporting continuous integration (e.g., Jenkins), source control management (e.g., GIT), and build management (e.g., Maven). These tools are not designed only for developers but are part of operating a continuous integration model [14], which is common when using Agile development. The level of the demand is not high, and supporting this is the fact that these tools are easy to operate for standard usage - minimizing the need for a specialized skill set.

TABLE 9. Demands for development tools and frameworks.

Jenkins	Open source automation server	14.1%
Postman	Collaboration Platform for API Development	9.7%
Azure	Cloud computing service	3.8%
GIT	Development platform	3.6%
MS SQL	Database management system	3%
Microsoft Visual Studio	Integrated development environment	2.3%
Maven	Build automation tool	1.6%
SharePoint	web-based collaborative platform	0.89%

3) REQUIRED SOFT SKILLS

In the analysis for soft skills in each ad, a textual analysis was executed on the job description as described in Section 3, and then mapped into to one or more soft skills defined in the Soft Skills Taxonomy by Mahasneh and Thabet [39] (see Table 10).

In their paper on the evaluation of the demand for soft skills in software developers [1], Faheem et. al. revealed that the software industry was not focusing on the importance of soft skills for software testers.

This finding is in contrast with the present study's findings that 70% of the ads asked for at least one soft skill, and 56% asked for at least two.

Communication skills comprising of effective presentation, reading, writing, and verbal skills are among the most demanded by the employers (41.2%).

Workplace thinking skills comprising of analytical, conceptual, and critical thinking as well as effective decision making, problem-solving, and reasoning were in second place with 22.6% of the job posts. The employers were requesting at least one skill in this category. Teamwork and Collaboration skills come third with 18.9%.

TABLE 10. Distribution of extracted soft skills from the ads sample into soft skills taxonomy by mahasneh and thabet [39].

Communications Skills	Listening communication, presentation skills, reading communication, speaking communication, and writing communication	41.2%
Workplace thinking skills	Analytical thinking, conceptual thinking, critical thinking, decision or problem solving, reasoning	22.6%
Teamwork and Collaboration skills	Coaching, collaboration, cooperative ability, work with others	18.9%
Self intelligence skills	Accurate self-assessment, positive attitude, self-control, self-management	10.3%
Planning and organizing skills	goal management, information management, planning strategic planning, time management	7.8%
Workplace productivity skills	Achievement, creativity, enterprise skills, life-long learning, outcome oriented	2.3%
Social intelligence skills	customer service, diplomacy, empathy, influence others	2.3%
Workplace professionalism skills	Commitment, common sense, professionalism	2%
Conflict resolution and negotiation	Conflict management, mediation, negotiation	1.1%
Stress management skills	Work under pressure, accepting criticism, adaptability, adversity, change catalyst, change management,	1%
Workplace ethics skills	Awareness of ethical values, honesty, integrity, transparency, trustworthiness	0.9%
Workplace diversity skills	Work with diversity, global citizenship, and cultural awareness	0.3%

D. ANSWERS TO RQ4: EDUCATION ATTAINMENT AND CERTIFICATIONS

The greatest number of job posts (63%) ask for completed bachelor degrees as a minimum educational requirement. About 49% ask for an associated degree (e.g., GED) and about 22% ask for at least a high school degree. Only (2%) ask for the completion of a masters degree. While (26%) don't ask for any degree requirements. None of the ads are asking for Ph.D. studies.

Certifications are a common way to complement a degree. However, the industrial demand for certifications continues to be low when compared to classic undergraduate or graduate degree. One in ten hiring employers asks for particular certifications. When we scanned these ads thoroughly, we observed that 12% of these mentioned ISTQB Foundation Level Tester certification, making it the most popular. About 19% of these ads referred to other testing-related certificates (e.g., ASQ, QAI), and some of these ads requested a candidate that is certified in security (e.g, DOD-8570) (16%), or in

Application Life Cycle Management (ALM) (e.g., Lean, Six Sigma, Scrum Master) (13%).

Despite the low demand for certificates, it would be expected that demand will increase in the training and testing-related areas. A study performed by Garousi *et al.* on what industry wants from academia in software testing [20] supports this point by showing an increase of attention to offering certifications and training on software testing.

Ninety-Nine Percent of the posts listed a minimum years of experiences as a requirement, making it the most demanded requirement among all. The average number for the minimum years of experiences from all posts is 3 years. This average number varies from 1.5 years for entry-level positions to 4.5-5 years for senior and management positions.

V. DISCUSSIONS AND IMPLICATIONS

The results of this study indicate that software testers need to master a wide range of competencies. Our study can be used by candidates who are looking to pursue a career in software testing.

The results indicate that knowledge in high-level testing is on high demand. There is also high of demand on using test automation (72.6% of the overall ads). In spite of the high demand on automated testing skills, and although test automation could help improve test repeatability and reusability while reducing the testing effort [49], other survey results indicated a low adoption for automated testing in practice [32], [49], and [37]. For example, the data from a previous survey study conducted in 2017 on the state of practice of software testing [32] observes that test automation was a practice in only 34% of the surveyed projects. This gap between the high demand and lower applicability of automation could be the result of the high automating tool cost and the training required for using these tools. Eventhough the majority employers are wishful to apply automation, and they are looking for candidates with relevant skills, they may not all end up with conducting automation in practice. Many studies show indeed that the adoption of test execution tools is low in practice [21], [45], and [32]. Causevic et. al. conducted a survey where the results showed that participants mostly used free open-source testing tools for the purpose of unit testing and used proprietary testing tools primarily for higher-level system testing [7]. This finding is in agreement with the results from our previous survey study [32].

Even though the results indicate a demand for testers to track the life-cycle of the bugs (33% of the ads), there was much less demand for competency in bug-tracking tools. This is a surprising finding considering that these tools can be quite effective in collecting and analyzing software error reports. Whichever error tracking tool is used, there are confounding factors underlying the bug reports, and hence, appropriate assignment for repair. For example, duplicated error reports can raise the sense of urgency on behalf of the maintainers, even though the error is trivial. Errors may incorrectly be identified as a duplicate of another already reported. Or users may employ inconsistent terminology, causing the maintainers not to recognize duplication. These problems suggest that a more fine-grained bug classification system would be more effective in reducing bug report duplication, and assist in error repair assignment. In spite of these problems, few job posts explicitly ask for competency in a bug tracking tool. These results are supported by the fact that a significant number of companies employ bug-tracking tools. One interpretation of this data is that these tools are configured by a separate team-handling infrastructure. It is also likely that projects utilize same bug-tracking tools as end-users reporting bugs. This data finding also suggests that the operation of these tools is straightforward and requires minimal special skills that are not explicitly requested in a job ad.

The results also indicate that there is a high demand for testers who act as quality assurance professionals who are not limited solely to test case generations and execution, but also to in planning, reporting and test evaluation. While the majority of ads require some level of programming competency, there is a strong indication of industrial preference to technically skilled testers. The results also indicate that the majority of employers value the experience more than the education when it comes to hiring into a testing role.

While typically most testers use more than one testing environment, previous survey results [32] indicate that 76% used the development system as a testing environment; while 39% even used the production system as a testing environment. This finding may be an explanation on why only 5% of the ads we surveyed listed setting up a separate testing environment as an entitled activity.

Besides potential testers, this study can also be used by employers to calibrate their requests for software-testing related positions when advertising. This study can serve as a mapping tool for employers to identify spectrum of skills of local teams and compare these with what is currently in demand in the industry. This mapping can influence the implementation of any necessary training to existing personnel.

Finally, the findings from this study can help improve post-secondary or continuing education courses in testing. For example, based on the findings in this research, faculty designing and teaching in software Engineering programs or corporate software testing courses should insure that their Software Testing courses offer enough coverage of test automation and building testing strategy.

VI. THREATS TO VALIDITY

The research process used and the results found in this study were compared with various applicable internal, external, conclusion and construct validity threats as defined in [61].

A potential internal threat is related to selection bias which refers to the ‘‘distortion of statistical analysis owing to the criteria used to select the publications’’ [61]. To address this, a multistage process was used, and inclusion/exclusion criteria were defined in Section 3 to select job ads exclusively relevant to the study. ‘‘indeed.com’’ is the most popular job search engine in the U.S.; hence, its selection is not biased. The selection of the search keywords ''Software Tester'' and ''Software QA'' to form the search string didn't limit the scope of the search results as the engine interprets the search string and gives relevant results for a range of job posts related to the search terms.

A potential external threat could be related to the ''interaction of history and treatment which is the effect of that the data collection is conducted on a special time or day which affects the results'' [61]. For the purpose of this work, the data extraction spanned over 5 months period (April 1-August 31, 2020) which minimizes the effect of this threat. Another potential external threat is related to the ''interaction of selection and treatment which is an effect of having a subject population, not representative of the population we want to generalize to''. Our sample data includes job ads from the 50 states where each state is represented with the first 20 job ads that were returned from the search and met the inclusion criteria.

Inaccuracy in data extraction and mis-classification refer to ''the possibility that information is extracted and interpreted differently by different reviewers'' [16]. To address this threat, the full text of each extracted job post was reviewed thoroughly by at least two of the researchers. To review the agreements and disagreements raised in the assessments, researcher consensus meetings were conducted during the data evaluation and analysis process. Existing published taxonomies were used to map certain aspects of the results to reduce the mis-classification.

Threats to conclusion validity (e.g. the concern that the ''ability to draw the correct conclusion about relations between the treatment and the outcome of an experiment are not possible with the extracted data'' [61]) is not a problem for this research. This is supported by the large sample size for this study with 1000 job extracted job ads helps to reduce this threat.

VII. CONCLUSION

Throughout this paper, we have reported on a structured inspection of 1000 job adverts extracted through a quasi-systematic process to analyze the essential duties that a software tester in the U.S job market is expected to perform along with industrial demand for competencies needed to perform these duties. The findings from this study observed that the software tester is being shaped as a distinct role that involves several testing and technical competencies that are valued more than domain-specific knowledge. Some of the notable findings include:

1) There is a high demand for professionals with competency in the whole testing process, including test strategy planning and execution monitoring.
2) There is a high demand for automated testing. In 13 out of 20 investigated business domains, the demand was above 70% from the domain-specific ads. The demand was equal or above 50% in all ads. This is supported by the high demand for testing automation tools, with Selenium being the most popular among all tools (43.2% of all ads).
3) Most employers are looking for competency in high-level functional testing. Competency in regression testing was the highest among all other types of testing in 17 out of 20 investigated business domains. There is also a high interest in acceptance testing. In half of the business domains we investigated, we saw acceptance testing be demanded at 25% or higher in the corresponding ads.
4) It was surprising to observe that although a significant number of companies employ test management and bug-tracking tools, only a few job posts explicitly require competency in these tools.
5) There is an evident preference for software testers with programming skills, with 56.8% of ads require skills in at least one programming language. But even with this high number, programming skills will be most likely utilized in writing simple testing scripts or SQL queries. It is less likely that a tester will be engaged in highly technical software development tasks. Only 11.8% of employers explicitly ask for working knowledge of software development.
6) Previous experience plays an important role during hiring for a software tester role and more than the academic degrees and certificates.

We intend this study to advance the understanding of the software tester's role within the U.S. market and to provide much-needed contemporary data to software engineering practitioners, researchers, and educators. The results for all the raw data from this study are available through the link: https://bit.ly/3lPcDfx. Researchers and practitioners are welcome to execute further analysis of the data.

As our subsequent work:

1) In the short term, we intend to collect and analyze more software testing-related job ads from other sources, particularly LinkedIn. We intend to use the new batch of collected job ads to enrich and validate the presented results.
2) We will conduct a survey study to investigate the gap between practitioners and educators on the software testers tasks and skills reported in this exploratory study. Besides, to provide a deeper understanding of the state-of-the-practice of software testers roles in the U.S, it could also be worthwhile to interview hiring IT managers to understand how they perceive this role.
3) We also intend to replicate the study for different job markets and then conduct a comparative evaluation of the collected results. It will be interesting to see the extent to which cultural factors and local market incentives affect how practitioners think of the software tester role. This effort is directed towards theory-building [60] regarding the software tester profession.

4) We are also hoping to replicate this study for the U.S. market in few years to investigate the changing landscape of profiles of software testing Jobs over time.

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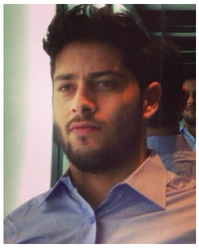

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