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Effort Estimation in Global Software Development: An Updated Systematic Literature Review

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***Abstract*—** Effort estimation remains a critical and unsolved challenge in global software development (GSD), where increase in project complexity, rapid technological growth, and the occurrence of distributed teams across the globe have declared traditional estimation paradigms insufficient for estimating a product. This updated systematic literature review thoroughly examines the evolution and empirical foundation of estimation methods in GSD, drawing on studies published between 2020 to 2024. Our analysis exposes a persistent trust in expert judgment and algorithmic models, with only experimental adaptation of AI/ML and hybrid approaches, none of which comprehensively address GSD-specific drivers such as time zone distribution, cultural differences, and coordination interruptions. Despite the proliferation of new techniques, there remains a noticeable scarcity of large-scale context-aware metric development, empirical validation and standardization. Particularly, our research gap mapping reveals that no prevailing method fully meets the core needs of modern GSD, indicating systemic weaknesses in methodological and practical applicability. By critically synthesizing these limitations and highlighting the disengagement between academic innovation and industrial adoption, this review provides not only an authoritative assessment of the current state-of-the-art methods for estimation but also a persuasive direction for the development of empirically grounded, standardized, and contextually adaptive estimation models. These insights are intended to guide researchers, practitioners, and policymakers towards resolving the long-standing bottlenecks that delay reliable effort estimation in global software engineering.

Keywords*— *Effort Estimation, Global Software Development, Systematic Literature Review.

I. INTRODUCTION

Software industry is experiencing outstanding growth in both scale and complexity globally, making accurate effort estimation a constant challenge for project managers and team members. With the increase adaptation of Global Software Development (GSD), where the teams are distributed globally and with organizational boundaries, new layers of complexity have emerged including coordination across time zones, cultural and language barriers, and diverse work practices that often compromise the accuracy of traditional estimation approaches [1] . Software development is really a complex process that consists of different stages from requirement elicitation to the deployment of the project. Poor effort estimation is a leading cause of project delays and budget overruns and has been linked to a significant number of software project failures [2] . As a solution many software companies started to hire the people globally. The reason is low cost of work hours and to utilize the time evenly by working on a project for 24 hours in any of the region. These projects are distributed in different countries. This distribution and its management are called Global Software Development (GSD) [3].

Traditionally the solution for estimation is to take the advice of expert and according to their judgments and expertise a project can be estimated but these types of methods are more likely to be compromised when there is a complex project is in line which can impact based on changes in requirements, team expertise, project size team members geographical location, communication, trust, and coordination over distance. Estimation and prediction are very important to cover the future losses in every project. In a bird eye view software development estimation can be categorized into two ways, algorithmic and non-algorithmic. Traditional estimation models such as algorithmic approaches like the Lines of Codes (LOC), Constructive Cost Model (COCOMO) and Function Point Analysis were primarily designed for co-located teams and controlled settings. However, these models frequently fall short in distributed environments, where factors such as communication delays, varying team expertise, and unpredictable handovers can significantly affect productivity and resource needs [4] [5] [6] and are not appropriate for the estimation in GSD [7]. This highlights the needs for dedicated research in estimating the globally developed software. Three key challenges which make GSD projects hard to manage are communication, trust and coordination over distance.

- **Communication:** Different languages in different regions leads the conversation to misunderstandings and it is a significant challenge in GSD. This barrier of language delays the project timelines, despite the resources like video conferencing and other fast mediums but still it is crucial to ensure that all stakeholders clearly understand the task and its objectives [8], [9]
- **Trust:** Globally distributed people have strong reservations regarding trust due to the cultural differences. Remotely working teams often faced these issues due to different expectations based on their cultural backgrounds. This can be reduced by frequent meetings with peers to build trust among team members [10] [11]
- **Coordination Over Distance**: Different time zones create significant coordination challenges, especially

between the hand-off between sites. So that the new team can start the work on the provided work from the previous team and it is difficult to maintain the time zone differences to share the projects progress [8], [10].

In recent years, researchers have explored advanced estimation methods based on machine learning, analogy-based reasoning and hybridization to tackle the complexity of GSD [12], [13]. Yet, despite these innovations, there remains a lack of standardized frameworks and empirical evidence addressing the unique challenges faced by globally distributed teams [14]. To address these persistent challenges, this study conducts an updated systematic literature review (SLR) of effort estimation practices in GSD for identification of challenges, evaluation of existing estimation practices, different roles of tools and techniques, understanding the factors which are influencing the accuracy and effectiveness of estimation i.e. team distribution, cultural differences different time zones and highlight critical gaps in the existing literature.

To take this research, questions are formulated after the consideration of criteria proposed by [15] with some amendments as per the domain of this study. The attributes proposed are *population, intervention, comparison, outcomes,* and *context.* Whereas we are not comparing, we are taking the following attributes from the criterion attributes.

- Population – SGD projects.
- Intervention – Methods, techniques, cost and size for effort estimation.
- Outcomes – Accuracy of the methods and techniques for effort estimation.
- Context – Any study in the context of GSD.

Based on these attributes the formulated research questions are as below *(every question is considered under the context of GSD).*

- Question 1 – What are the methods and techniques used for effort estimation?
- Question 2 – What attributes (cost drivers/ any size metrics) of efforts are used for estimation?
- Question 3 – What type of datasets are used for effort estimation?
- Question 4 – What type of sourcing strategies such as offshore insourcing or offshore outsourcing are used?
- Question 5 – What types of activities are involved in effort estimation?

II. Related Work

A. Traditional Estimation Methods in GSD

Early research on effort estimation in Global Software Development (GSD) was mostly about the traditional software estimation methods to work in distributed settings. Britto et al [3] did a basic SLR and found that traditional methods like expert judgment, algorithmic models like COCOMO, and function point analysis were widely used. However, these methods often didn't consider the extra complexity that comes with distribution, like cultural diversity and geographic dispersion. Wickramarachchi and Lai [7] second the work of Britto and expressed the restrictions by stressing that standard models weren't made to handle GSD's natural coordination, time zone, and communication problems. Da Silva et al. [20], [21] and Prikladnicki and Audy [24] looked at process models and project management frameworks twice. They pointed out that estimation methods that work well for teams working in the same place don't always work well for projects that are globally distributed.

TABLE I. Traditional Effort Estimation Methods in GSD

Model/ Technique	Type	Specific Features Discussed	Ref
Expert Judgment	Human-based	experts experience; most common in Agile	[3] [7]
COCOMO II & Parametric Models	Algorithmic/ Parametric	Traditional estimation i.e. COCOMO II, Function Points	
Function Points / Use Case Points	Size-based	Size metric for estimation	
Analogy-Based Estimation	Comparative	Estimates by comparing with similar past projects, challenged in GSD due to variability in contexts	[3]
Historical Data Analysis	Data-driven	Uses organization's previous project data, though cross-site data comparability is often weak in GSD	[3]
Planning Poker / Delphi	Group Consensus	Consensus-based expert methods; popular in Agile and distributed teams, but effectiveness can vary in virtual settings	[3] [7]
Hybrid Approaches	Mixed	Blends expert opinion with algorithmic or data-driven models to address GSD uncertainty	[3]
Process Maturity/ Capability Models	Organizational	Not an estimation model but widely referenced to assess readiness/ process discipline for distributed development	[20] [21] [24]

B. AI-Based and Hybrid Estimation Techniques

Advancement in computational intelligence is increasing continuously. Professionals are using Artificial Intelligence (AI) and Machine Learning (ML) together to estimate how much effort and time software will take. Dantas et al. [16] talked about how AI/ML is becoming increasingly common for estimating effort in Agile and GSD settings. They emphasize the need for testing estimation techniques in real-world world applications of GSDs. Azura Zakaria et al. [4], Jadhav et al. [5], and Shameem et al. [13] have all suggested

different AI-based and hybrid methods, such as ensemble learning, analogy-based reasoning, and genetic algorithms respectively, to improve the accuracy of estimates and deal with the complexities that come with globally distributed development. Ahmed et al. [14] and Ghiduk and Qahtani [12] both said that AI/ML methods look promising, but there isn't a lot of real-world proof that they work in a wide range of GSD situations, and there isn't a consistent way to use them.

TABLE II. TRADITIONAL EFFORT ESTIMATION METHODS IN GSD

Model/ Technique	Type	Specific Features Discussed	Ref
AI/ML-Based Models	Machine Learning	Predictive modeling using ML algorithms (RF, SVM, ANN, LR)	[5] [4] [14] [16]
Ensemble Learning	Machine Learning	Combines multiple ML models (e.g., Random Forest)	[5] [4]
Analogy-Based Reasoning	Comparative	Effort estimation via project similarity metrics	[5]
Genetic Algorithm-Based Model	Nature-Inspired ML	Optimization of success/cost predictions using GA	[13]
Hybrid Model (COCOMO II + ANN + GSD Drivers)	Hybrid/ML + Algorithmic	Integration of COCOMO II, ANN, and GSD-specific cost drivers	[14]
Decision Model for GSD Coordination (CCRD)	Simulation/Decision Model	Localized decision-making for distributed coordination	[12]

C. Coordination and Communication Approchaes in GSD

Numerous reviews have highlighted that coordination and communication problems are major barriers to estimating GSD efforts even without the consideration of effort estimation, in addition to estimation methods. Hossain et al. [18] , Mishra et al. [22], and Steinmacher et al. [30] all looked at problems such communication breakdowns, differences in time and culture, and problems with transferring knowledge in a systematic way. These studies show that even the best estimating models can be hurt by problems within an organization and how teams work together across different locations. Nidhra et al. [29] and Gomes and Marczak [31] are two further assessments that go into more detail about mitigation techniques and best practices. They also agree that no one approach has completely solved the many coordination problems that exist in GSD contexts.

TABLE III. COORDINATION AND COMMUNICATION APPROCHAES IN GSD

Model/ Technique	Type	Specific Features Discussed	Ref
Daily Scrum & Synchronous Meetings	Agile Practice	Regular daily meetings for status sharing and rapid issue resolution	[18]
Communication Tools (Email, IM, Video Conf.)	Tool Support	Use of email, video conferencing for real-time and asynchronous collaboration	[18] [22] [30]
Knowledge Repositories & Wikis	Tool Support	Centralized storage for project knowledge and documentation sharing	[29] [31]
Cultural Awareness Training	Management Practice	Training to bridge cultural differences and improve communication	[29] [31]
Process Standardization	Management Practice	Definition of common workflows and standards across sites	[22] [31]
Periodic Face-to-Face Meetings	Management Practice	Onsite visits or temporary co-location to strengthen team bonds	[18] [29]

D. Overview of Systematic Reviews in Global Software Development

A systematic literature review for the use of agile methodologies in GSD is done by [17]. [19] investigated the GSD under the area of Software Engineering. [20], [21] gave two SLRs based on project management in GSD. SLR performed by [23] classified the solutions according to the process areas in GSD. [24] distinguished the papers based on the processes models for GSD considering the overseas outsourcing of resources. [25] gave a SLR for training and teaching methodologies for developers and students for the need of GSD projects. [26] identified the existing metrics and indicators specially used for GSD. [27] investigated the literature to find empirical evidence reading GSD. [28] highlighted the risks and precautions to overcome those risks related to GSD based projects. [29] explore the current practices about transferring knowledge in GSD. Whereas many of the previous studies i.e. [32], [33] focused on the issues and solutions like communication, coordination and cooperation in GSD.

TABLE IV. COORDINATION AND COMMUNICATION APPROCHAES IN GSD

Ref	Methodology	Key Findings	Recommendations
[17]	SLR	Communication and coordination are persistent issues	Need for empirical studies on agile adoption in GSD.
[19]	Mapping SLR	Categorized GSE research into themes, showing trends and research maturity over time.	Emphasized under searched areas and need for more empirical research.
[20]	SLR	project management challenges, i.e. coordination, communication,	More solutions focused empirical validation needed.

Ref	Methodology	Key Findings	Recommendations
[17]	SLR	Communication and coordination are persistent issues	Need for empirical studies on agile adoption in GSD.
		trust and summarized solutions.	
[21]	Systematic Mapping	Proposed evidence-based management model, mapping key challenges	Need for practical application and validation in industry.
[23]	SLR	Classified solutions by process area i.e. knowledge transfer, requirements	Highlighted the lack of integrated, validated frameworks.
[24]	SLR	mapped evolution of models over time	Emphasized on the need for comparative studies on model effectiveness
[25]	SLR	Reviewed training and teaching approaches for GSD in academia and industry	Need to bridge the gap between education and industrial outcomes.
[26]	SLR	Identified metrics/indicators used in GSD, i.e. task distributor, performance of team	No standard metrics are defined.
[27]	SLR	Concise current empirical studies, showing insufficient high-quality, large-scale empirical works in GSD.	Identify the need for more robust empirical research and replication.
[28]	SLR + Survey	common risks (e.g., time zone, culture, coordination) identified	No sufficient work has been done in context-specific risk strategies
[29]	SLR + Validation	Major Knowledge Transfer barriers, i.e. tacit knowledge, culture	In depth study on effectiveness of strategies is needed
[32]	SLR	Studies influence of team dispersion on coordination and project performance in GSD	Additional studies needed on coordination-performance connection.
[33]	SLR (3C Model)	Recorded tools and methods for communication, coordination, cooperation awareness in GSD.	Show the need of underneath support for communication awareness.

Despite various empirical studies and systematic reviews on global software development (GSD), numerous research gaps are still unfilled, particularly in this rapid shift of technological advancement and organizational transformation that is ongoing. Recent reviews and practical studies have emphasized the emergence of improved effort estimating methods, such as hybrid AI/ML approaches, ensemble learning, and context-aware models, but there is a constant lack of comprehensive evaluation and consistency across GSD [13], [14]. Additionally, studies continue reporting the barriers related to coordination, knowledge transfer, and cultural alignment, with many recommended moderation strategies lacking robust empirical validation in modern GSD environments.

Remote-first work, project complexity and increased tool diversity are newly emerged challenges, yet existing SLRs either cannot systematically synthesize their impact on estimation accuracy and team performance. These limitations underscore the need for an updated, intensive SLR that not only explores the latest methodological advances and coordination practices, but also critically inspect their empirical effectiveness and practical relevance in current GSD. This study addresses these gaps, providing a timely synthesis and analysis to inform both research and practice.

This paper is distributed as Section I and II are articulating the necessity of this SLR. Further sections of the paper are as follows. Section III describes the methodology followed. Section IV is based on the results. Discussion of results is done in Section V. Section VI mentioning the threats to validity. Further Section VI is proposing the research gaps and open issues based on the findings and in the last, Section VII is concluding the study.

III. Systematic Literature Review

This section is based on detailed SLR, including research questions which provides the basis for this research. Procedures which were taken to conduct this research are also in this section. The guidelines herein followed are by [34].

A. Search Strategy

After researching questions, we need to set up a strategy for search strings to identify the primary studies. We have used the following procedure to make search strings used in this paper to reduce the bias of the researchers.

1) After analysis of the research questions we have identified the primary words regarding the attributes of criteria i.e. population, intevention and outcome.
2) Collection of relevant papers and checking of keywords.
3) Finding out the different words and synonyms for major terms.
4) Connecting words by Boolean OR.
5) Linking the main terms with alternative words by using Boolean AND;
6) We assessed the search strings and modify them by quasi-gold standards [35].

As a result, we have obtained the following search words with OR operator:

The first group of strings with synonyms is, *effort* ***OR*** *cost* ***OR*** *size* ***OR*** *measurement* ***OR*** *resources* ***OR*** *metric.* The second group of strings is, *estimating* ***OR*** *estimate* ***OR*** *estimation* ***OR*** *prediction* ***OR*** *calculation* ***OR*** *sizing* ***OR***

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assessment ***OR*** *predicting* ***OR*** *measuring* ***OR*** *measure* ***OR*** *calculating.* Third string is, *"global software development"* ***OR*** *"distributed software development"* ***OR*** *"distributed development"* ***OR*** *"globally distributed work.*

The combinations which were formed based on these strings to search were eighteen which are given below in Table I.

TABLE V. SEARCH STRINGS

No.	Search String with AND operators
1.	"effort" AND "estimation" AND "global software development"
2.	"effort" AND "estimating" AND "global software development"
3.	"effort" AND "prediction" AND "global software development"
4.	"cost" AND "estimation" AND "global software development"
5.	"cost" AND "estimating" AND "global software development"
6.	"cost" AND "prediction" AND "global software development"
7.	"resources" AND "estimation" AND "global software development"
8.	"resource" AND "estimating" AND "global software development"
9.	"resource" AND "prediction" AND "global software development"
10.	"effort" AND "estimation" AND "distributed software development"
11.	"effort" AND "estimating" AND "distributed software development"
12.	"effort" AND "prediction" AND "distributed software development"
13.	"cost" AND "estimation" AND "distributed software development"
14.	"cost" AND "estimating" AND "distributed software development"
15.	"cost" AND "prediction" AND "software development"
16.	"resources" AND "estimating" AND "globally distributed work"
17.	"resource" AND "estimation" AND "globally distributed work"
18.	"resource" AND "prediction" AND "distributed software development"

B. *Inclusion and Exclusion Criteria for the Selection*

- Inclusion Criteria:
  1) Studies covering effort estimation in the context of Global Software Development and based on any model, or method will be included.
  2) Studies based on empirical evidences.
  3) Studies published in English languge.
  4) Studies published in any journal, peer review conference or workshop. Any thesis if found in the same context.

- Exclusion Criteria:
  1) Studies not covering effort estimation in the context of Global Software Development.
  2) Studies which are not providing the empirical evidences.
  3) Studies which are not published in English languge.

C. *Study Selection Process*

After the formulation of search strings, initially the search process involved the identification of primary studies from primary resources. We selected the databases mentioned in Table II along with the number of results obtained by the defined search strings and their combinations and the relevant papers. We have covered the largest sources where GSD and estimation of effort related studies are published. Searching was done with the title and abstract of the articles. Our search is limited to peer-reviewed conferences articles, journal articles, published between 2014 till 2024. Here, we need to justify that this study is an updated version of the [3]. Before this [16] gave an updated version of the study with the name an updated review and the study was [17]. So, considering this practice we are writing an updated version of the study done in 2014.

TABLE VI. CONSOLIDATED SEARCH RESUTLS

Database name / Search Engine	Search Results	Selected articles
Scopus	55	19
IEEExplore	17	06
ACM Digital Library	06	02
Science Direct	01	01
Total	79	28

In the screening process 28 articles were judged as relevant studies as shown in Table II by reading titles and abstracts of all the findings done by the authors. We have used letters (St) for identification of studies ranging from 1 to 28.

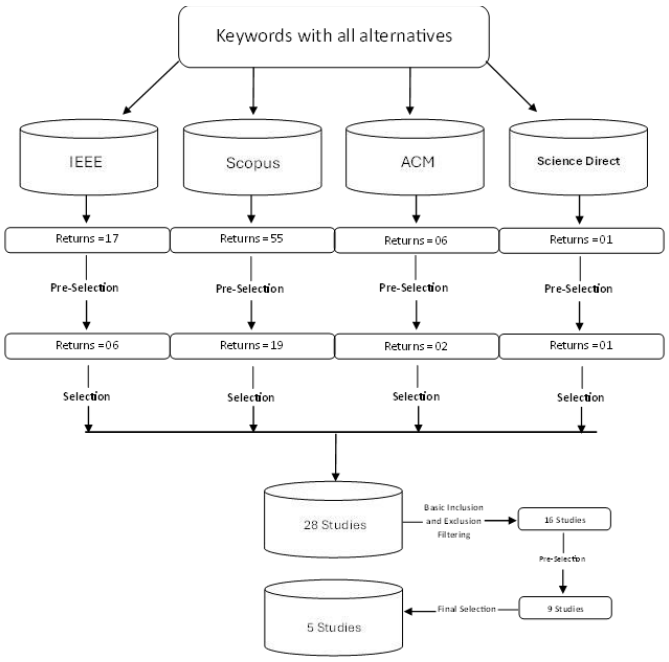


Fig. 1. The Study selection Process

In the screening process 28 articles were judged as relevant studies as shown in Table II by reading titles and abstracts of all the findings done by the authors. We have used letters (St) for identification of studies ranging from 1 to 28.

We have downloaded the full text of these 28 articles from different databases i.e. SCOPUS, IEEExplore, ACM Digital Library and one from Science Direct. The first phase of screening is based on reading the abstract of all the 28 papers we excluded 16 articles because they are not focusing on effort estimation in GSD which is the first exclusion criteria. In the second phase we read all the remaining papers thoroughly and ultimately, we discovered that 9 studies are more which do not empirically explain the results and findings related with effort estimation in GSD.

Hence, by the end of the selection procedure we found 5 studies relevant and fulfilling the inclusion criteria.

D. Study quality assessment

To decrease the bias for the assessment of the selected articles we have developed a framework based on a questionnaire with 13 questions. The assessment is taken in the basis of score from 0 to 13. A higher score indicates the better quality of the paper in terms of evidence. The framework based on the questionnaire was constructed with the guidelines provided by [34].

The framework keeps some quantitative assessment i.e. for every question which is fulfilling the study the study will be rewarding 1 by considering (Yes) if it is fulfilling the question partially so it will be rewarded as 0.5 (Partially) and finally for any question study is failed to answer a 0 (No) will be marked for that question. Any study scoring below 3.5 will be excluded. Below are the questions for the questionnaire.

- Are research objectives specifically mentioned?
- Was the design of the study suitable to achieve the objectives of the study?
- Was the selection of prediction techniques justified and clearly described?
- Are the considered variables suitable for the study and measured properly?
- Are the data collection methods explained in detail?
- Is the data collected explained thoroughly?
- Either the purpose of the data analysis clear or not?
- Are statistical techniques used for analysis of data adequately described?
- Are the results discussed instead of only presentation?
- Is there anything discussed by the researchers regarding any problems with the validity/reliability of the results?
- Are all research questions answered sufficiently?
- Is the link between the data, its interpretation and conclusion clear or not?
- Are results and findings based on different projects?

On the established criteria for quality assessment. We performed the assessment on 5 primary studies. The score of studies is given in Table III.

TABLE VII. SCORE OF THE STUDY

Study ID Number	Score of Study
St2	10
St3	11.5
St6	10.5
St8	10
St10	10

The list of all the finalized studies and after their inclusion and exclusion is shown in Table IV A and Table IV B respectively.

TABLE VIII. INCLUDE STUDIES AFTER SELECTION PROCESS AND QUALITY ASSESSMENT BASED ON THE SCORE

Included Studies	Title
St2 [36]	An expert-based requirements effort estimation model using bayesian networks
St3 [37]	An Empirical Investigation on Effort Estimation in Agile Global Software Development
St6 [38]	Analogy-based software development effort estimation in global software development
St8 [39]	A specialized global software engineering taxonomy for effort estimation
St10 [40]	Scheduling Based Cost Estimation Model: An Effective Empirical Approach for GSD Project

E. Data from Selected Studies

After selection of the papers, we extracted the data from the selected 5 studies. Comparison of results is an important part as work is divided by the authors of this paper. The process of extraction of the data from the selected studies is based on the research questions which are mentioned in the previous section of this paper.

IV. RESULTS

The extracted data is consolidated in tables to make it easier to understand and interpret the relationship between the values and the research questions

Percentage in every table indicates the ratio of the study out of the total number of studies

A. Methods and Techniuqes used for Effort Estimation

To extract the data for the methods and techniques used for effort estimation in the context of GSD, we need to extract the methods and techniques used in the studies for effort estimation in GSD. The data is here in Table V, which shows the pre-defined estimation methods or techniques from the literature. These techniques and methods are divided in

categories i.e. i) expert-based approaches; Delphi [41], expert judgment [42], planning poker [43], ISBSG: ii) algorithmic based approaches are COCOMOII [42] and SLIM [44]; and iii) artificial intelligence based approach; case-based reasoning [42].

TABLE IX. EFFORTS ESTIMATION METHODS

Method	Approach	Study	%
Delphi	Expert Based	St3	20
Expert Judgment	Expert Based	St2, St6, St8	60
Planning poker	Expert Based	St3	20
ISBSG based expert judgment	Expert Based	St6,	20
COCOMO II	Algorithmic	St,3 St10,	40
SLIM	Algorithmic	St10	20
Case-based Reasonig	Artificial Intelligence	St2, St6	40
Funtion point count	Matric Based	St3,	20
Use case point count	Metric Based	St3,	20

Among different methods and techniques, we found that Expert judgment is the most dominant among all primary studies. It was used by St2, St6 and St8 and kept 60% of overall studies. After that we observed that COCOMOII and SLIM are the most used techniques as two of the primary studies have used them and both belonged to Algorithmic based techniques. St6 and St8 also used Artificial Intelligence based methods i.e. case-based reasoning and make 40% of overall primary studies. Function point count and Use case point is only used by St3.

B. *Attributes used for Effort Estimation*

For data extraction regarding cost drivers or any size metrics we must find the attributes affecting effort to measure the effort shown in Table VI.

TABLE X. COST DRIVERS IN PRIMARY STUDIES

Cost Drivers	Study	Percentage
Process Model	St2	20
Communication	St2	20
Team Skills	St3	40
Time Zone Difference	St3, St6, St10	60
Team Experience	St3	40
Technical Dependencies	St3	40
Working Hour Difference	St3	40
Uncertainty Level	St3	40
Team Size	St8, St6	20
Geographical Distance	St8	20
Temporal Distance	St8	20
Cultural Differences	St10	20
Language Barriers	St10	20
Outsourcing Fit	St10	20
Project Management Experience	St10	20
Buyer Outsourcing Experience	St10	20
Buyer Project Managers	St10	20
Supplier Outsourcing Experience	St10	20
Supplier Project Managers	St10	20
Development Type	St6	20
Recording Method	St6	20

We have evaluated all the cost drivers from all the primary studies. Most dominant cost-driver is time zone difference as most of the studies are mentioned and counted as the major cost effect attribute. As the term emphasis Global Software Development so the effect of time zone cannot be ignored. Another important attribute is Team in different aspects, we have separated all of them and counted as a separate identity i.e. team skills, team experiences, team size. The third most prominent cost driver is communication. Rest can be noted from Table VI.

C. *Datasets used for Effort Estimation*

To identify the datasets used for effort estimation. We have looked at the primary studies to find which datasets are used in the primary studies. We have assessed according to the following basis.

- Either the domain of the data sets used in a primary study is industry or institutional.
- Either the data belongs to one company, or it involves the data from multiple companies.
- Application type of the dataset that either requires the offline application or web-based infrastructure.

TABLE XI. DOMAIN OF THE DATASETS

Domain	Study	Percentage
Industry	St2, St3, St6, St8, St10	100
Institutional	No study related with institution or academia	0

TABLE XII. TYPES OF DATASETS

Domain	Study	Percentage
Individual Company	St2	10
Multiple Companies	St3, St6, St8, St10	80

TABLE XIII. DATA SETS APPLICATION

Domain	Study	Percentage
Offline Desktop Application	St2, St8	40
Web-Based Application	St3, St6, St8, St10	80

In Table VII, we found nothing related to academia or institutional in the dataset in any of the primary studies. In Table VIII, only one study is based on single company data, and all others have datasets from multiple companies. In Table IX, among all the datasets 80 percent of datasets are acquiring web infrastructure, whereas datasets in St2 are solely based on offline desktop traditional application along with St8's some portions are related with offline application.

D. Sourcing strategies

Sourcing strategies are strategies to appoint the software engineers/ developers or coders, which could be of two types. Offshore insourcing or offshore outsourcing. In the selected studies Table X synthesis, the data related to question 4. We have evaluated the studies in three strategies of offshore insourcing and offshore outsourcing according to the literature. The third strategy can be a hybrid of both. The terms offshore insourcing, and offshore outsourcing are defined by [45] as when a company assigned the development of software to another company which is based in abroad is called offshore outsourcing. Whereas offshore insourcing means when a company assigned the development of the projects to another branch of the same company established abroad.

TABLE XIV. SORCING STRATEGIES

Strategy	Study	Percentage
Offshore Insourcing	-	0
Offshore Outsourcing	St2, St10	40
Hybrid	St3, St8	40
Not Defined	St6	20

Table X can be interpreted as no study out the primary study is only focusing on offshore insourcing. St2 and St10 are based on offshore outsourcing only whereas St3 and St8 have followed both strategies. No evidence has been found in St6 regarding any sourcing strategy.

E. Activities involved in Effort Estimation

Table XI shows the activities involved in the effort estimation process. There are several activities followed by different studies. Here are the details of each study.

TABLE XV. ACTIVITIES IN STUDIES

Study	Activities
St2	Requirements gathering, Specification, Validation
St3	Project planning, coordination, communication and control
St6	Historical data collection, analogy-based assessment.
St8	Classification of factors in GSE, knowledge sharing, coordination complexity and cost drivers
St510	Productivity indexing, geographical and temporal analysis and scheduling.

The model in St1 defined in the study emphasizes the participation of project managers and expert judgments to examine the efforts considering the requirement phase also. St2 used activities like project planning, coordination communication and control. Mainly focused on the estimation in agile development in the under the consideration of geographical issues. St6 applies analogy-based effort estimation comparing the current projects with the historical data of previous projects to explore the similarities and differences for each of them. St8 proposed a taxonomy which helps to standardize the measurement of effort estimation in GSD with different factors. St10 combines the elements affecting the estimation like time zones, coordination to estimate the efforts in GSD by using COCMOII and SLIM. abbreviations in the title or heads unless they are unavoidable.

V. DISCUSSION

The findings related to methods and techniques used for effort estimation in GSD, expert judgment is mostly used and a dependable method, but studies also show that this is not applicable to all the projects. It is also observed that sound contextual knowledge and experience can estimate the efforts in such a way that automatic techniques may not be able to do so. At some points we also found that there is a blend also of algorithmic approaches and human based approaches. The combination of all three approaches like expert based, algorithmic and Artificial Intelligence can lead to more efficient and accurate effort estimations in GSD. Regarding the attributes used in effort estimation in GSD, the studies identified many cost drivers which are affecting effort estimation in GSD. The main challenges faced by the companies are different time zones, cultural and language barriers. No study we found to discuss the cost drivers in detail or to enlist them at all. A trend which studies are showing that companies are adopting the local estimation method as per their region for GSD projects with the integration of cost drivers. In addition, the metric for measuring the functionality and length with the function points and lines of codes are the most frequently used methods. Only industrial data is taken for the assessment of the effort estimation. 80 percent of datasets were based on multiple companies' data whereas, only 20 percent of the data were based on in single company. One more thing that can be noticed in the primary studies is that mainly the applications are web based. The observation indicates that no study has particularities in each sourcing strategy. The studies are mixed up of both no study was found for offshore insourcing only. There are two studies following the hybrid approach. One of the studies does not follow any of the sourcing strategies. Offshore sourcing can be helpful in effort

estimation as the companies can find employees from different regions at the same place to reduce the cultural or language gaps. There is no pattern observed in activities followed by the authors. There are several mentioned in Tablet XV.

The investigation of recent primary studies and recent reviews reveals a tenacious support on expert judgment and algorithmic methods for effort estimation in GSD, but still experimental adoption of AI/ML based models is needed [4], [14]. Notably, expert-based estimation remains dominant due to its adaptability to domain-specific factors; still, it is also subject to bias and is not universally applicable, as proved in both large-scale and cross-company settings [5], [13] . Algorithmic methods, particularly COCOMO II and SLIM, have been restructured to address distributed development, but their performance differs, as they are dependent on how effectively cost drivers like time zone, cultural, and communication factors are integrated.

A new approach is the rise of hybrid approaches integrating with expert input, historical data, and AI models aimed to tackle the complexity and dynamic nature of GSD. However, our synthesis shows that there is no clear consensus on best practices or standard metrics, reflecting the conclusions of recent SLRs the inconsistency in dataset types, project contexts, and sourcing strategies largely focused on industrial settings and datasets from different companies further complicates generalization.

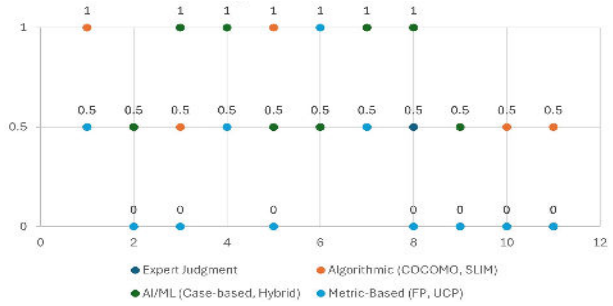


Fig. 2. Estimation Techniques vs. Cost Drivers in GSD Studies

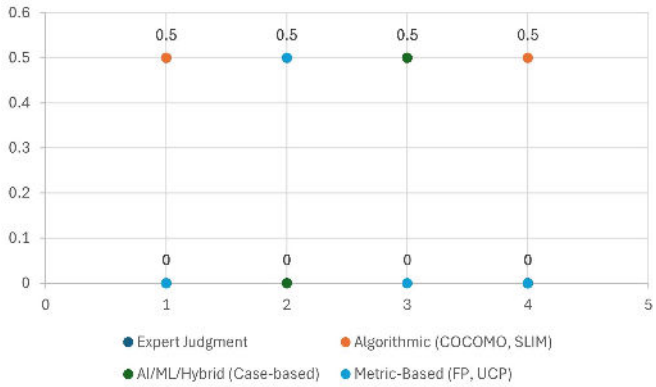
It can be observed in Fig 2. Each point shows the extent to which estimation approaches (Expert Judgment, Algorithmic, AI/ML, Metric-Based) address key GSD cost drivers, as synthesized from included primary studies (2021–2024). (1 = explicitly addressed; 0.5 = partially; 0 = not addressed.)

The research gap map in Figure. 3 clearly illustrates the persistent limitations of current effort estimation techniques in global software development. As shown, none of the mainstream approaches whether expert judgment, algorithmic models like COCOMO and SLIM, AI/ML-hybrid techniques, or metric-based methods such as function or use case points fully satisfy the critical requirements of empirical validation, standardization, contextualization to GSD-specific factors, or metric development. Each point represents the extent to which leading estimation approaches (Expert Judgment, Algorithmic, AI/ML-Hybrid, Metric-Based) key research and practice needs in global software development, as synthesized from recent primary studies (2021–2024). (0.5 = partially fulfilled; 0 = not fulfilled.)

Fig. 3. Core Research and Practice Needs by Estimation Technique in GSD

We observe a lack of rigorous, large-scale empirical validation while comparing recent models,. Whereas advanced techniques such as ensemble learning, genetic algorithms, and hybrid models show promising outcomes ccording to several studies presented in this study, they are rarely appraised across diverse, real-world GSD settings. This aligns with the concerns raised in contemporary research . The predominance of web-based applications in recent datasets may also bias findings and limit applicability to other software domains.

Our review demonstrates that contextual factors such as time zones, team experience, communication effectiveness with cost drivers and cultural distance are measured differently in different studies, in result it is limiting the



comparability of results and the development of generalized frameworks. Studies continue to highlight the lack of standardized, GSD specific metrics and the need for robust approaches.

VI. Open Issues and Research Gaps

This study points out some open issues regarding software estimation in GSD like existing estimation models are not fully applicable to GSD. The reason behind not fulfilling the GSD requirement is time difference, language barriers, cultural barriers and due to these hurdles' communication problems occur. Insufficient empirical research and validation in real world settings is also an issue. This study concludes to have more empirical studies to propose different models based on different real-world settings. Cost drivers have a significant role in the production of any product so if we consider software as a product the cost drivers could be time zones, communication problems etc. in GSD context, which need to be studied very critically and thoroughly. Another gap which is identified by this study is there are no standardized metrics for effort estimation in GSD. Some researchers have followed function points and lines of codes, but these are not sufficient for the GSD as it has a complex and unique mechanism. The data from industry which is used in limited it should be more

from both the industry and academic as well. This is one of the reasons that generalizability of the findings is facing the problem.

VII. Threats to Validity

For threats to validity for this SLR, the most important issue to mention here is whether we were able find all the relevant studies or not. And to reduce this threat we followed a deep-down searching strategy, as we finalized the keywords first with the words which keep the same context and then create their strings in the context of effort estimation in the context of Global Software Development.

We cannot claim that we have retrieved all the related literature aligning with our SLR objectives, but we can say that we have tried our best to find the maximum number of possible studies we could find by just restricting our search strings and criteria we have developed earlier.

Initially we found 78 studies. After the screening process we found only 28 studies relevant. We have gone through the title and abstracts of all the studies after we subtracted 16 studies which are not relevant. In the second phase we excluded 9 studies which are providing the empirical findings of the study. So, we have tried to least the threats to validity as much as possible. Ultimately, we have a few studies to assess, extract data and draw conclusions about the work done in previous years regarding efforts estimation in the GSD context. It is very difficult to get a general idea about the findings.

VIII. Conclusion

Global software development has changed the dynamics of software development. It gave opportunities as well as challenges. This updated SLR provides a timely, critical synthesis of effort estimation practices, methods, and challenges in global software development, defining developments and current gaps in literature since 2020. By systematically mapping of traditional, algorithmic, and AI-driven estimation methods and contextualizing them within the complications of modern GSD, our review highlights the vital need for empirically validated, context-aware models and standardized metrics. The analysis underscores that no single approach or metric yet addresses the complicated, dynamic nature of GSD, especially in the face of emerging trends like remote-collaboration and increased project complexity. Our contributions advise both researchers and practitioners, providing a basis for methodological improvement and strategic adoption of new estimation approaches and frameworks. Future work must emphasize large-scale empirical validation, cross-domain dataset sharing, and the integration of human and contextual factors for estimation in GSD. Only through such joint, evidence-based efforts can determined the challenges of effort estimation in global software development be meaningfully addressed. We just want to admit that this research is an updated version of a SLR published 2014 by [3].

IX. References

[1] P. Suresh Kumar, H. S. Behera, J. Nayak, and B. Naik, “A pragmatic ensemble learning approach for effective software effort estimation,” *Innov Syst Softw Eng*, vol. 18, no. 2, pp. 283–299, Jun. 2022, doi: 10.1007/s11334-020-00379-y.

S. Hameed, Y. Elsheikh, and M. Azzeh, “An optimized case-based software project effort estimation using genetic algorithm,” *Inf Softw Technol*, vol. 153, Jan. 2023, doi: 10.1016/j.infsof.2022.107088.

R. Britto, V. Freitas, E. Mendes, and M. Usman, “Effort estimation in global software development: A systematic literature review,” in *Proceedings - 2014 IEEE 9th International Conference on Global Software Engineering, ICGSE 2014*, Institute of Electrical and Electronics Engineers Inc., Oct. 2014, pp. 135–144. doi: 10.1109/ICGSE.2014.11.

N. Azura Zakaria, A. Ritahani Ismail, A. Yakath Ali, N. Hidayah Mohd Khalid, and N. Zainal Abidin, “Software Project Estimation with Machine Learning,” 2021. [Online]. Available: http://promise.site.uottawa.ca/serepository/datasets-page.html

A. Jadhav, M. Kaur, and F. Akter, “Evolution of Software Development Effort and Cost Estimation Techniques: Five Decades Study Using Automated Text Mining Approach,” 2022, *Hindawi Limited*. doi: 10.1155/2022/5782587.

M. A. Latif, M. K. Khan, and U. Hani, “Using Standard Deviation with Analogy-Based Estimation for Improved Software Effort Prediction,” *KSII Transactions on Internet and Information Systems*, vol. 17, no. 5, pp. 1356–1376, May 2023, doi: 10.3837/tiis.2023.05.003.

D. Wickramaarachchi and R. Lai, “Effort estimation in global software development - a systematic review,” *Computer Science and Information Systems*, vol. 14, no. 2, pp. 393–421, Jun. 2017, doi: 10.2298/CSIS160229007W.

B. Hayat Malik, S. Faroom, M. Nauman Ali, N. Shehzad, S. Yousaf, and H. Saleem, “Geographical Distance and Communication Challenges in Global Software Development: A Review,” 2018. [Online]. Available: www.ijacsa.thesai.org

H. and G. E. and S. K. Siakas Errikos and Rahanu, “Towards Reducing Communication Gaps in Multicultural and Global Requirements Elicitation,” in *Systems, Software and Services Process Improvement*, P. and M. R. and R. M. Yilmaz Murat and Clarke, Ed., Cham: Springer International Publishing, 2021, pp. 257–277.

E. Y. Cho, “Exploring Challenges in Global Software Development A Case Study of a Collaboration between a Korean and a Swedish Company.”

J. L. Scott Charles P. R. and Wildman, “Culture, Communication, and Conflict: A Review of the Global Virtual Team Literature,” in *Leading Global Teams: Translating Multidisciplinary Science to Practice*, R. L. Wildman Jessica L. and Griffith, Ed., New York, NY: Springer New York, 2015, pp. 13–32. doi: 10.1007/978-1-4939-2050-1_2.

A. S. Ghiduk and A. M. Qahtani, “An empirical study of local-decision-making-based software customization in distributed development,” *IET Software*, vol. 15, no. 2, pp. 174–187, Apr. 2021, doi: 10.1049/sfw2.12016.

M. Shameem, M. Nadeem, and A. T. Zamani, “Genetic algorithm based probabilistic model for agile project success in global software development,” *Appl Soft Comput*, vol. 135, Mar. 2023, doi: 10.1016/j.asoc.2023.109998.

[14] M. Ahmed *et al.*, "A Hybrid Model for Improving Software Cost Estimation in Global Software Development," *Computers, Materials and Continua*, vol. 78, no. 1, pp. 1399–1422, 2024, doi: 10.32604/cmc.2023.046648.

[15] Mark. Petticrew and Helen. Roberts, *Systematic reviews in the social sciences : a practical guide*. Blackwell Pub., 2006.

[16] E. Dantas, M. Perkusich, E. Dilorenzo, D. F. S. Santos, H. Almeida, and A. Perkusich, "Effort estimation in agile software development: An updated review," in *Proceedings of the International Conference on Software Engineering and Knowledge Engineering, SEKE*, Knowledge Systems Institute Graduate School, 2018, pp. 496–501. doi: 10.18293/SEKE2018-003.

[17] S. Jalali and C. Wohlin, "Global software engineering and agile practices: A systematic review," Oct. 2012. doi: 10.1002/smr.561.

[18] E. Hossain, M. Ali Babar, and H. Y. Paik, "Using scrum in global software development: A systematic literature review," in *Proceedings - 2009 4th IEEE International Conference on Global Software Engineering, ICGSE 2009*, 2009, pp. 175–184. doi: 10.1109/ICGSE.2009.25.

[19] J. Kroll, R. Prikladnicki, J. Luis, and N. Audy, "Mapping the Evolution of Research on Global Software Engineering-A Systematic Literature Review. MAPPING THE EVOLUTION OF RESEARCH ON GLOBAL SOFTWARE ENGINEERING A Systematic Literature Review," 2011. [Online]. Available: https://www.researchgate.net/publication/220708951

[20] F. Q. B. Da Silva, C. Costa, A. C. C. França, and R. Prikladnicki, "Challenges and solutions in Distributed Software Development Project Management: A systematic literature review," in *Proceedings - 5th International Conference on Global Software Engineering, ICGSE 2010*, IEEE Computer Society, 2010, pp. 87–96. doi: 10.1109/ICGSE.2010.18.

[21] F. Q. B. Da Silva, R. Prikladnicki, A. C. C. França, C. V. F. Monteiro, C. Costa, and R. Rocha, "An evidence-based model of distributed software development project management: Results from a systematic mapping study," *Journal of software: Evolution and Process*, vol. 24, no. 6, pp. 625–642, Oct. 2012, doi: 10.1002/smr.563.

[22] D. Mishra, A. Mishra, R. Colomo-Palacios, and C. Casado-Lumbreras, "Global Software Development and Quality Management: A Systematic Review," 2013.

[23] S. Schneider, R. Torkar, and T. Gorschek, "Solutions in global software engineering: A systematic literature review," *Int J Inf Manage*, vol. 33, no. 1, pp. 119–132, 2013, doi: 10.1016/j.ijinfomgt.2012.06.002.

[24] R. Prikladnicki and J. L. N. Audy, "Process models in the practice of distributed software development: A systematic review of the literature," 2010, *Elsevier B.V.* doi: 10.1016/j.infsof.2010.03.009.

[25] M. J. Monasor, A. Vizcaíno, M. Piattini, and I. Caballero, "Preparing students and engineers for global software development: A systematic review," in *Proceedings - 5th International Conference on Global Software Engineering, ICGSE 2010*, IEEE Computer Society, 2010, pp. 177–186. doi: 10.1109/ICGSE.2010.28.

E. H. M. H. TaniaF. C. T. Euclides Alfredo Matusse, *Metrics and Indicators to Assist in the Distribution of Process Steps for Distributed Software Development: A Systematic Review*. IEEE, 2012.

D. Šmite, C. Wohlin, T. Gorschek, and R. Feldt, "Empirical evidence in global software engineering: A systematic review," *Empir Softw Eng*, vol. 15, no. 1, pp. 91–118, Feb. 2010, doi: 10.1007/s10664-009-9123-y.

I. Nurdiani, R. Jabangwe, D. Šmite, and D. Damian, "Risk identification and risk mitigation instruments for global software development: Systematic review and survey results," in *Proceedings - 2011 6th IEEE International Conference on Global Software Engineering Workshops, ICGSE Workshops 2011*, 2011, pp. 36–41. doi: 10.1109/ICGSE-W.2011.16.

S. Nidhra, M. Yanamadala, W. Afzal, and R. Torkar, "Knowledge transfer challenges and mitigation strategies in global software development—A systematic literature review and industrial validation," *Int J Inf Manage*, vol. 33, no. 2, pp. 333–355, Apr. 2013, doi: 10.1016/j.ijinfomgt.2012.11.004.

I. Steinmacher, A. P. Chaves, and M. A. Gerosa, "Awareness support in distributed software development: A systematic review and mapping of the literature," Apr. 01, 2013, *Kluwer Academic Publishers*. doi: 10.1007/s10606-012-9164-4.

V. Gomes and S. Marczak, "Problems? We all know we have them. Do we have solutions too? A literature review on problems and their solutions in global software development," in *Proceedings - 2012 IEEE 7th International Conference on Global Software Engineering, ICGSE 2012*, 2012, pp. 154–158. doi: 10.1109/ICGSE.2012.43.

Nguyen Duc Anh, Daniela S. Cruzes, and Reidar Conradi, *Dispersion, Coordination and Performance in Global Software Team A Systematic Review*. ACM Digital Library, 2013.

I. Steinmacher, A. P. Chaves, and M. A. Gerosa, "Awareness Support in Global Software Development: A Systematic Review Based on the 3C Collaboration Model."

B. Kitchenham, "Guidelines for performing Systematic Literature Reviews in Software Engineering," 2007. [Online]. Available: https://www.researchgate.net/publication/302924724

H. Zhang and M. A. Babar, "On searching relevant studies in software engineering On searching relevant studies in software engineering On Searching Relevant Studies in Software Engineering," 2010. [Online]. Available: https://hdl.handle.net/10344/730

E. Mendes, V. T. Vaz, and F. Muradas, "An expert-based requirements effort estimation model using bayesian networks," in *Lecture Notes in Business Information Processing*, Springer Verlag, 2016, pp. 79–93. doi: 10.1007/978-3-319-27033-3_6.

R. Britto, E. Mendes, and J. Borstler, "An Empirical Investigation on Effort Estimation in Agile Global Software Development," in *Proceedings - 2015 IEEE 10th International Conference on Global Software Engineering, ICGSE 2015*,

Institute of Electrical and Electronics Engineers Inc., Aug. 2015, pp. 38–45. doi: 10.1109/ICGSE.2015.10.

[38] M. El Bajta, "Analogy-based software development effort estimation in global software development," in *Proceedings - 2015 IEEE 10th International Conference on Global Software Engineering Workshops, ICGSEW 2015*, Institute of Electrical and Electronics Engineers Inc., Aug. 2015, pp. 51–54. doi: 10.1109/ICGSEW.2015.19.

[39] R. Britto, E. Mendes, and C. Wohlin, "A specialized global software engineering taxonomy for effort estimation," in *Proceedings - 11th IEEE International Conference on Global Software Engineering, ICGSE 2016*, Institute of Electrical and Electronics Engineers Inc., Sep. 2016, pp. 154–163. doi: 10.1109/ICGSE.2016.11.

[40] Mr.S.Ramacharan and Dr.K. Venu Gopala Rao, *Scheduling Based Cost Estimation Model: An Effective Empirical Approach for GSD Project2016 Thirteenth International Conference on Wireless and Optical Communications Networks (WOCN) : 21-23 July*. IEEE, 2016.

B. W. Boehm, "Software Engineering Economics."

E. Mendes, "Cost Estimation Techniques for Web Projects," 2007. [Online]. Available: https://api.semanticscholar.org/CorpusID:107768033

M. Cohn, "Agile estimating and planning".

N. Panlilio-Yap, "Software Estimation Using the SLIM Too l."

D. Šmite, C. Wohlin, Z. Galviņa, and R. Prikladnicki, "An Empirically Based Terminology and Taxonomy for Global Software Engineering."