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RESEARCH ARTICLE

Evaluating Success Factors of Software Project Management in Global Software Development

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ABSTRACT At present, global software development (GSD) is gaining considerable attention in the realm of software engineering. The project management of global software projects presents substantial complexity owing to several inherent challenges of GSD. The software project management practices employed for in-house development appear inadequate to address the unique challenges posed by global software projects, making their management a formidable task. Software organizations rely on traditional software project management practices to manage global projects, often resulting in impairments or failures. This paper explores the critical success factors (CSFs) in software project management for global projects by developing a framework for effective project management within the context of GSD. The study focuses on identifying and prioritizing CSFs in software project management within a GSD setting utilizing multi-criteria decision-making (MCDM) analysis methods. Therefore, the present research provides an extensive literature review of CSFs in software project management within GSD. Additionally, the research applies the combinatorial approach to assess the various dimensions and CSFs of software project management in GSD. The proposed approach aids in measuring and comparing the effects of several dimensions and CSFs of software project management in GSD. Five dimensions and twenty factors have been determined through a literature review and further evaluated for prioritization using the combinatorial approach. The identified dimensions and factors will be valuable in devising strategies to effectively manage global software projects.

INDEX TERMS GSD, MCDM, CSFs, success, effective project management, critical success factors.

I. INTRODUCTION

Global software development (GSD) refers to the process that involves collaboration with team members across the globe to develop software products. GSD is an emerging aspect of software development embraced by the majority of software organizations [1]. The extensive practice of GSD has become feasible due to fast and inexpensive international telecommunication means as well as the availability of highly skilled software practitioners at low cost. Access to global talent is a main motivational factor for software companies opting to develop software within a GSD setting [2]. Currently, the execution of GSD projects is prevalent in the software industry due to the numerous benefits it offers, such as round-the-clock development, attractive cost structures, reduced time to market, innovation, and shared best practices [3]. However, despite the numerous positive effects of GSD on software development, it presents challenges at both management and technical levels. Software development, whether co-located or distributed, is inherently a human activity. Consequently, issues related to trust, communication, and coordination at a distance affect the performance of distributed teams. GSD entails cultural, language and time zone differences that intensify these issues, hampering knowledge sharing, team

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management, and eventually posing hazards to project success. Addressing such issues requires project managers in GSD settings to possess additional understanding, skills and consideration [3]. Project management has strong effect on software development and becomes particularly important within GSD settings. Many software organizations adopt GSD without prior knowledge and exposure to its issues, resulting in their failure to successfully manage and complete projects. The main reason behind such failure is the application of inappropriate project management practices that do not align with the context of GSD [4]. Success in global projects depends on employing project management practices which are pertinent to a GSD setting.

Project management practices vary between developed and developing countries with respect to communication, working habits, organizational structure and culture [4]. GSD projects are prone to numerous threats including language differences, cultural differences and compliance issues which require identification and control through an effective mechanism. Effective project management of GSD projects is crucial to ensure timely delivery, allegiance to budget constraints, meeting quality standards, alleviating risks and ensuring client satisfaction. It helps to communicate frequently in clear terms within the team members located at different geographical locations, time zones and cultural background to ensure that the final product will meet the required quality standards, customer requirements and expectations [5]. Critical Success Factors (CSFs) play an important role in the effective project management of GSD projects. These factors are essential for the success of global projects. CSFs can assist project managers in determining the critical areas that require their attention and support them in accomplishing project success. CSFs are factors that, if addressed properly can considerably improve the likelihood of project success. Numerous studies in project management have identified CSFs that may influence the success of GSD projects but such CSFs are mainly related to general projects rather than focusing on the issues of GSD projects [6]. Previous studies proposed various CSFs models to effectively manage the global software projects.

However, these models are deficient in respect of focusing important aspects of global software project management, covering big geographical region and their integration with software project management framework. Furthermore, the use of decision-making techniques and GSD experts' perspectives have not been taken to develop such models. Still, there is a lack of comprehensive models with a strong theoretical background in software project management for GSD projects. So, this research aimed to introduce a CSFs model for effective software project management in a GSD setting.

This study raised two key research questions, which are as follows:

(i) What factors predominantly influence managing software projects in a GSD setting?
(ii) How will these factors be evaluated and prioritized?

Considering management of software projects in the GSD context a multi-dimensional problem comprising various criteria (aka dimensions) and sub-criteria (aka factors)., this work has taken into account the multi-criteria decision-making (MCDM) techniques, accompanied by a substantial literature review to offer a model for effective project management of software projects in GSD. Generally, MCDM techniques are used to make decisions when there are quite a few factors. The analytic hierarchy process (AHP) [7] is one of the most popular MCDM techniques that is adequate to make decisions using pairwise comparison of qualitative and quantitative factors. It provides an outstanding procedure to compute the weights of factors used in experts' reasoning processes [8]. However, the traditional AHP lack the ability to completely display the ambiguities that exist in human judgment. Consequently, a precise criterion cannot be produced. Furthermore, the AHP method does not eliminate the biases of decision-makers. The decisions made by humans always undergo from irregularities, such as imprecision, vagueness, and incapacity to offer accurate placement of Saaty's scale during pairwise comparison. These deficiencies of AHP can be addressed by the fuzzy analytic hierarchy process (FAHP), which has the capacity to overcome such limitations. FAHP considers linguistic ambiguity and imprecision during decision-making.

It has been employed in numerous MCDM problems owing to its potential to settle vague information. It permits experts to deliver consistency in their judgment. FAHP consists of simple steps used to derive the weights in relation to other MCDM techniques including fuzzy best worst method (FBWM), fuzzy characteristic objects method (FCOMET), and technique for order performance by similarity to ideal solution (TOPSIS) [9]. Therefore, considering the possibility of higher accuracy in analysis, time constraints and convenience for researchers and experts, AHP and FAHP are employed in this study.

The rest of the paper is orchestrated as follows: Section II presents an extensive review of recent literature for this study. Section III is about the role of CSFs in GSD project management. Section IV presents a framework for the CSFs of software project management in GSD. Section V provides an overview of MCDM-based research methodologies. Section VI presents the results of the study. Section VII is about discussion. Finally, section VIII provides the conclusion and future work.

II. RELATED WORK

Numerous research studies have been conducted in the past few years to introduce CSFs-based models and frameworks to effectively manage projects in the context of global software development. The CSF models and frameworks introduced by prior research are as follows:

Chua and Ong [10] proposed the Global Software Development Success Factors (GSDSF) model to effectively manage global projects. The model consists of six CSFs, including communication, coordination, culture, human resource management, infrastructure, and process. It helps to identify and prioritize CSFs for global projects. However, the model lacks a clear and succinct way to measure the contribution of each factor towards the success of projects; it assumes that all factors are equally important, which limits its practicality. Björndal et al. [1] revealed the challenges of GSD activities with respect to project management. The data has been collected using interviews and questionnaires and is based on the perceptions and experiences of professionals in the area of global project management. The findings of the research study are helpful for practitioners to effectively plan and execute global projects. Guzmán et al. [11] discussed several important factors that contribute to the effective management of global virtual teams. These factors were extracted from a large-scale industrial software development project that lasted for a long time and involved various global teams. Nine identified CSFs were further categorized into three dimensions of project management, including technology, human factors, and processes. Cicibas et al. [12] comparatively analyze the productivity and management perspectives of in-house development and GSD. Results showed low performance by project managers in global projects in comparison to in-house development. The major cause of a low performance was lack of communication, coordination, control, feedback, and conflict resolution in the GSD setting. It has been revealed that project managers performance in GSD is influenced by various factors and management skills rooted in communication, coordination, and negotiation. Niazi et al. [13] underlined another major issue, the majority of clients sanction global contracts without confirming the project management readiness of vendors for global activity. The authors identified project management challenges associated with GSD through a systematic literature review. The major challenges identified are lack of cultural understanding, lack of communication, lack of coordination, time zone differences, and knowledge management. In another study, the authors proposed a framework to evaluate the project management readiness of software organizations to conduct GSD projects. Such a framework consists of 18 success factors; most of the identified factors were mainly related to two knowledge areas of PMBOK, including communication and human resource management. Only a few factors were associated with scope, cost, and time management knowledge areas of project management [14]. Jain and Suman [15] proposed a framework encompassing the aspects that should be taken into account while executing projects in a distributed setting. Such a framework comprises team and resource management, knowledge management, performance management, integration management, and risk management. A new framework is developed, taking into account CSFs extracted from research studies considered from an industrial perspective. This framework extends Jane & Suman with communication management and requirement management [16]. Radujkovic and Sjekavica [17] research emphasizes project management practices to make the area more effective, which will ultimately lead to the success of projects. Such practices include project team competencies, emotional intelligence, skills, tools, and techniques, awareness of organizational structure and culture. Nurdiani et al. [18] introduced a framework to manage risks in GSD projects. The proposed framework is a matrix of risk factors caused by GSD dimensions (i.e., temporal, geographical, and sociocultural distance), processes (i.e., communication, coordination, and control), and mitigation strategies. The study was carried out using the systematic literature review (SLR) technique. Through SLR, 48 risk-related issues and 42 mitigation strategies were identified which encompassed the proposed framework. Another study identified risk factors related to software project management activities in GSD and proposed an integrative framework incorporating such risks. The framework encompasses 39 risk factors extracted through SLR, concentrating on studies addressing project management issues and risks that arise in global projects [19]. Marinho et al. [20] focused on managing uncertainties in global projects by mapping the uncertainty management approach (MUSP) with the global teaming model (GTM). The findings of this research indicated that MUSP satisfies the recommendations of the GTM model and can be applied to global projects. Manjavacas et al. [3] conducted a research study to figure out the challenges of GSD in relation to governance. They found several key elements that were not explored in previous research. Such elements include processes, principles, policies, culture, knowledge, people skills and competencies, infrastructure, and application. Lim [21] studied the relationship between roles and methods used to manage projects and their effect on the success of projects using a quantitative correlational study. The variables associated with roles and methods include monitoring and controlling performance, competencies and methodologies, strategic management, organizational learning, and organizational structure. The results revealed that the variables associated with roles and methods are predictors of global project success. Another study examined the influence of human resources on the success of GSD projects. The challenges related to human factors in GSD settings have been identified, and recommendations have been given to reduce the impact of identified challenges on the success of global projects [22]. Chadli et al. [23] discover and classify various tools cited in the literature that offer support to GSD project managers in managing distributed projects. They categorized tools corresponding to software life cycle stages and describe the process by which such tools support communication, collaboration, and cooperation. Bajta et al. [24] conducted a research study to identify and classify software project management approaches cited in the literature specifically for GSD. The software project management approaches have been analyzed in terms of their application in industry, strengths, and weaknesses. Results revealed that the most frequently used methods include coordination, planning, and monitoring. The authors stressed the need to further investigate the methods and factors of software project management for GSD. A SLR identified 25 practices to effectively manage software projects in a GSD setting. The authors believed that implementing such practices could assist in effectively managing global projects [25].

A variety of CSF-based models and frameworks have been proposed by different researchers; however, certain limitations are perceived in such models.

Firstly, some studies on the CSF model emphasized on a limited set of factors, such as project management practices, risk factors, and managing global virtual teams, while neglecting other crucial factors that could influence the success of global projects. The incomplete coverage leads to the partial insight of project managers working in GSD settings. Secondly, prior research on CSF models has limited scope, focusing on specific geographical regions, which restricts the applicability of their findings. There is an overreliance on previous research on finding factors through systematic literature surveys rather than applying other useful research methods. Although plentiful research studies have been conducted to recognize the CSF for effective project management in GSD, however, there is still a need to develop a comprehensive model by reviewing the literature extensively and consulting GSD researchers, experts, and practitioners involved in global projects with the help of decision-making methods.

III. ROLE OF CSFs IN GSD PROJECT MANAGEMENT

Critical success factors (CSF) are key activities performed by organizations to achieve competitive performance.

CSFs help every kind of organization decide what to emphasize in order to produce the desired results [17]. To assist GSD companies in successful project management, the concept of CSFs is gaining importance. Rockart (1979) CSFs are defined as "the limited number of areas in which results, if they are satisfactory, will ensure satisfactory competitive performance for the organization" [26]. The identification of CSFs for effective management of GSD projects has been viewed as one of the most significant issues to explore further [27].

Planning and organizing projects to support identified CSFs bring about optimistic results based on thoughtful consideration. The CSFs used for effective management act as a framework that can guide stakeholders in global projects, especially those with a leading role in defining and determining crucial elements necessary for meeting project objectives successfully. During the planning phase, CSFs are considered the most impactful variables and should be treated prudently to ensure the effective implementation of the entire strategy [28].

The fundamentals of CSFs are that they should be measurable, manageable, and verifiable so that they support the entire management process. Thus, CSFs should be handled carefully during the management of global software projects so that project success can be achieved, as shown in Figure 1.

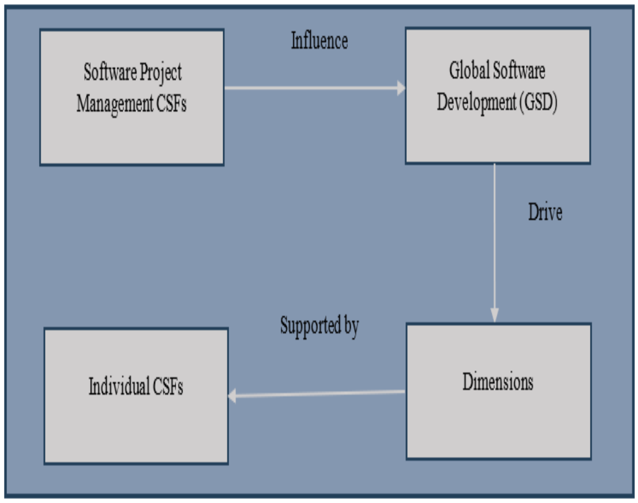

FIGURE 1. Hierarchy of software project management CSFs in GSD.

IV. FRAMEWORK FOR CSFs OF SOFTWARE PROJECT MANAGEMENT IN GSD

To identify CSFs that influence the management of global software projects, the extensive research literature on software project management in the GSD context has been reviewed. The relevant literature was gathered by exploring the most important and widely used scientific repositories, including IEEE Xplore, Science Direct, Google Scholar, and Web of Science. Various search strings were employed to access the necessary research papers. Only the papers most relevant to the goals of our study were extracted for further exploration; the rest were initially disregarded.

Keeping in view the CSFs effect on the management of global software projects, the CSFs have been categorized into several dimensions, such as Communication, Coordination, Human Resource Management, Technology and Project Management. The steps taken to identify CSFs that influence software project management in GSD are as follows:

- Extensive review of literature that discusses the CSFs of software project management in GSD.
- Identification of frequently used CSFs for software project management in GSD.

Using the above-mentioned method, a framework for the selection of CSF has been formulated and presented in Figure 2. Subsequently, combinatorial approaches like AHP-GDM and FAHP have been applied to determine the weight of CSFs for their prioritization. Based on the extensive literature review of software project management in GSD, 7 dimensions and 36 CSFs have been identified. In the end, 5 dimensions and 20 CSFs were chosen after excluding factors cited less frequently in the literature and removing dimensions that overlapped with others. The selected dimensions and CSFs have been described further and presented in Table 1.

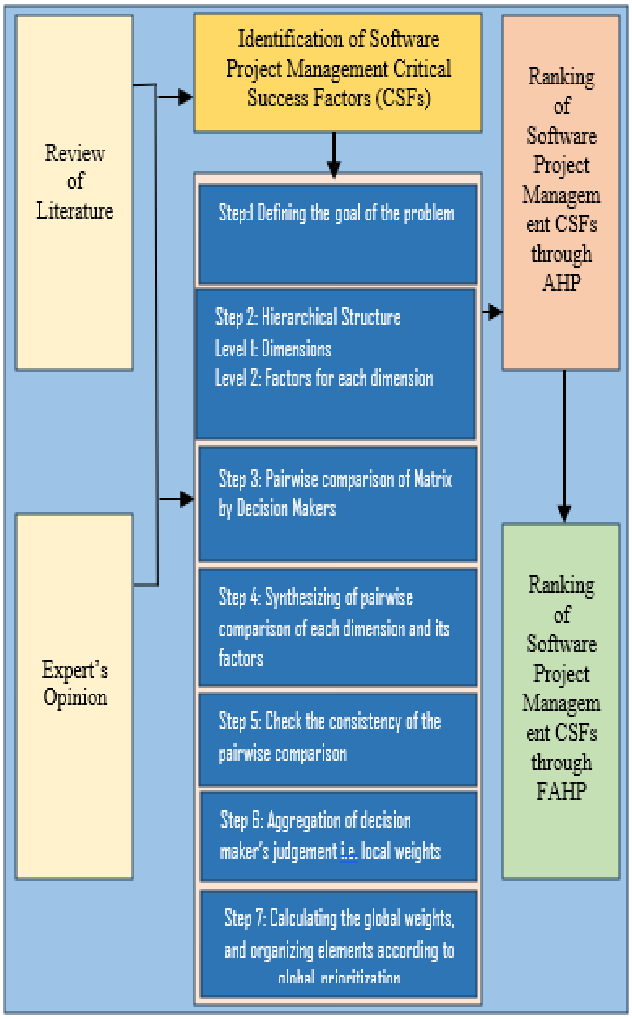

FIGURE 2. **Framework for AHP & FAHP based Prioritization of software project management in GSD.**

A. COMMUNICATION

Communication plays a significant role in the effective management of global software projects. There is a lot of diversity in GSD, as project team members, clients and stakeholders come from different cultural backgrounds. Effective communication helps in bridging cultural gaps and making it certain that everyone is on the same wavelength. There is a relatively higher tendency for misunderstandings and conflicts to arise in global projects. Communication helps in addressing such issues promptly and finding win-win situations. In a nutshell, communication is the backbone of successful global software project management.

B. COORDINATION

Coordination is a crucial aspect of managing global software projects. It involves organizing the efforts of various stakeholders to ensure they work together efficiently toward project goals. Coordination makes it certain that all stakeholders understand project work and are aligned with the project goals, objects, and deliverables, despite working from different geographical locations. It allows efficient allocation of resources and smooth workflow, which eventually lead to the successful completion of the project.

C. HUMAN RESOURCE MANAGEMENT

Human Resource Management (HRM) plays an important role in the success of global software projects. It helps in identifying required resources with desired skill sets for several roles in the project and confirms that the right talent is required. HRM is premised on the belief that placing the right people on the right team fosters a positive working environment. Additionally, this dimension focuses on developing and managing the human capital involved in global projects.

D. TECHNOLOGY

In GSD, technology has a central role in the management of global software projects. It facilitates effective communication and collaboration and helps overcome geographical barriers to ensure the successful delivery of projects. Various tools, like Jira, Trello, and Asana, etc., are available to virtual teams, which allow them to communicate and collaborate quickly and answer queries of each other promptly.

E. PROJECT MANAGEMENT

Project management is indispensable to the success of GSD projects. It is useful to handle the complexities exhibited by geographical dispersion, cultural diversity, and time zone differences. It also helps to record, organize project documents, and establish a knowledge base. Project management processes regularly monitor the progress of global projects being executed at various nodes to remain updated about their health.

V. OVERVIEW OF MCDM-BASED RESEARCH METHODOLGIES

Managing global software projects is a multi-criteria decision-making problem, and understanding it is imperative for discovering the dimensions and factors on which it is based. In this section, we outline the AHP-Group Decision Making (GDM) and FAHP techniques. The AHP-GDM is employed for systematic group decision-making to address complicated issues with many criteria. This technique exhibits good strength in making decisions through pairwise comparison of qualitative, quantitative, and uncertain factors. To further strengthen the AHP, the fuzzy method is integrated into it. FAHP keeps the procedure simple, even when the number of alternative cases grows. FAHP helps in discovering more decisive results by replacing the membership scales with Saaty's scale (1–9) and weighing them in the presence of uncertainties. FAHP combines fuzzy set theory and extension principles to eliminate ambiguity in decision-making.

A. AHP METHODOLOGY

The Analytical Hierarchy Process (AHP) is a widely known multi-criteria method that was developed by Saaty to find the most appropriate alternatives [42]. Analytics in AHP

TABLE 1. CSFS of software project management in GSD obtained through literature review.

Dimensions	CSFs	References
Communication (Com)	Effective communication skills	[1][3][4][6][7] [8]
	Good negotiation strategies	[16][17][18] [19]
	Communication Frequency	[22][23][24][25]
Coordination (Coo)	3C (Communication, Coordination, Control)/Better coordination & Control	[1][2][3][4] [5][6][8]
	Effective customer involvement	[2][6][14][27]
	Member collaboration/cooperation	[1][3][4][8][11][12][13]
	Regular Meetings (communication and coordination)	[7][8][26][27]
Human Resource Management (HRM)	Experienced developers	[2][4][8][31]
	Self-organizing teams	[2][7][8][12]
	Good Cultural awareness	[1][5][6][7]
	Team Formulation	[32][33][34][35]
	Member Skills Roles and Responsibilities	[1][3][4][7]
Technology (Tec)	Rich technological infrastructure	[2][4][6][8][29][30]
	Technology Differences	[4][8][12][29][31]
	Software tools	[6][12][23][29]
Project Management (PM)	Knowledge sharing management	[36][37][38][39]
	Cultural difference management	[3][14][18][19]
	Management of time-zone differences	[3][14][18][19][40]
	Essential project management processes	[3][14][18][19][21]
	Progress Tracking	[4][5][8][14]

show that the topic is dissected into its constituent parts. Hierarchy refers to the identification of a hierarchy of constituent elements in relation to the main goal. The process involves processing data and making decisions to achieve the intended result. The AHP is a decision-support tool designed to solve the problem by decomposing, classifying, and then arranging the potential solutions into a hierarchical structure.

This method compares the parameters with the established measurement scale in order to meet the priority requirements. Expert opinion is the primary source of feedback for the AHP technique, adding subjectivity to the decision-making process. In order to determine the subjective weights of various evaluation criteria, AHP is used. The methodology is as follows:

The pairwise comparison matrix is used, and it can be represented as:

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{1n} & \cdots & a_{nn} \end{bmatrix}, \quad a_{ii} = 1,\ a_{ij} = {}^{1}\!/_{a_{ji}},\ a_{ji} \neq 0 \tag{1}$$

where the criteria are denoted by a_1, a_2, . . ., an. The relative importance of two criteria is rated using a scale as described by [41] and shown in Table 2.

TABLE 2. Relative importance in the comparison of two criteria.

Digits	The relative importance of the two criteria
2,4,6,8	Compromise between slightly different judgements
9	Absolutely more important
7	Demonstrably more important
5	Strongly more important
3	Slightly more important
1	Equally important

Equations 3 to 4 are used to determine the consistency ratio (CR) and consistency index (CI), where n is the number of criteria. The pairwise comparison matrix is acceptable if the CR is < 0.1. Table 3 shows a random index for a given n.

$$CR = \frac{CI}{RI} \tag{2}$$

$$CI = (\lambda_{max} - n) \big/ (n - 1) \tag{3}$$

TABLE 3. Random index.

n	1	2	3	4	5	6	7	8	9	10
Random Index	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

B. FAHP METHODOLOGY

Triangular fuzzy numbers (TFNs) can serve as an alternative to Satty's scale, as illustrated in the derived pair- wise comparison shown in Section VI. The extension concept can be applied to determine the intersection of two fuzzy sets. When compared to AHP, the use of fuzzy numbers can lead to more precise decision-making. Because the AHP is typically dependent on the expert's competence, biased decision-making is a possibility. TFNs may help to lessen ambiguity and bias in decision-making [43]. Thus, fuzzy set theory and extension principle can help provide more accuracy in decision-making. The general fuzzy set theory and extension principles are discussed further:

1) FUZZY SET THEORY

The efficient use of fuzzy set theory ensures good judgment. Since experts have more freedom to make decisions while using fuzzy set theory, personal bias and ambiguity may be readily reduced. Therefore, applying fuzzy set theory and the fuzzy extension principle can aid in making the right choices in a fuzzy context. The triangular fuzzy numbers (p_1, p_2, p_3) or trapezoidal numbers (p_1, p_2, p_3, p_4) can be used in pair-wise decision-making [45], as shown in Figure 3.

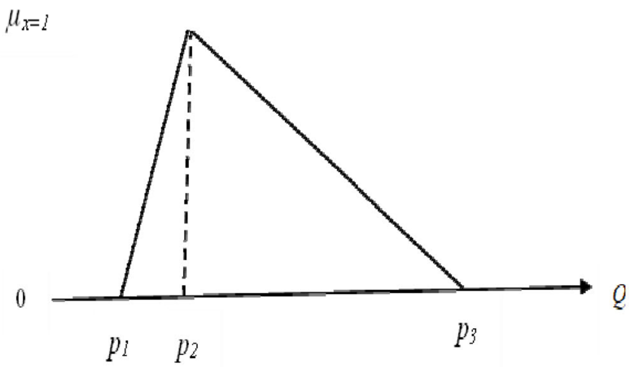

FIGURE 3. Triangular fuzzy number (*P*).

The fuzzy set theory uses TFNs for various arithmetic operations [46]. TFNs may be represented by Q_1 and Q_2 as (r_1, s_1, t_1) and (r_2, s_2, t_2) respectively.

Two TFNs can be used to perform arithmetic operations such as subtraction, addition, division, and multiplication. Such arithmetic operations can be represented by the following Equations (4-8):

$$\tilde{Q}_1 \oplus \tilde{Q}_2 = (r_1+r_2, s_1+s_2, t_1+t_2) \tag{4}$$

$$\tilde{Q}_1 \ominus \tilde{Q}_2 = (r_1-r_2, s_1-s_2, t_1-t_2) \tag{5}$$

$$\tilde{Q}_1 \otimes \tilde{Q}_2 = (r_1 r_2, s_1 s_2, t_1 t_2) \tag{6}$$

$$\lambda \otimes \tilde{Q}_1 = (\lambda_1 r_1, \lambda_1 s_1, \lambda_1 t_1) \quad \text{where } \lambda > 0,\ \lambda \epsilon R \tag{7}$$

$$\tilde{Q}_1^{-1} = \left(\frac{1}{t_1}, \frac{1}{s_1}, \frac{1}{r_1}\right) \tag{8}$$

2) APPLICATION OF THE THEORY OF EXTENT ANALYSIS IN MCDM IN FUZZY ENVIORNMENT

Two triangular fuzzy numbers (TFNs) can be compared using the extent principle [47]. A set of priorities and a set of targets may be viewed as two sets, i.e., $Y = \{y_1, y_2, \ldots\ldots\ldots, y_n\}$ and $Z = \{z_1, z_2, \ldots\ldots\ldots, z_3\}$ respectively. respectively. Therefore, each objective can be extracted using extension theory, and extent analysis can be carried out for each goal. As a consequence, the values of the m extent analysis for each objective can be obtained as follows:

$$Q_{gi}^1, Q_{gi}^2 \ldots Q_{gi}^m, \quad i = 1, 2, \ldots, n \tag{9}$$

where Q_{gi}^j $(j = 1, 2, \ldots m)$ are TFNs represented as (r, s, t). The method is explained below, based on extent analysis as demonstrated in [43].

Step 1: Establishing an organizational structure for the target provided

Dimensions and CSFs are just two of the many categories that make up the current framework. Experts' feedback might be used to confirm the hierarchy. It is crucial to frame the hierarchical ranking system.

Step 2: Establishing the pair-wise comparison for dimensions and CSFs of software project management using TFNs

The dimensions and CSFs of software project management in GSD may be analyzed and compared using feedback from experts. The pair-wise comparison of dimensions and CSFs of software project management in GSD is finally established. In the entire pair-wise comparison matrix, the TFNs are used to fix the relationship among such pair-wise comparisons.

Step 3: Obtaining the value of fuzzy synthetic extent

$$F_i = \sum_{j=1}^{m} Q_{gi}^j \otimes \left[\sum_{i=1}^{n}\sum_{j=1}^{m} Q_{gi}^j\right]^{-1} \tag{10}$$

Using fuzzy summation of TFNs, m extent analysis values $\sum_{j=1}^{m} Q_{gi}^j$, may be obtained as:

$$\sum_{j=1}^{m} Q_{gi}^j = \left(\sum_{j=1}^{m} r_j, \sum_{j=1}^{m} s_j, \sum_{j=1}^{m} t_j\right) \tag{11}$$

and $\left[\sum_{j=1}^{n}\sum_{j=1}^{m} Q_{gi}^j\right]^{-1}$, gives the fuzzy summation of Q_{gi}^j $(j = 1, 2, \ldots, m)$ values are calculated as

$$\sum_{i=1}^{n}\sum_{j=1}^{m} N_{gi}^j = \left(\sum_{j=1}^{m} r_j, \sum_{j=1}^{m} s_j, \sum_{j=1}^{m} t_j\right) \tag{12}$$

The inverse of the vector may be obtained as:

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} Q_{gi}^j\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} t_i}, \frac{1}{\sum_{i=1}^{n} s_i}, \frac{1}{\sum_{i=1}^{n} r_i}\right) \tag{13}$$

Step 4: Obtaining the degree of possibility of supremacy for two tfns i.e., $Q_2 = (r_2, s_2, t_2) \geq Q_1 = (r_1, s_1, t_1)$

$$V(Q_2 \geq Q_1) = \sup\left[min(\mu_{Q_1}(x), \mu_{Q_2}(y))\right], \quad y \geq x \tag{14}$$

and can be represented as:

$$V(Q_2 \geq Q_1) = hgt(Q_1 \cap Q_2) = \mu_{Q_2}(f) \tag{15}$$

$$\mu_{Q_2}(f) = \begin{cases} 0 & \text{if } s_2 \geq s_1 \\ 1 & \text{if } r_1 \geq t_2 \\ \dfrac{r_1 - t_2}{(s_2 - r_2) - (s_1 - r_1)} & \text{otherwise} \end{cases} \quad (16)$$

Various experts are involved in the group decision-making process. For instance, K experts are participating; thus, the subsequent pair-wise comparisons yield n elements. A set of K matrices, $\check{A}_k = \{\check{q}_{ijk}\}$, where $\check{A}_k = \check{q}_{ijk} = (r_{ijk}, s_{ijk}, t_{ijk})$ represents the relative importance of elements i to j, as derived by expert k. The aggregation may be obtained using Equation (17).

$$r_{ij} = min\left(r_{ijk}\right), \quad k = 1, 2, \ldots k$$
$$s_{ij} = \sqrt[k]{\prod_{k=1}^{K} s_{ijk}}$$
$$t_{ij} = max\left(t_{ijk}\right), \quad k = 1, 2, \ldots k \quad (17)$$

The two TFNs i.e. (r_1, s_1, t_1) and (r_2, s_2, t_2) intersect at d which is shown in Figure 3. It also gives ordinate d, from the possible highest intersection between two fuzzy numbers Q_1 and Q_2 denoted as Q. Thus Q_1 and Q_2, maybe calculated through the values of $V(Q_1 \geq Q_2)$ and $V(Q_2 \geq Q_1)$.

Step 5: Obtain the degree of possibility for a given convex fuzzy number such that it is greater than K convex

Fuzzy number Q_1 $(i = 1, 2, \ldots, k)$ may be derived as

$$V(Q \geq Q_1, Q_2 \ldots Q_k)$$
$$= V[(Q \geq Q_1) \text{ and } (Q \geq Q_2 \text{ and } \ldots \ldots \ldots \text{ and } (Q \geq Q_k))]$$
$$= \min V(Q \geq Q_i), \quad i = 1, 2, \ldots \ldots \ldots, k \quad (18)$$

Considering,

$$d'(B_i) = \min V(S_i \geq S_k) \quad for\ k = 1, 2, \ldots, m; k \neq i \quad (19)$$

The weight vector is may be derived as:

$$G' = \left(d'(B_1), d'(B_2), \ldots \ldots \ldots, d'(B_n)\right)^T$$

Such that B_i $(i = 1, 2, \ldots, n)$ has n elements.

Step 6: Obtain the normalized weight vectors.

The normalized weight vector is calculated using Equation (20).

$$C = (d(B_1), d(B_2), \ldots \ldots \ldots, d(B_n))^T \quad (20)$$

where C denotes the crisp number.

Step 7: Obtaining the total score of each dimension of CSFs and its prioritization factors

Total priority weights for each dimension as well as CSFs for software project management will be included in the local weight and global weight products. To achieve higher-order priorities, the dimensions and CSFs can be ranked and prioritized in descending order.

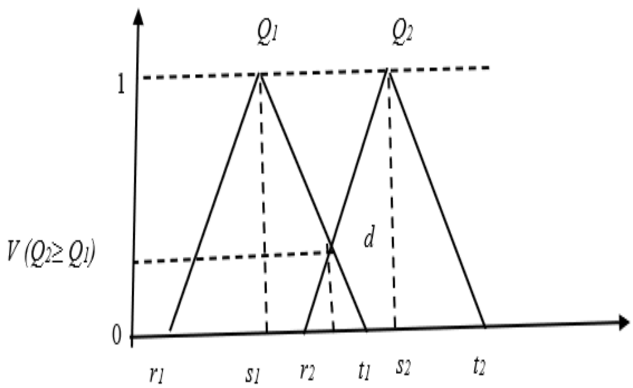

FIGURE 4. The intersection of TFNs [38].

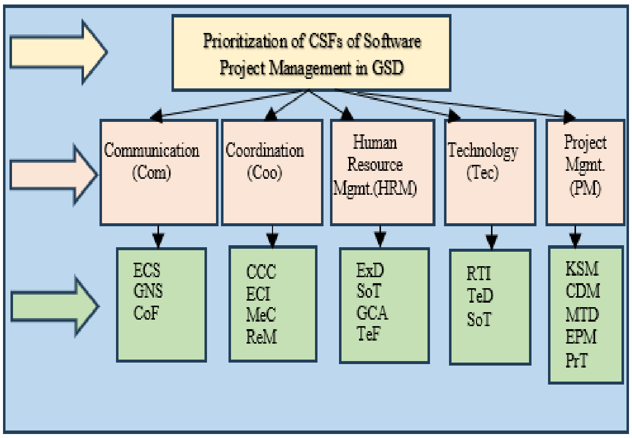

FIGURE 5. MCDM model for effective project management in GSD.

VI. RESULTS

A combinatorial approach based on AHP-GDM and FAHP has been employed in determining and ranking the CSFs of software project management in GSD. AHP facilitates evaluation with the help of experts in the field, whereas FAHP aids in eliminating biases that exist in decision-making. Experts have an important role in qualitative assessment. In this study, five experts with over five years' experience in software project management within a GSD setting were chosen. A few of them also have research exposure in software project management at GSD in addition to their industrial experience. An in-depth literature review has been conducted to identify the CSFs of software project management in GSD. Five dimensions, including Communication (Com), Coordination (Coo), Human Resource Management (HRM), Technology (Tec) and Project Management (PM) were identified. Figure 5 portrays the framework to evaluate and prioritize the CSFs of software project management in GSD.

The selected experts, namely Expert1, Expert2, Expert3, Expert4, and Expert5, evaluated five dimensions, which are presented in the table 4, table 5, table 6, table 7, and table 8. The synthesis of five decision matrixes has been performed using geometric mean (GM), as shown in table 9. Similarly, a pairwise comparison of all the factors within the main

TABLE 4. Comparison of dimensions of software project management in global software development by Expert1.

	Com	Coo	HRM	Tec	PM	Weights
Communication (Com)	1	3	4	6	5	0.459964
Coordination (Coo)	1/3	1	4	5	6	0.297955
Human Resource Management (HRM)	1/4	1/4	1	3	3	0.123641
Technology (Tec)	1/6	1/5	1/3	1	1/3	0.045776
Project Management (PM)	1/5	1/6	1/3	3	1	0.072664

TABLE 5. Comparison of dimensions of software project management in global software development by Expert2.

	Com	Coo	HRM	Tec	PM	Weights
Communication (Com)	1	3	4	7	4	0.457511
Coordination (Coo)	1/3	1	3	6	5	0.279529
Human Resource Management (HRM)	1/4	1/3	1	4	3	0.140137
Technology (Tec)	1/7	1/6	1/4	1	¼	0.038346
Project Management (PM)	1/4	1/5	1/3	4	1	0.084477

TABLE 6. Comparison of dimensions of software project management in global software development by Expert3.

	Com	Coo	HRM	Tec	PM	Weights
Communication (Com)	1	2	4	6	4	0.413942
Coordination (Coo)	1/2	1	4	5	4	0.309487
Human Resource Management (HRM)	1/4	1/4	1	3	4	0.147680
Technology (Tec)	1/6	1/5	1/3	1	1/3	0.047169
Project Management (PM)	1/4	1/4	1/4	3	1	0.081722

TABLE 7. Comparison of dimensions of software project management in global software development by Expert4.

	Com	Coo	HRM	Tec	PM	Weights
Communication (Com)	1	3	5	8	4	0.48295348
Coordination (Coo)	1/3	1	3	5	4	0.25276325
Human Resource Management (HRM)	1/5	1/3	1	4	4	0.14751015
Technology (Tec)	1/8	1/5	1/4	1	1/3	0.03951504
Project Management (PM)	1/4	1/4	1/4	3	1	0.07725808

TABLE 8. Comparison of dimensions of software project management in global software development by Expert5.

	Com	Coo	HRM	Tec	PM	Weights
Communication (Com)	1	3	6	8	5	0.505631
Coordination (Coo)	1/3	1	3	6	4	0.248864
Human Resource Management (HRM)	1/6	1/3	1	5	3	0.131975
Technology (Tec)	1/8	1/6	1/5	1	¼	0.034512
Project Management (PM)	1/5	1/4	1/3	4	1	0.079018

TABLE 9. Synthesized pairwise comparison of dimensions of software project management in global software development by Expert1 to Expert5 using AHP-GDM.

	Com	Coo	HRM	Tec	PM	Weights
Communication (Com)	1	2 3/4	4 1/2	7	4 3/8	0.46515
Coordination (Coo)	1/3	1	3 3/8	5 3/8	4 ½	0.27920
Human Resource Management (HRM)	2/9	2/7	1	3 3/4	3 3/8	0.13626
Technology (Tec)	1/7	1/5	1/4	1	2/7	0.04143
Project Management (PM)	2/9	2/9	2/7	3 3/8	1	0.07797

dimensions, such as Communication (Com), Coordination (Coo), Human Resource Management (HRM), Technology (Tec) and Project Management (PM), has been carried out by the five experts (Expert1–Expert5). Table 10 presents the composite weights of CSFs for software project management in GSD obtained through AHP-GDM.

In the same way, FAHP has been applied in calculating the weights of CSFs of software project management in GSD to find the required ranking. The TFN scale, as shown in table 11 has been used to determine the weights of the CSFs of software project management in GSD and its dimensions. The systematic methodology, as discussed in the previous section may be followed to establish the weights. Table 12 shows the composite weights of the CSFs of software project management in GSD. The prioritization obtained using the AHP-GDM and FAHP methods has been compared, as shown in table 13.

VII. DISCUSSION

In recent years, GSD has emerged as an important phenomenon in software development. The challenges inherent in GSD put additional pressure on project managers while managing global software projects. This study reveals several dimensions and factors crucial for the effective manage-

TABLE 10. Composite weight and rank of dimensions and factors software project management in global software development using AHP-GDM.

Dimension	Dimension weight	Factors	Local Weights	Global Weights	Overall Ranking
Communication (Com)	0.4651	Effective communication skills (ECS)	0.6963	0.3239	1
		Good negotiation strategies (GNS)	0.0840	0.0391	7
		Communication Frequency (CoF)	0.2197	0.1022	3
Coordination (Coo)	0.2792	3C (Communication, Coordination, Control)/Better coordination & Control (CCC)	0.6338	0.1770	2
		Effective customer involvement (ECI)	0.2095	0.0585	5
		Member collaboration/cooperation (MeC)	0.0522	0.0146	13
		Regular Meetings (communication and coordination) (ReM)	0.1045	0.0292	10
Human Resource Management (HRM)	0.1363	Experienced developers (ExD)	0.4946	0.0674	4
		Self-organizing teams (SoT)	0.0603	0.0082	16
		Good Cultural awareness (GCA)	0.0363	0.0049	17
		Team Formulation (TeF)	0.1345	0.0183	12
		Member Skills Roles and Responsibilities (MSR)	0.2743	0.0374	8
Technology (Tec)	0.0414	Rich technological infrastructure (RTI)	0.7308	0.0303	9
		Technology differences (TeD)	0.0696	0.0029	19
		Software tools (SoT)	0.1996	0.0083	15
Project Management (PM)	0.0780	Knowledge sharing management (KSM)	0.1078	0.0084	14
		Cultural difference management (CDM)	0.0580	0.0045	18
		Management of time-zone differences (MTD)	0.0343	0.0027	20
		Essential project management processes (EPM)	0.5234	0.0408	6
		Progress Tracking (PrT)	0.2764	0.0216	11

TABLE 11. TFN scale.

Linguistics scale for the importance	Triangular fuzzy scale	Triangular fuzzy reciprocal scale
Equally Importance (EI)	(1,1,1,)	(1,1,1)
In between Value	(1,2,3)	(1/3,1/2,1/1)
Weakly more importance (WMI)	(2,3,4)	(1/4,1/3,1/2)
In between Value	(3,4,5)	(1/5,1/4,1/3)
Strongly more importance (SMI)	(4,5,6)	(1/6,1/5,1/4)
In between Value	(5,6,7)	(1/7,1/6,1/5)
Very strongly more importance (VSMI)	(6,7,8)	(1/8,1/7,1/6)
In between Value	(7,8,9)	(1/9,1/8,1/7)
Absolutely more importance (AMI)	(9,9,9)	(1/9,1/9,1/9)

ment of such projects. The findings of this study are supported by previous research studies emphasizing the significance of communication, coordination, knowledge management, human resource management, and technology for effectively managing global software projects [10], [11], [13], [44]. However, these previous studies discussed these factors at a broader level, lacking detailed key aspects essential to assisting project managers in GSD settings in their decision-making process. Other studies have emphasized additional factors, including integration management, risk management, mitigation strategies, emotional intelligence, planning, and monitoring organizational structure and

TABLE 12. Composite weight and rank of dimensions and factors software project management in global software development using FAHP.

Dimension	Dimension weight	Factors	Local	Global	FAHP Ranking
Communication (Com)	0.3715	Effective communication skills (ECS)	0.6622	0.2460	1
		Good negotiation strategies (GNS)	0.0899	0.0334	9
		Communication Frequency (CoF)	0.2479	0.0921	4
Coordination (Coo)	0.1887	3C (Communication, Coordination, Control)/Better coordination & Control (CCC)	0.6293	0.1187	3
		Effective customer involvement (ECI)	0.2043	0.0385	7
		Member collaboration/cooperation (MeC)	0.0629	0.0119	15
		Regular Meetings (communication and coordination) (ReM)	0.1035	0.0195	12
Human Resource Management (HRM)	0.0970	Experienced developers (ExD)	0.4295	0.0417	6
		Self-organizing teams (SoT)	0.0756	0.0073	18
		Good Cultural awareness (GCA)	0.0463	0.0045	19
		Team Formulation (TeF)	0.1244	0.0121	14
		Member Skills Roles and Responsibilities (MSR)	0.3242	0.0315	10
Technology (Tec)	0.0364	Rich technological infrastructure (RTI)	0.7123	0.0260	11
		Technology differences (TeD)	0.0801	0.0029	20
		Software tools (SoT)	0.2075	0.0076	17
Project Management (PM)	0.3063	Knowledge sharing management (KSM)	0.1135	0.0348	8
		Cultural difference management (CDM)	0.0599	0.0183	13
		Management of time-zone differences(MTD)	0.0360	0.0110	16
		Essential project management processes (EPM)	0.4911	0.1504	2
		Progress Tracking (PrT)	0.2995	0.0917	5

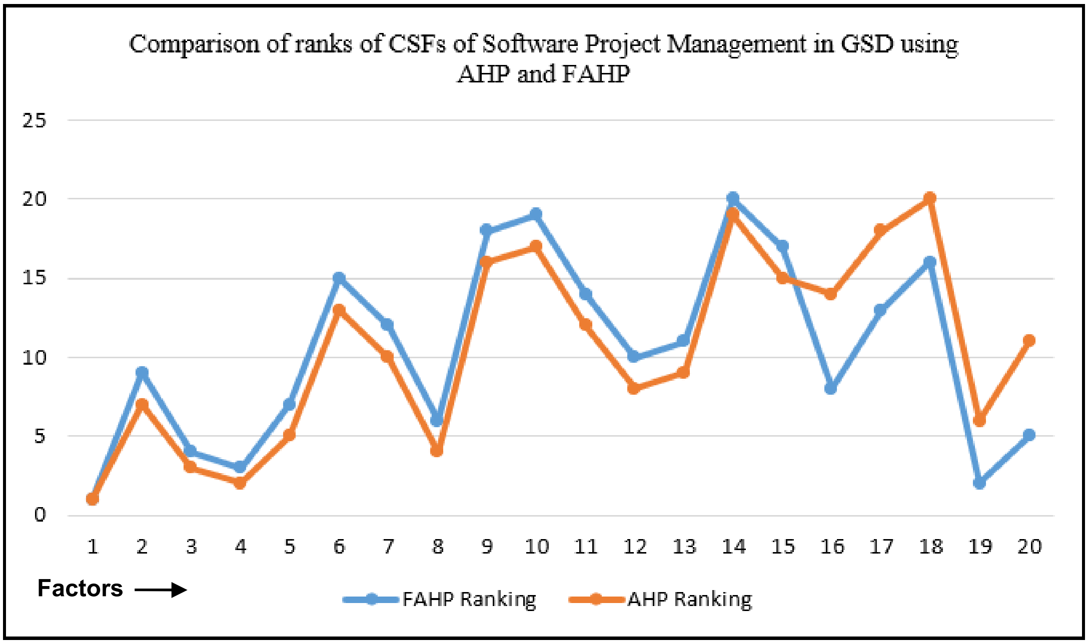

FIGURE 6. Comparing ranks of factors of software project management in GSD.

TABLE 13. Comparison of composite weightages and ranks weight and rank of dimensions and factors software project management in global software development using AHP-GDM and FAHP.

Dimensions	Dimensions weight		Factors	Local weight		Global weight		Overall Ranking	
	AHP	FAHP		AGP	FAHP	AHP	FAHP	AHP Ranking	FAHP Ranking
Communication (Com)	0.4651	0.3715	Effective communication skills (ECS)	0.6963	0.6622	0.3239	0.2460	1	1
			Good negotiation strategies (GNS)	0.0840	0.0899	0.0391	0.0334	7	9
			Communication Frequency (CoF)	0.2197	0.2479	0.1022	0.0921	3	4
Coordination (Coo)	0.2792	0.1887	3C (Communication, Coordination, Control)/Better coordination & Control (CCC)	0.6338	0.6293	0.1770	0.1187	2	3
			Effective customer involvement (ECI)	0.2095	0.2043	0.0585	0.0385	5	7
			Member collaboration/cooperation (MeC)	0.0522	0.0629	0.0146	0.0119	13	15
			Regular Meetings (communication and coordination) (ReM)	0.1045	0.1035	0.0292	0.0195	10	12
Human Resource Management (HRM)	0.1363	0.0970	Experienced developers (ExD)	0.4946	0.4295	0.0674	0.0417	4	6
			Self-organizing teams (SoT)	0.0603	0.0756	0.0082	0.0073	16	18
			Good Cultural awareness (GCA)	0.0363	0.0463	0.0049	0.0045	17	19
			Team Formulation (TeF)	0.1345	0.1244	0.0183	0.0121	12	14
			Member Skills Roles and Responsibilities (MSR)	0.2743	0.3242	0.0374	0.0315	8	10
Technology (Tec)	0.0414	0.0364	Rich technological infrastructure (RTI)	0.7308	0.7123	0.0303	0.0260	9	11
			Technology differences (TeD)	0.0696	0.0801	0.0029	0.0029	19	20
			Software tools (SoT)	0.1996	0.2075	0.0083	0.0076	15	17
Project Management (PM)	0.0780	0.3063	Knowledge sharing management (KSM)	0.1078	0.1135	0.0084	0.0348	14	8
			Cultural difference management (CDM)	0.0580	0.0599	0.0045	0.0183	18	13
			Management of time-zone differences (MTD)	0.0343	0.0360	0.0027	0.0110	20	16
			Essential project management processes (EPM)	0.5234	0.4911	0.0408	0.1504	6	2
			Progress Tracking (PrT)	0.2764	0.2995	0.0216	0.0917	11	5

culture [15], [17], [18], [24]. These are common factors and mainly influence projects executed in co-located settings, unrelated to GSD projects. Therefore, the model proposed in this research encompasses crucial dimensions and their related factors aimed at addressing project management issues in GSD.

CSFs of software project management are very important in the context of GSD. To figure out the significance of each CSF, there is a need for a systematic approach. This study attempts to quantify the CSFs of software project management using MCDM-based methodologies. The results obtained by both the AHP-GDM and FAHP methodologies are also compared in order to determine accurate prioritization. The project managers working in a GSD environment may find the CSFs prioritization helpful in executing the global software project in an optimized and effective manner. The combinatorial approach of AHP-GDM and FAHP may be used in obtaining and ranking. A comparison of the weights of software project management in GSD using AHP-GDM and FAHP may be useful in figuring out the importance of each CSF. The comparison of weights of CSFs for software project management in GSD was found using AHP-GDM and FAHP, as shown in Figure 6.

From the MCDM-based result analysis, it has been found that the five dimensions of software project management in GSD have the following priorities: Communication (Com) > Coordination (Coo) > Human Resource Management (HRM) > Technology (Tec) > Project Management (Pm). The corresponding weights are 0.4651 > 0.2792 > 0.1363 > 0.0414 > 0.0780, where '>' represents 'more significant'. Similar prioritization is found through the fuzzy AHP method. The respective weights obtained are $0.3715 > 0.1887 > 0.0970 > 0.0364 > 0.3063$ where '>' represents 'more significant'.

VIII. CONCLUSION

This research presented a framework to manage software projects in a GSD setting, comprising five dimensions and twenty CSFs related to these dimensions. This study found that the most significant factors among the twenty are communication and coordination. Other factors have their own significance in respect of managing projects in a GSD setting. Among key factors, technology differences were found to be the least important but that doesn't mean that this factor has no value. It is a very important factor in GSD scenarios where technology variations need to be considered. The findings of this study imply that the management of software projects in a GSD setting should be driven by the factors delineated in the proposed framework. It is a general framework to support the execution of projects in GSD. It may be expanded further, considering different domains of software projects and GSD contexts. In this study, ranking and prioritization of CSFs for project management in GSD are carried out in Pakistan and the Kingdom of Saudi Arabia with a limited number of available experts. Future studies may be conducted involving a large number of experts from several regions.

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