Front. Eng. Manag. 2018, 5(2): 251–267
https://doi.org/10.15302/J-FEM-2018086

RESEARCH ARTICLE

Tsegay GEBREHIWET, Hanbin LUO

Detection of schedule delay risk of empirical construction projects

Abstract In Ethiopian construction projects, schedule delay risk is a predominant issue because it is not properly addressed. Although several studies have been focused on the various effects of risk in construction projects, limited efforts have been made to investigate the typical and the overall schedule delay risk. In this study, our aim is to detect the typical and overall schedule delay risk throughout the construction project lifecycle, which consists of the pre-construction, construction, and post-construction stages, and compare the stages with each other. Common criteria, sub-criteria, and attributes were developed for all alternatives for the purpose of making a risk decision. The methodology that was followed integrated the multiple-criteria decision-making (MCDM) model of fuzzy analytic hierarchy process comprehensive evaluation (FAHPCE) and the relative important index (RII). Data were collected from 77 participants, who were selected through purposive sampling from different contracting organizations in Ethiopian construction projects by means of questionnaires that were distributed to experienced experts. The findings showed that there is a typical delay risk either in the type or in the level of the different construction activities. Consequently, the most influenced alternative is the construction stage because of the high-risk responsibility, resource, and contract condition related criteria. The post-construction stage was the second most influenced stage because of the high-risk responsibility-related criteria. The pre-constructed stage was the least influenced stage that consist high-risk criteria of responsibility, resource, and contract condition related. These differences provided noteworthy information about risk mitigation in construction projects by identifying the exact risk level on specific activity to make appropriate decision.

Keywords fuzzy analytic hierarchy process comprehensive evaluation, construction project, detection of delay risk, relative important index

1 Introduction

The uncertainties in construction projects are caused by more inherent risks owing to the unique features of construction activities, such as taking long duration, harsh environment, financial intensity, and dynamic organizational structures (Zou et al., 2007). Construction projects require on-schedule completion; however, unexpected conditions or planning errors may lead to failures, which can undermine the successful realization of the objectives of time, cost, scope, quality, safety, and security. These events are considered as project risks and they require identification, analysis, and treatment before they occur (Forteza et al., 2017). The unique nature of construction projects in developing countries, such as Ethiopia, causes a higher degree of schedule delay risk; consequently, it negatively impacts the quality, budget, and safety of construction projects. Construction projects undergo large deviations in terms of schedule delays, project scope, cost overruns, and quality issues, thus resulting to unsuccessful project accomplishment (Rao and Raghavan, 2014). Schedule delay can lead to several undesirable effects on projects and their participating parties, such as lawsuits between utilities and contractors, increased costs, loss of revenue, and contract termination (Hossen et al., 2015). In 70% of construction projects, time overrun occurred; 76% of contractors and 56% of consultants faced an average of 10% to 30% of time overrun that causes the cost overrun to exceed 50% (Assaf and Al-Hejji, 2006). Therefore, project delays and cost overruns are common because potential

Received November 14, 2017; accepted January 1, 2018

Tsegay GEBREHIWET (✉), Hanbin LUO
Department of Construction Management, School of Civil Engineering and Mechanics, Huazhong University of Science and Technology, Wuhan 430074, China
E-mail: i201522187@hust.edu.cn

risks are overlooked (Rao and Raghavan, 2014). Successful construction project management requires identification and evaluation of schedule delay risk factors (Hossen et al., 2015). Next, it is important to detect the probability of occurrence of schedule delay risk, when managing a construction project risk (Luu et al., 2009). The effective detection of project risk can improve project performance (Kuo and Lu, 2013). Moreover, it prioritizes risk factors for further analysis of their probability of occurrence and their impact (Luu et al., 2009). The condition for risk reduction is the identification of risk events and the evaluation of their probability of occurrence and severity (Toth and Sebestyen, 2015). The detection of delay risk is essential to develop controlling strategies for the elimination and mitigation of risks (Samantra et al., 2017). Therefore, it is important to conduct studies to detect significant factors in schedule delay risk.

Most previous studies have been focused on the impact of the general risk on construction project objectives, and there is limited research on the schedule delay risk. The difference in the risk level of construction activities varies; therefore, the focus of the present study is to detect the delay risk in the lifecycle of a construction project in terms of both the typical and the overall risk occurrence and severity.

The Federal Democratic Republic of Ethiopia (FDRE) is one of the developing countries that relies on the construction industry to be a major contributor to its gross domestic product (GDP), expecting that development in the construction industry will improve growth in other sectors. However, this growth has not been achieved to the desired level owing to various problems, limitations, and drawbacks. In addition, delay has been reported to be highly common, occurring among 40% to 60% of the Ethiopian construction projects (Ayalew et al., 2016). The actual completion time of construction projects can vary substantially from the initial schedule, and this uncertainty is crucial to Ethiopian construction projects, because it exposes them to high risk. It is essential that the detection of schedule delay risk be considered throughout the construction process, as it contributes to the further evaluation of the typical and the overall risk impact in order to support the decision-making process for risk mitigation.

In this study, our aim is, primarily, to investigate the typical schedule delay risk throughout the construction lifecycle, which consists of the pre-construction, construction, and post-construction stages, and to compare the stages with each other. Second, the difference in the delay risk factors of criteria, sub-criteria, and attributes will be investigated in relation to the construction lifecycle for different types of organizations in Ethiopian construction projects. Finally, the multiple-criteria decision-making (MCDM) model of the FAHPCE will be combined with the RII method to detect the schedule delay risk in the lifecycle of construction projects.

2 Literature review

Construction project risk is the likelihood of event of any unexpected or disregarded occasions that can ruin the accomplishment of objectives (Adeleke et al., 2017). The degree of risk exposure to negative events and its potential consequences affects the construction project objectives that are expressed in terms of time, cost, scope, and quality (Luu et al., 2009). The most significant sources of risk include inefficient planning, unexpected ground utilities, design problems, delays in approvals, and delays in expropriations (El-Sayegh and Mansour, 2015).

The identification of sources and of the conditions under which risk occurs is the important step in risk detection. Construction project risk can be divided into different types, depending from the point of view. Delay is the greatest concern in construction projects worldwide, particularly owing to the effects of lengthened schedules and cost overruns that often jeopardize the quality and safety performance (González et al., 2014).

The detrimental effects of delay include late completion, increased cost, disruption, loss of productivity and quality, third-party claims, disputes, and termination of contracts (Mahamid et al., 2012). Delay is considered to have a major negative influence on projects and on participating parties (Abd El-Razek et al., 2008). Schedule delay risk has several attributes and can be easily influenced by various risk factors. The risk factors in construction project delay include poor project scope definition, project complexity, inadequate planning, impropriate project schedule, design variations, inaccurate engineering estimates, inaccuracies in the material estimate, material and equipment shortage, long lead-time items, shortage of skilled labor, poor labor productivity, and unpredictable weather conditions (Zou et al., 2007). The aforementioned delay risk factors have been classified into certain categories. One category includes factors that are related to clients, contractors, consultants, and designers. Another category is dedicated to the construction process, which comprises factors that are related to materials, workforce, and equipment. Next, environment-related factors, such as inclement weather, changes in government regulations and laws, traffic control and restriction at job site, and slow municipality permits, are exogenous factors. In addition, the category related to unrealistic contract duration, ineffective delay penalties, type of project bidding and award, and the type of construction contract are factors in this category. Finally, project-related factors are derived from the project characteristics and the project delivery system (Luu et al., 2009).

In most previous studies, great efforts have been made on the identification of construction project risk, and the focus was mainly placed on the examination of the impacts of risks on project objectives with respect to time, cost, and/or safety; however, only few studies have been focused on the assessment of the general schedule delay risk for construction projects.

Schedule delay risk has been investigated from a different perspective among certain countries owing to the fact that its effects differ from one country to another, from year to year, and from one project to another. Consequently, certain aforementioned studies investigate what the effects of delay risk entail (Luu et al., 2009; Toth and Sebestyen, 2015; Hossen et al., 2015; Gładysz et al., 2015; Ibrahim, 2011; Wang and Yuan, 2017). These effects have been studied in different countries; however, it is still a major concern in developing countries such as Ethiopia. This study addresses the typical delay risk and the relation between the typical schedule delay risk factors in the lifecycle of the construction project using systematic means of identification and minimization. The schedule delay risk can be expressed in two manners: (1) the delay of construction tasks or (2) project reworks (Wang and Yuan, 2017). However, this study is focused on the detection of the frequency of occurrence and the severity of the typical delay risk on construction activities and compares the impact levels of the stages with each other. The delay risk will be investigated throughout the lifecycle of the construction process to assess the degree of uncertainty and effect.

Risk is a measurable part of uncertainty through which the probability of occurrence and the severity can be estimated. Therefore, risk detection is important for project selection and coordination. Detection improves the decision-making process and gives further contentions, which help to choose the optimal variation of construction projects (Dziadosz and Rejment, 2015). Risk management has become an essential requirement and an important part of the decision-making process for construction projects (Abd El-Karim et al., 2017). Improper risk management has been found to be the cause of time overrun in construction projects (Koushki et al., 2005). Risk management is the precise procedure of identifying, analyzing, and responding to project risk; it incorporates boosting the likelihood and outcomes of positive attributes and limiting the likelihood and results of negative ascribes to project objectives (Abd El-Karim et al., 2017). Risk detection can be expressed as a part of risk management in a structured process to manage uncertainty (Gibson et al., 2003). The risk detection in construction projects is the most decisive stage of risk analysis. Quantitative risk detection is the identification of risks factors using the probability of occurrence and the severity (Mojtahedi et al., 2010).

In this work, the present authors will introduce the MCDM model of the FAHPCE and the RII to investigate the typical schedule delay risk in the lifecycle of construction projects. The RII can be considered as an independent index, the weight/score of which can be calculated by multiplying the frequency weight by the severity weight (Fallahnejad, 2013). The FAHPCE model will be used to obtain reliable results in evaluating alternatives usually in an uncertain environment (Saaty, 1980). A significant advantage of the FAHPCE model is its ability to generate weights and prioritize alternatives from the highest to lowest in hierarchy using expert judgment (Nguyen et al., 2015). The FAHPCE approach leads to reliable decisions and has strong evaluation abilities (Li et al., 2013).

In the present study, the difference in the criteria, sub-criteria, and attributes of delay risk factors in Ethiopian construction projects will be investigated using the MCDM model of the FAHPCE and the RII.

3 Research methodology

Risk assessment is a highly important management process to achieve the project objectives; this process includes the identification, prioritization, estimation, and evaluation of risk (Hossen et al., 2015). The process of risk assessment provides information on risk impacts for decision-making processes (Liu et al., 2014). The quantitative risk-assessment process evaluates individually identified project risks to detect risk factors based on agreed-upon characteristics (Hossen et al., 2015). In this study, the methods of the MCDM model of FAHPCE and the RII will be combined to detect the schedule delay risk in construction projects. In the research design, the MCDM model of the FAHPCE will be employed to detect the severity index and the overall risk impact of the schedule delay risk, whereas the RII will be employed to detect the frequency with which delay risk occurs. The combined approach includes the following crucial steps: (1) selection of significant delay risk factors, (2) identification of the RII value to evaluate the delay risk frequency occurrence, (3) calculation of the local weight using the FAHPCE to prioritize the severity of schedule delay risk, (4) use of the combined method of the FAHPCE weight with the RII to identify the risk index, and (5) the estimation of the overall risk impact that has been based on the fuzzy comprehensive evaluation and likelihood, as shown in Fig. 1.

3.1 Selection of significant delay risk factors

The selection of delay risk factors is important in determining the risk factors that affect the construction projects and their characteristics. It is based on evidence from previous experience that apply to the current case study. Moreover, it involves the identification of risk sources, events, and potential consequences (Hossen et al., 2015). An extensive literature review was conducted; based on this review, a sample questionnaire was developed. A pilot study was conducted in different organizations, where experienced participants were interviewed and responded to the aforementioned questionnaire. Detailed and inclusive information was obtained from the pilot study. The pilot study enabled the present authors to identify significant delay risk factors through the

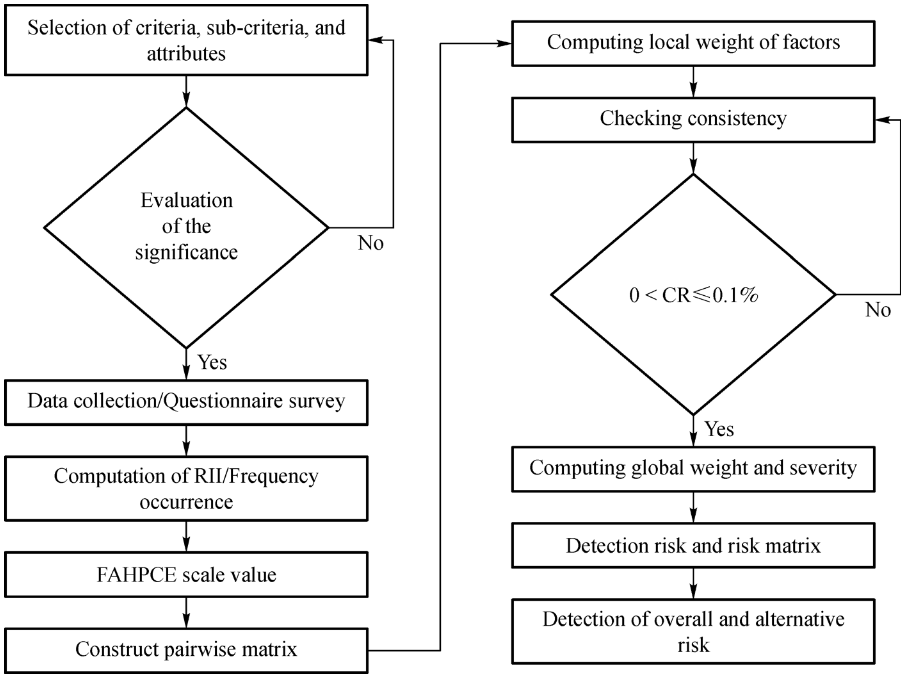

Fig. 1 Proposed model to detect delay risk factors in the construction lifecycle

professional knowledge and experience of the participants. Six professionals of higher ranked assessed the validity of the questionnaire to confirm clarity, completeness, and applicability in Ethiopian construction projects. Therefore, the main objective of in the selection of delay risks is to identify and classify the delay risk factors that are likely to affect the successful completion of construction projects. In the present research, the pre-construction stage consisted of activities pertaining to the feasibility study, the reconnaissance, the data collection for design, the design, the planning, the procurement, and the project sites handover. The construction stage included activities pertaining to the mobilization, the site organization, the execution of construction activities, and the inspection of time, cost, and quality. The activities in post-construction stage included the identification of defect liability, the rework and maintenance of defects, the inspection of the completion of works, the approval, the taking-over final certificate, the claims and disputes, and the closing of contractual activities. Then the factors in the index system for the evaluation of the delay risk in a construction projects (Table 1) were carefully selected according to the

Table 1 The index system for the evaluation of delay risk factors in a construction project

Goal	Criteria	Sub-criteria	Alternatives
Construction project delay factors	Responsibility-Related (A)	Client-related (A1)	Lack of on-time finance and payments of completed work (A11)
			Interference in the execution of the work (A12)
			Slowness in decision making (A13)
			Late site delivery for construction work and design (A14)
			Improper project feasibility study (A15)
			Poor communication and coordination with other parties (A16)
		Contractor-related (A2)	Subcontractor-related problems (A21)
			Poor site management and performance (A22)
			Ineffective project planning and scheduling (A23)
			Inappropriate construction methods (A24)
			Poor communication and coordination with other parties (A25)
			Inadequate contractor experience (A26)
			Rework for the correction of unsatisfactory work (A27)

(*Continued*)

Goal	Criteria	Sub-criteria	Alternatives
		Consultant-related (A3)	Inadequate experience of consultant (A31)
			Late in approving and receiving a complete project work (A32)
			Poor supervision and late in performing inspection and testing (A33)
			Poor communication and coordination with other parties (A34)
		Designer-related (A4)	Unclear and inadequate details and specification of design (A41)
			Late design and design documents (A42)
			Design mistakes and errors (A43)
			Misunderstanding of client requirements (A44)
	Resource-Related (B)	Material-related (B1)	Lack of quality materials (B11)
			Slow delivery of material (B12)
			Changes in material types and specifications (B13)
			Damage of materials (B14)
			Inflation/price increase in materials (B15)
		Finance-related (B2)	Problem in the processing of financial claims (B21)
			Government funding processes (B22)
			Late-release budget/funds (B23)
			Global financial crisis (B24)
		Labor-related (B3)	Low productivity (B31)
			Less motivation and lower morale (B32)
			Unqualified/inexperienced workers (B33)
			Discipline problem (conflicts and absenteeism) (B34)
			Labor accidents and injuries (B35)
		Equipment-related (B4)	Insufficient or shortage of equipment (B41)
			Low efficiency and productivity of equipment (B42)
			Failures of equipment and lack of spare parts (B43)
			Equipment allocation or mobilization problem (B44)
			Outdated equipment (B45)
	Contract-Related (C)		Absence of alternative dispute resolution (ADR) on contract (C1)
			Mistakes & discrepancies/ambiguities in contract documents (C2)
			Unrealistic contract durations and cost (C3)
			Inadequate delay penalties/poor incentives in contract (C4)
			Insufficient details in contract documents (C5)
			Lack of clear understanding of contract documents (C6)
	External-Related (D)		Adverse weather conditions (D1)
			Force majeure (acts of God) (D2)
			Corruption (D3)
			Effect of social and cultural factors (D4)
			Government policy and commitment (D5)
			Unavailability of utilities on site (D6)

literature review and the pilot study. The selection was based on the influence that directly or indirectly fitted to the classified activities of construction. However, the impact level of the factors is entirely different among the activities, which is highly important in the decision making that pertains to the schedule delay risk. Accordingly, a questionnaire with 4 criteria, 8 sub-criteria, and 52 attributes was developed to detect the delay risk level for each of the pre-construction, construction, and post-construction stages, as summarized in Table 1.

3.2 The RII

The RII is a statistical method that is used for the interpretation of the collected data (El-Sayegh, 2008). The RII was used for the assessment of the frequency occurrence of schedule delay risk in pre-construction, construction, and post-construction in Ethiopian construction projects. The RII value ranged from 0 to 1 (0 not included); the higher the value of the RII, the higher the frequency occurrence of the schedule delay risk factor. The five-point Likert scale — ranging from 1 (very low level of impact) to 5 (very high level of impact) — was adopted, which was then transformed to the RII of each factor using Eq. (1). In Eq. (1), i is the category index (in our case 1, 2, 3, 4, and 5), W_i is the weight assigned to each factors by the respondents (ranging from 1 to 5), F_i is the frequency of the respondent for each weight, A is the highest weight value (i.e., 5), and N is the total number of respondents.

$$\mathrm{RII} = \frac{W_i F_i}{AN}. \tag{1}$$

3.3 The FAHPCE approach

The FAHPCE method is a MCDM that assesses both qualitative and quantitative analyses, which has a strong evaluation ability and is important in terms of providing reliable decision-making information (Zeng et al., 2007). The FAHPCE method considers the influence of several factors and minimizes the impact of artificial factors (Lee, 2014). In this study, quantitative and qualitative analysis was conducted through the FAHPCE approach, and was based on expert judgment. The procedure of the FAHPCE approach for the detection of the local weights and for the comprehension of the overall delay risk consists of the following steps: 1) setting criteria, sub-criteria, and attributes; 2) development of a pairwise comparison matrix; 3) finding a normalized weight or a local weight; 4) checking the consistency; and 5) performing a comprehensive and multi-comprehensive evaluation to estimate the overall schedule delay risk of the construction project. Details on the aforementioned steps of this decision-support system are described below.

1) Setting criteria, sub-criteria, and attributes. The FAHPCE enables the decision makers to structure a complex problem in the form of a simple hierarchy in order to evaluate a large number of quantitative and qualitative risk factors in a systematic manner under multiple conflicting criteria (Lee, 2014). In this step of the FAHPCE, the complex problem was segmented into a hierarchy of criteria, sub-criteria, and attributes of delay risk factor, as listed in Table 1.

2) Development of a pairwise comparison matrix. A matrix of the pairwise comparison between the risk factors in the hierarchy was built by the FAHPCE. The pairwise matrix was constructed from expert judgment. The local weight of the factors was computed based on the pairwise comparison matrix. To determine the local weight of the factors in the matrix, the responses in the five-point Likert scale were converted to correspond to a nine-point scale, as summarized in Table 2.

Table 2 The scale of the pairwise comparison matrix

Linguistic variables	Fuzzy number
Very low level of impact	1
Low level of impact	3
Medium level of impact	5
High level of impact	7
Very high level of impact	9

The pairwise comparison matrix was constructed based on the rating of the respondents, as shown in Eq. (2), where A is the pairwise matrix of the delay risk factors, a_{ij} represents the elements of the pairwise matrix in column i and row j, and corresponds to the rated weight of the risk factors, and $W = (w_1, w_2, ..., w_n)$, where $(i,j = 1,2, ..., n)$, and n is the number of factors in the hierarchy.

$$A = \begin{bmatrix} 1 & \frac{w_1}{w_2} & \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & 1 & \cdots & \frac{w_2}{w_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \cdots & 1 \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}. \tag{2}$$

3) Estimation of the normalized weight. The normalized weights for each delay risk factor in the hierarchy were detected according to their perceived contribution to an unsafe situation during the construction phase (Amin-

bakhsh et al., 2013). The normalized weight was computed from the pairwise comparison matrix of the FAHPCE using the mean method to represent the local weight. The weights of each pairwise comparison matrix of a row or a column ($\overline{w}$) is divided by the sum of each row or column ($\sum_{i=1}^{n} \overline{w}_i$) to obtain each normalized weight, as shown in Eq. (3). The highest value of the local weight, w_i, indicates the highest risk factor and vice versa. In Eq. (3), w_i is the normalized weight from the cumulative weight of $\overline{w} = (\overline{w}_1,\overline{w}_2,...,\overline{w}_n)$.

$$w_i = \frac{\overline{w}_i}{\sum_{i=1}^{n} \overline{w}_i} \quad and$$

$$\overline{w}_i = \sum_{j=1}^{n} a_{ij}(i = 1,2,...) \ and \ (j = 1,2,3,...,n). \quad (3)$$

4) Checking consistency. Consistency determines whether the judgment of decision makers is consistent or not (Zhu et al., 2016). The consistency index (*CI*) was calculated via Eq. (4). Next, the consistency ratio (*CR*) was calculated by comparing the *CI* with random indexing (*RI*), which was randomly generated. In general, if the *CR* is found to be greater than or equal to zero and less than or equal to 0.1, the judgment is consistent (Lee, 2014).

$$CR = \frac{CI}{RI} \ and \ CI = \frac{\ddot{e}_{\max} - n}{n-1},$$

$$\text{where } \ddot{e}_{\max} = \sum_{i}^{n} a_{ij} \cdot w_i. \quad (4)$$

5) Establishing the element set and the grade factor. According to the characteristics of the index system of delay risk factors, the element set is $U = \{u_1,u_2,...,u_n\}$, $u_i = (i = 1,2,...,n)$, whereas the five-grade factor can be determined as $V = \{v_1,v_2,v_3,v_4,v_5\}$, which represents very low, low, medium, high, and very high levels of impact, respectively.

6) Constructing the membership degree matrix "*R*" from *U* to *V*. The membership degree matrix is used to present the evaluation results of the object. The membership degree vector, R_i, can be expressed using Eq. (5), where n represents the attributes, k is the grade factor, r_i is the rate provided by the respondents for the grade factor, N is the total number of respondents, and R_i represents the membership degree matrix. The sum of the elements in each row of the membership degree matrix should be equal to one; $\sum_{i=1}^{n} r_{ik} = 1, r_i \geqslant 0, \{i = 1,2,...,n\}$ and $\{k = 1,2,3,4,5\}$:

$$r_{ik} = \frac{r_i}{N}, \text{ then } R_i = \begin{bmatrix} r_{11} & r_{12} & r_{13} & r_{14} & r_{15} \\ r_{21} & r_{22} & r_{23} & r_{24} & r_{25} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ r_{n1} & r_{n2} & r_{n3} & r_{n4} & r_{n5} \end{bmatrix}. \quad (5)$$

7) Comprehensive and multi-comprehensive evaluation. The comprehensive evaluation method compiles the membership matrix of the delay risk factors with the FAHPCE relative weight of the sub-criteria. This evaluation is performwhere W_i is the normalized weight of the sub-criteria, R_i is the membership degree matrix, and B_i is the comprehensive result of the prioritized sub-criteria, namely $\{b_{i1} \ b_{i2} \ b_{i3} \ b_{i4} \ b_{i5}\}$.

$$B_i = W_i \cdot R_i = \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} \begin{bmatrix} r_{11} & r_{12} & r_{13} & r_{14} & r_{15} \\ r_{21} & r_{22} & r_{23} & r_{24} & r_{25} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ r_{n1} & r_{n2} & r_{n3} & r_{n4} & r_{n5} \end{bmatrix}$$

$$= [b_{i1} \ b_{i2} \ b_{i3} \ b_{i4} \ b_{i5}]. \quad (6)$$

The multi-comprehensive evaluation is used as input to detect the overall risk level and the risk at the different alternatives, and is computed via on Eq. (7), where B_i is the prioritized weight of the criteria $\{b_{i1} \ b_{i2} \ b_{i3} \ b_{i4} \ b_{i5}\}$, R_i is the matrix of the sub-criteria from the comprehensive evaluation, and W_i is the normalized weight of the criteria from the pairwise matrix of the FAHPCE.

$$B_i = W_i \cdot R_i = \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} \begin{bmatrix} b_{11} & b_{12} & b_{13} & b_{14} & b_{15} \\ b_{21} & b_{22} & b_{23} & b_{24} & b_{25} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ b_{n1} & b_{n2} & b_{n3} & b_{n4} & b_{n5} \end{bmatrix}$$

$$= [b_{i1} \ b_{i2} \ b_{i3} \ b_{i4} \ b_{i5}]. \quad (7)$$

3.4 Risk evaluation based on the frequency occurrence and the severity

Risk severity was detected based on the local and global weights that had been determined from the FAHPCE. Local weights indicate the relative importance levels of risk factors within the group, whereas global weights prioritize the factor with respect to the schedule delay risk. The global weight of attributes was calculated by multiplying the local weight of the criteria, sub-criteria, and attribute with one another. In addition, the global weight of the sub-criteria was calculated by multiplying the local weight of the criteria and that of the sub-criteria. The global weight was then converted to severity based on the severity scale (very low = 0.05, low = 0.10, moderate = 0.20, high = 0.40, and very high = 0.80 (Hossen et al. 2015). The risk factor with the highest global weight was assigned a severity value of 0.8, and the risk factor with the lowest global weight was assigned a severity value of 0.05. Then, the severity values of the remaining risk factors were determined using linear interpolation. After obtaining the severity and the frequency occurrence, the frequency–severity matrix was used for the prioritization of delay risk factors based on Table 3. In the matrix, the risk levels of the factors were classified as high-, medium-, and low-risk, as summarized in Table 3.

3.5 Probability of risk occurrence

To detect the probability level of delay risk occurrence, the severity obtained from the linear interpolation is required to be combined with the frequency occurrence obtained from the RII value of the risk factors (Hossen et al., 2015). The risk index probability of the projects may be expressed as in Eq. (8).

$$\text{Risk} = \text{Severity of delay factor} \times \text{Frequency of occurrence of delay factor}. \quad (8)$$

The overall project delay risk and the alternative factor delay risk were determined by multiplying the multi-comprehensive result with the likelihood (Wu et al., 2010). The identified risks were divided into low-, medium-, and high-class based on the equal risk curve method. The low-class risk (less than 0.3) indicates a slight effect on the project target. The medium-class risk (0.3 to 0.7) and the high-class risk (0.7 and above) have a strongly negative impact on the achievement of the project objective (Wu et al., 2010). The overall level of risk probability (P_f) may be expressed as in Eq. (9), where V is the likelihood or the linguistic number and B_i is the multi-comprehensive result of factor $i = 1, 2,...,n$.

$$P_f = V^{\mathrm{T}} \times B_i = \{B_1, B_2, B_3, ..., B_n\} \times (V_1, V_2, V_3, ..., V_n)^{\mathrm{T}}. \quad (9)$$

4 Results and discussion

The study is demonstrated through a descriptive case of Ethiopian construction projects. To collect data, the participating organizations and experts were selected based on purposive sampling of their experience in different regional states. The respondents were experienced and they worked as managers, contractors, consultants, clients, engineers, designers, surveyors, and other related positions. The data were collected from 77 different participants. For the questionnaire survey, the five-point Likert scale was employed, where each point from one to five corresponded to a very low (1), low (2), medium (3), high (4), and very high (5) level of impact.

The local and global weight of the criteria, sub-criteria, and attributes of the delay risk factors in Ethiopian construction projects were computed, and are listed in Tables 4 and 5. The frequency occurrence and the severity were computed based on the RII value and the FAHPCE, respectively and are listed in Tables 6 and 7. The multiplication of the severity and the frequency occurrence of the delay risk prioritized the risk of the criteria,

Table 3 Frequency–Severity matrix

		Severity				
		$0 < S \leqslant 0.05$	$0.05 < S \leqslant 0.1$	$0.1 < S \leqslant 0.2$	$0.2 < S \leqslant 0.4$	$0.4 < S \leqslant 0.8$
Frequency	$0.7 < P \leqslant 0.9$	Low	Medium	High	High	High
	$0.5 < P \leqslant 0.7$	Low	Medium	Medium	High	High
	$0.3 < P \leqslant 0.5$	Low	Low	Medium	High	High
	$0.1 < P \leqslant 0.3$	Low	Low	Medium	Medium	High
	$0 < P \leqslant 0.1$	Low	Low	Low	Low	Medium

Table 4 Global and local weights on the criteria and sub-criteria of the construction lifecycle

					Pre-construction		Construction		Post-construction	
	Global Weight	Global Weight	Global Weight		Local Weight	Global Weight	Local Weight	Global Weight	Local Weight	Global Weight
A	0.3182	0.35	0.3182	A1	0.3462	0.110	0.3889	0.1361	0.3182	0.1012
				A2	0.2692	0.0857	0.2778	0.0972	0.3182	0.1012
				A3	0.1923	0.0612	0.2778	0.0972	0.2273	0.0723
				A4	0.1923	0.0612	0.0556	0.0194	0.1364	0.0434
B	0.3182	0.25	0.3182	B1	0.45	0.1432	0.35	0.0875	0.4375	0.1392
				B2	0.35	0.1114	0.35	0.0875	0.4375	0.1392
				B3	0.15	0.0477	0.15	0.0375	0.0625	0.0199
				B4	0.05	0.0159	0.15	0.0375	0.0625	0.0199
C	0.2273	0.25	0.2273							
D	0.1364	0.15	0.1364							

Table 5 Global and local weights on the attributes of the construction lifecycle

Attributes	Pre-construction		Construction		Post-construction	
	Local Weight	Global Weight	Local Weight	Global Weight	Local Weight	Global Weight
A11	0.1471	0.0162	0.2917	0.0397	0.2778	0.0281
A12	0.2059	0.0227	0.2083	0.0284	0.1667	0.0184
A13	0.0882	0.0097	0.125	0.0170	0.0556	0.0062
A14	0.2059	0.0227	0.2083	0.0284	0.2778	0.0306
A15	0.2647	0.0292	0.125	0.0170	0.1667	0.0184
A16	0.0882	0.0097	0.0417	0.0057	0.0556	0.0062
A21	0.1111	0.0095	0.1707	0.0166	0.2	0.0203
A22	0.2593	0.0222	0.2195	0.0213	0.2	0.0203
A23	0.3333	0.0286	0.1220	0.0119	0.1556	0.0158
A24	0.1111	0.0095	0.1707	0.0166	0.0667	0.0068
A25	0.0370	0.0032	0.0732	0.0071	0.0667	0.0068
A26	0.1111	0.0095	0.1707	0.0166	0.1556	0.0158
A27	0.0370	0.0032	0.0732	0.0071	0.1556	0.0158
A31	0.2273	0.0139	0.1364	0.0133	0.1154	0.0083
A32	0.3182	0.0195	0.3182	0.0309	0.3462	0.0250
A33	0.2273	0.0139	0.2273	0.0221	0.2692	0.0195
A34	0.2273	0.0139	0.3182	0.0309	0.2692	0.0195
A41	0.3	0.0184	0.2692	0.0052	0.25	0.0109
A42	0.3	0.0184	0.3462	0.0067	0.35	0.0152
A43	0.3	0.0184	0.2692	0.0052	0.25	0.0109
A44	0.1	0.0061	0.1154	0.0022	0.15	0.0066
B11	0.2195	0.0314	0.2432	0.0213	0.2432	0.0339
B12	0.2195	0.0314	0.2432	0.0213	0.2432	0.0339
B13	0.1707	0.0245	0.1892	0.0166	0.1351	0.0188
B14	0.1707	0.0245	0.0811	0.0071	0.1351	0.0188
B15	0.2195	0.0314	0.2432	0.0213	0.2432	0.0339
B21	0.2692	0.0300	0.25	0.0219	0.219	0.0305
B22	0.2692	0.0300	0.1786	0.0156	0.281	0.0392
B23	0.2692	0.0300	0.3214	0.0281	0.281	0.0392
B24	0.1923	0.0214	0.25	0.0219	0.219	0.0305
B31	0.2941	0.0140	0.1579	0.0059	0.2308	0.0046
B32	0.1765	0.0084	0.2632	0.0099	0.2308	0.0046
B33	0.4118	0.0197	0.3684	0.0138	0.3846	0.0077
B34	0.0588	0.0028	0.0526	0.0020	0.0769	0.0015
B35	0.0588	0.0028	0.1579	0.0059	0.0769	0.0015
B41	0.4546	0.0072	0.4286	0.0161	0.4667	0.0093
B42	0.2728	0.0043	0.4286	0.0161	0.3333	0.0066
B43	0.0909	0.0014	0.0476	0.0018	0.0667	0.0013
B44	0.0909	0.0014	0.0476	0.0018	0.0667	0.0013
B45	0.0909	0.0014	0.0476	0.0018	0.0667	0.0013
C1	0.05	0.0114	0.0455	0.0114	0.1786	0.0406
C2	0.05	0.0114	0.0455	0.0114	0.0357	0.0081
C3	0.25	0.0568	0.3182	0.0796	0.25	0.0568

(*Continued*)

Attributes	Pre-construction		Construction		Post-construction	
	Local Weight	Global Weight	Local Weight	Global Weight	Local Weight	Global Weight
C4	0.15	0.0341	0.2273	0.0568	0.25	0.0568
C5	0.25	0.0568	0.2273	0.0568	0.1786	0.0406
C6	0.25	0.0568	0.1364	0.0341	0.1071	0.0244
D1	0.1	0.0136	0.0385	0.0058	0.0333	0.0046
D2	0.1	0.0136	0.0385	0.0058	0.1	0.0136
D3	0.3	0.0409	0.3462	0.0519	0.3	0.0409
D4	0.0333	0.0046	0.0385	0.0058	0.0333	0.0046
D5	0.1667	0.0227	0.1923	0.0289	0.2333	0.0318
D6	0.3	0.0409	0.3462	0.0519	0.3	0.0409

Table 6 Severity and frequency occurrence of sub-criteria of the schedule delay factors

Sub-criteria	Pre-construction		Construction		Post-construction	
	Severity	RII	Severity	RII	Severity	RII
A1	0.6053	0.6346	0.8	0.6448	0.5614	0.6104
A2	0.4611	0.6097	0.8	0.6371	0.5614	0.6039
A3	0.3168	0.5937	0.8	0.6354	0.3796	0.5916
A4	0.3168	0.5803	0.05	0.6051	0.1977	0.5591
B1	0.8	0.6406	0.8	0.6602	0.8	0.6293
B2	0.8	0.6021	0.8	0.6461	0.8	0.6210
B3	0.8	0.5615	0.1661	0.6067	0.05	0.5463
B4	0.05	0.5458	0.2241	0.6011	0.05	0.5431

Table 7 Severity and frequency occurrence of the attributes of schedule delay factors

Attributes	Pre-construction		Construction		Post-construction	
	Severity	RII	Severity	RII	Severity	RII
A11	0.2498	0.5893	0.4157	0.6348	0.4122	0.5855
A12	0.3376	0.6088	0.3063	0.6167	0.2802	0.5567
A13	0.1620	0.6270	0.1969	0.5886	0.1148	0.5387
A14	0.3376	0.6105	0.3063	0.6192	0.4456	0.5804
A15	0.4253	0.6676	0.1969	0.5881	0.2802	0.5719
A16	0.0578	0.5549	0.0546	0.5831	0.0559	0.5212
A21	0.0576	0.5677	0.0676	0.6418	0.0733	0.6353
A22	0.0695	0.6092	0.0732	0.6743	0.0733	0.6571
A23	0.0755	0.6897	0.0619	0.6333	0.0678	0.6061
A24	0.0576	0.5531	0.0674	0.6486	0.0565	0.5541
A25	0.0516	0.5514	0.0563	0.5973	0.0565	0.5565
A26	0.0576	0.5735	0.0674	0.6613	0.0672	0.6090
A27	0.0516	0.5172	0.0563	0.6028	0.0672	0.6091
A31	0.0617	0.5750	0.0635	0.6081	0.0584	0.5647
A32	0.0669	0.6242	0.0842	0.6553	0.0783	0.6686
A33	0.0617	0.5839	0.0739	0.632	0.0717	0.6114
A34	0.0617	0.5917	0.0842	0.6462	0.0717	0.5971

(*Continued*)

Attributes	Pre-construction		Construction		Post-construction	
	Severity	RII	Severity	RII	Severity	RII
A41	0.0659	0.6583	0.0541	0.6553	0.0614	0.5810
A42	0.0659	0.6658	0.0558	0.6732	0.0666	0.6226
A43	0.0659	0.6394	0.0541	0.6479	0.0614	0.5897
A44	0.0544	0.575	0.0505	0.6030	0.0562	0.5733
B11	0.0782	0.6343	0.0729	0.6879	0.0889	0.6414
B12	0.0782	0.6457	0.0729	0.6768	0.0889	0.6367
B13	0.0716	0.6164	0.0673	0.6364	0.0709	0.59
B14	0.0716	0.6235	0.0562	0.6135	0.0709	0.5869
B15	0.0782	0.6831	0.0729	0.6865	0.0889	0.65
B21	0.0768	0.5941	0.0736	0.6329	0.0848	0.6310
B22	0.0768	0.6	0.0663	0.632	0.0952	0.6381
B23	0.0768	0.620	0.0809	0.6754	0.0952	0.6433
B24	0.0688	0.5940	0.0736	0.6441	0.0848	0.6068
B31	0.0618	0.5882	0.0549	0.6107	0.0539	0.5516
B32	0.0566	0.5581	0.0595	0.6192	0.0539	0.5559
B33	0.0671	0.6539	0.0641	0.6494	0.0576	0.5788
B34	0.0513	0.4899	0.0502	0.5260	0.0502	0.5238
B35	0.0513	0.5175	0.0549	0.6	0.0502	0.5212
B41	0.0554	0.5778	0.0668	0.6632	0.0595	0.5911
B42	0.0527	0.5594	0.0668	0.6727	0.0563	0.5815
B43	0.05	0.5508	0.05	0.5730	0.05	0.5302
B44	0.05	0.528	0.05	0.5816	0.05	0.5188
B45	0.05	0.5129	0.05	0.5432	0.05	0.4939
C1	0.0564	0.5467	0.0566	0.5714	0.0933	0.5815
C2	0.0564	0.5206	0.0566	0.5811	0.0543	0.5516
C3	0.0993	0.582	0.1372	0.6448	0.1128	0.6035
C4	0.0779	0.5647	0.1103	0.6139	0.1128	0.6033
C5	0.0993	0.5913	0.1103	0.6343	0.0933	0.5759
C6	0.0993	0.5864	0.0835	0.6118	0.0738	0.5746
D1	0.0586	0.575	0.05	0.5842	0.05	0.5365
D2	0.0586	0.5544	0.05	0.5672	0.0609	0.5536
D3	0.0843	0.7273	0.1045	0.7781	0.0937	0.7576
D4	0.05	0.54	0.05	0.56	0.05	0.5508
D5	0.05	0.5970	0.05	0.6328	0.05	0.6167
D6	0.05	0.6781	0.5336	0.7371	0.5850	0.6730

sub-criteria, and attributes, as listed in Tables 8 and 9. The risk of the criteria, which consist of responsibility-, resource-, contract condition-, and external-related criteria and are represented by {A, B, C, D}, respectively, under the alternatives of pre-construction, construction, and post-construction are listed in Table 10. The overall delay risk of alternatives and the delay risk in Ethiopian construction projects are ranked based on the combined method of the fuzzy multi-comprehensive evaluation and likelihood, and are listed in Table 11.

4.1 Detection of delay risk at the pre-construction stage

The pre-construction stage presents the lowest delay risk alternative, with an occurrence probability level of 0.3033, as listed in Table 11. The highest-risk criteria, which are responsibility-related (0.4837) and these criteria consists the high-risk sub-criteria: client, contractor, consultant, and designer related, in the order of highest to lowest risk (Table 8 and Table 10). The second most critical high-risk criteria, which are resource-related (0.47) have the high-risk sub-criteria: construction material, finance, and labor related, in the order of highest to lowest risk (Table 8 and Table 10). The third most important high-risk criteria are related to the contract conditions (0.4522) under these criteria the following medium-risk attributes exist: insufficient details in contract documents, lack of clear understanding of contract documents, and unrealistic contract durations and cost (Table 9 and Table 10). However, external-related criteria are low-risk criteria with low-risk attributes (Table 9 and Table 10).

4.2 Detection of delay risk on construction stage

The construction stage presents the highest occurrence probability level (0.3238) of delay risk alternative, as observed in Table 11. At the construction stage, the highest-risk criteria are responsibility-related (0.5045) and these criteria contains a high-risk sub-criteria: client-, consultant-, and contractor-related in order of highest to

Table 8 Risk and risk matrix of the sub-criteria of the schedule delay factors

Sub-criteria	Pre-construction			Construction			Post-construction		
	Risk	Rank	Matrix	Risk	Rank	Matrix	Risk	Rank	Matrix
A1	0.3841	4	H	0.5159	3	H	0.3427	3	H
A2	0.2811	5	H	0.5097	4	H	0.339	4	H
A3	0.1881	6	H	0.5083	5	H	0.2246	5	H
A4	0.1839	7	H	0.0303	8	L	0.1105	6	H
B1	0.5125	1	H	0.5282	1	H	0.5034	1	H
B2	0.4817	2	H	0.5169	2	H	0.4968	2	H
B3	0.4492	3	H	0.1008	7	M	0.0273	7	L
B4	0.0273	8	L	0.1347	6	H	0.0272	8	L

Table 9 Risk rank and risk matrix of the attributes of the schedule delay factors

Attribute	Pre-construction			Construction			Post-construction		
	Risk	Rank	Matrix	Risk	Rank	Matrix	Risk	Rank	Matrix
A11	0.1472	4	H	0.2639	2	H	0.2413	3	H
A12	0.2055	3	H	0.1889	4	H	0.156	5	H
A13	0.1016	5	M	0.1159	5	M	0.0618	9	M
A14	0.2061	2	H	0.1897	3	H	0.2586	2	H
A15	0.284	1	H	0.1158	6	M	0.1602	4	H
A16	0.0321	36	M	0.0318	43	M	0.0291	45	M
A21	0.0327	34	M	0.0434	26	L	0.0466	21	M
A22	0.0423	23	M	0.0493	17	M	0.0482	20	M
A23	0.0521	11	M	0.0392	30	M	0.0411	28	M
A24	0.0319	38	L	0.0437	25	M	0.0313	40	M
A25	0.0285	45	L	0.0336	38	M	0.0314	39	M
A26	0.033	33	M	0.0446	23	M	0.041	30	M
A27	0.0267	48	L	0.0339	37	M	0.041	29	M

(*Continued*)

Attribute	Pre-construction			Construction			Post-construction		
	Risk	Rank	Matrix	Risk	Rank	Matrix	Risk	Rank	Matrix
A31	0.0355	30	M	0.0386	31	M	0.033	36	M
A32	0.0418	25	M	0.0552	11	M	0.0524	18	M
A33	0.036	29	M	0.0467	20	M	0.0438	22	M
A34	0.0365	27	M	0.0544	13	M	0.0428	23	M
A41	0.0434	22	M	0.0354	34	L	0.0357	32	M
A42	0.0439	21	M	0.0376	32	M	0.0414	27	M
A43	0.0421	24	M	0.035	35	L	0.0362	31	M
A44	0.0313	40	M	0.0305	45	L	0.0322	38	M
B11	0.0496	13	M	0.0501	15	M	0.057	13	M
B12	0.0505	12	M	0.0493	18	M	0.0566	14	M
B13	0.0441	18	M	0.0429	27	M	0.0418	25	M
B14	0.0447	17	M	0.0345	36	M	0.0416	26	M
B15	0.0534	10	M	0.05	16	M	0.0578	12	M
B21	0.0457	16	M	0.0466	21	M	0.0533	17	M
B22	0.0461	15	M	0.0419	28	M	0.0607	11	M
B23	0.0476	14	M	0.0546	12	M	0.0612	10	M
B24	0.0408	26	M	0.0474	19	M	0.0515	19	M
B31	0.0364	28	M	0.0335	39	L	0.0297	44	L
B32	0.0316	39	M	0.0368	33	M	0.03	42	L
B33	0.0439	20	M	0.0416	29	M	0.0333	35	M
B34	0.0251	52	L	0.0264	52	L	0.0263	49	L
B35	0.0265	49	L	0.0329	40	L	0.0262	50	L
B41	0.032	37	L	0.0443	24	M	0.0352	33	M
B42	0.0295	43	L	0.045	22	M	0.0328	37	M
B43	0.0275	46	L	0.0287	48	L	0.0265	48	L
B44	0.0264	50	L	0.0291	47	L	0.0259	51	L
B45	0.0256	51	L	0.0272	51	L	0.0247	52	L
C1	0.0309	41	M	0.0324	42	M	0.0542	15	M
C2	0.0294	44	M	0.0329	41	M	0.0299	43	L
C3	0.0578	9	M	0.0884	7	M	0.0681	7	M
C4	0.044	19	M	0.0677	10	M	0.068	8	M
C5	0.0587	7	M	0.07	9	M	0.0537	16	M
C6	0.0582	8	M	0.0511	14	M	0.0424	24	M
D1	0.0337	32	M	0.0292	46	L	0.0268	47	L
D2	0.0325	35	M	0.0284	49	L	0.0337	34	M
D3	0.0613	6	M	0.0813	8	H	0.071	6	M
D4	0.027	47	L	0.028	50	L	0.0275	46	L
D5	0.0299	42	L	0.0316	44	L	0.0308	41	L
D6	0.0339	31	L	0.3933	1	H	0.3937	1	H

Table 10 Risk rank and risk matrix of the criteria of the schedule delay factors

Criteria	Pre-construction			Construction			Post-construction		
	Risk	Rank	Matrix	Risk	Rank	Matrix	Risk	Rank	Matrix
A	0.4837	1	H	0.5045	1	H	0.4730	1	H
B	0.4700	2	H	0.5028	2	H	0.0293	3	L
C	0.4522	3	H	0.4876	3	H	0.0291	4	L
D	0.0306	4	L	0.0322	4	L	0.0307	2	L

Table 11 Occurrence probability of the risk in alternative and Ethiopian construction projects

Construction lifecycle	Likelihood					Risk occurrence
	0.1	0.2	0.3	0.4	0.5	
Pre-construction	0.1102	0.2544	0.2871	0.1891	0.1593	0.3033
Construction	0.0829	0.2182	0.2621	0.2519	0.1849	0.3238
Post-construction	0.0995	0.2480	0.2871	0.1970	0.1684	0.3087
Overall construction	0.0978	0.2411	0.2797	0.2108	0.1705	0.3115

lowest (Table 8 and Table 10). The second-in-order high-risk criteria are resource-related (0.5028) and these criteria have the high-risk sub-criteria: construction material-, finance-, and equipment-related, in the order of highest to lowest risk (Table 8 and Table 10). The third-in-order high-risk criteria are related to the contract conditions (0.4876) these criteria have the medium-risk attributes: unrealistic contract duration and cost, insufficient details in contract documents, and inadequate delay penalties/poor incentives in the contract (Table 10 and Table 9). However, external-related criteria are low-risk criteria, with only the two high-risk attributes of corruption and unavailability of utilities on site (Table 9 and Table 10).

4.3 Detection of delay risk at the post-construction stage

The post-construction stage is the second highest risk alternative with an occurrence probability level of delay risk of 0.3087 (Table 11). At this stage, the high-risk criteria are only responsibility-related (0.4730) and these criteria consist the high-risk sub-criteria: client-, contractor-, consultant-, and designer-related, in the order of highest to lowest risk (Table 10 and Table 8). However, resource-related criteria are low-risk, with only two high-risk sub-criteria, namely the material- and finance-related (Table 8 and Table 10). The contract condition-related criteria are low-risk criteria with five medium risks, and only one low-risk sub-criterion (Table 8 and Table 10). External-related criteria are low-risk criteria with only one high-risk attribute, namely that of unavailability of utilities on site, two medium-risks, and three low-risks attributes (Table 9 and Table 10).

4.4 Comparison of delay risk at each stage of construction

According to the risk matrix in Table 8, among the attributes at the pre-construction stage, there are 4 high-risk, 35 medium-risk, and 13 low-risk factors. At the construction stage, there are 5 high-risk, 33 medium-risk, and 14 low-risk factors among the attributes. At the post-construction stage, there are 5 high-risk, 36 medium-risk, and 11 low-risk factors among the attributes. From the combination of the multi-comprehensive evaluation matrix and the likelihood results in Table 11, the construction stage (0.3238) presents a high level of delay risk occurrence; the post-construction stage presents the second highest probability of occurrence of delay risk (0.3087) and the pre-construction stage presents the lowest probability of occurrence of delay risk (0.3033). As a result, it is evident that the risk impact differences at the different stages of construction are exist; however, the typical risk in terms of type or level at each stage in the construction project lifecycle is important. These differences provide noteworthy information about the delay risk mitigation in Ethiopian construction projects by identifying the appropriate level of risk at the appropriate activity in order to make the right decision. In the present study, the delay risk level in Ethiopian construction projects was detected. Ethiopian construction projects have been facing an average of 0.3115 of occurrence probability of delay risk (Table 11). Figures 2 and 3 illustrate the severity versus the frequency occurrence graphs for the sub-criteria and the attributes, respectively. By analyzing the severity and the frequency-occurrence matrix, the following risk levels were determined for the delay factors: high (H), medium (M), and low (L).

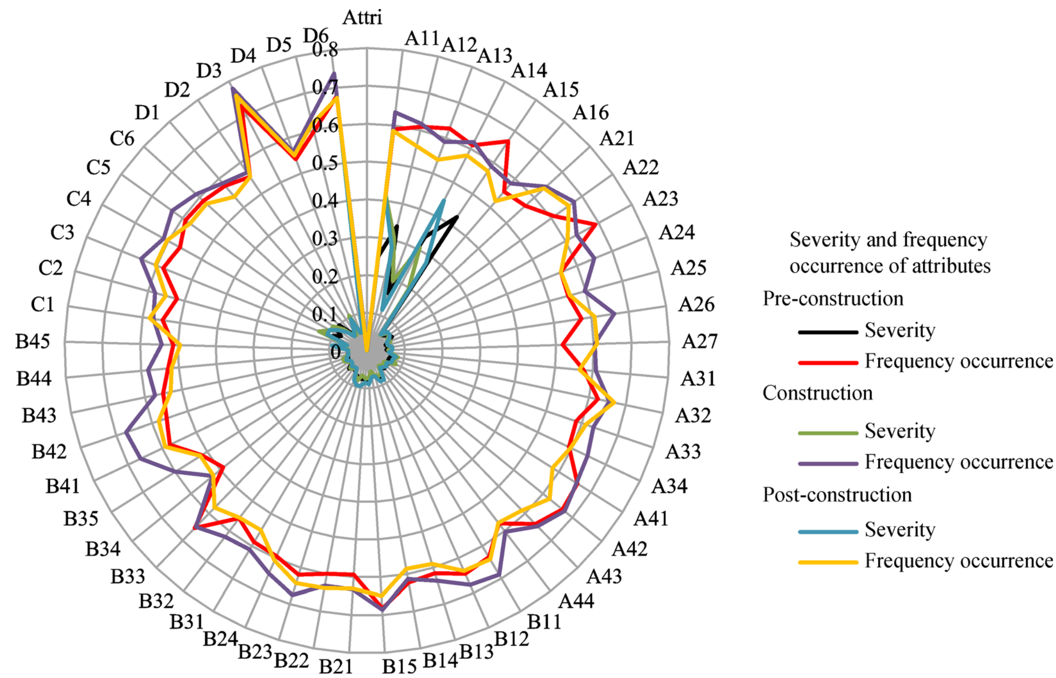

Fig. 2 Comparison of severity and frequency occurrence of attributes at each stage of construction
(the severity was determined through linear interpolation from the global weight and risk matrix; the frequency occurrence was computed via the RII to prioritize the delay risk factors)

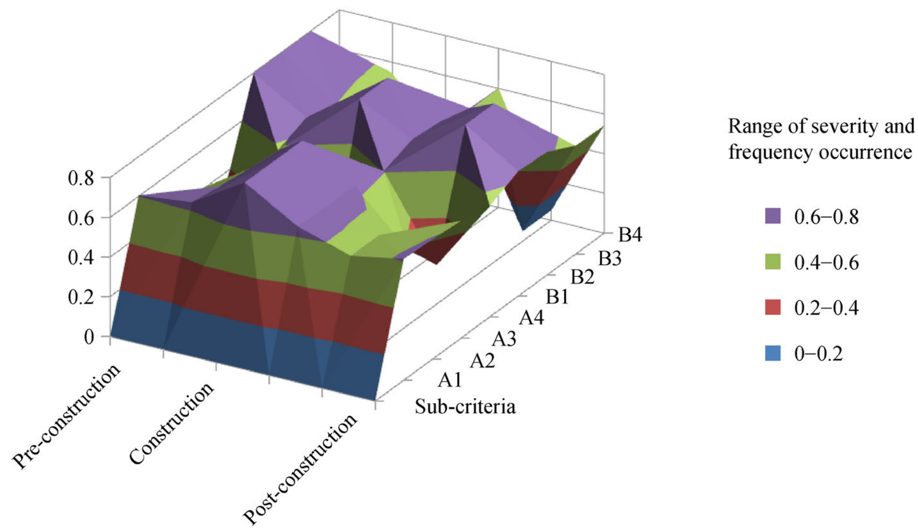

Fig. 3 Comparison of severity and frequency occurrence of sub-criteria at each stage of construction
(the severity was determined through linear interpolation from the global weight and risk matrix; the frequency occurrence was computed via the RII to prioritize the delay risk factors)

5 Conclusions

The delay risk is critical for the success of projects in developing countries such as Ethiopia; this has motivated the present authors to further investigate delay risk. The application of the MCDM model of the FAHPCE with the RII provides a useful tool in delay risk mitigation in construction projects. The application of the combined methods can detect the typical delay risk and can reflect the overall risk in Ethiopian construction projects as well. Based on the case study, the present authors concluded that the risk level of delay at different stages of the construction project lifecycle has differences and the typical risk in terms of type or level at each stage is important in Ethiopian construction projects. After comparing the risks impact that are present in the lifecycle of construction projects, the following lifecycle were identified: the construction stage, the post-construction stage, and the pre-construction stage, in the order of highest to lowest risk. The construction stage presented the highest occurrence of delay risk alternative owing to the high-risk criteria related to responsibility, resource, and contract condition. The post-construction stage presented the second highest occurrence of delay risk alternative with the high-risk responsibility-related criteria. The pre-construction stage presented the least occurrence risk alternative, because of the high-risk responsibility, resources, and contract condition related criteria. The aforementioned differences provided noteworthy information about the risk mitigation in construction projects by identifying the exact risk level that is relevant to a specific activity with the purpose of making an appropriate decision. This would help the construction organizations to identify which delay risk factors are high-, medium-, and low-risk. Moreover, these differences provided valuable information about the delay risk mitigation in Ethiopian construction projects by identifying the appropriate level of risk for the appropriate activity in order to make the right decision. Delay risk detection is important in terms of providing reliable decision-making information pertaining to the typical delay risk in construction activities in order to offer a typical solution. Although this research was conducted to identify the typical and overall delay risk factors in Ethiopian construction projects based on the construction lifecycle, the present research could be applied for the further study of a different country that faces the same situation. In the present work, the construction activity was classified into three main phases, namely the pre-construction, the construction, and the post-construction phase; this classification has certain limitations that would need to be further studied for level of each activity.

Acknowledgements The authors are deeply grateful to all organizations and participants in the research for their help, and to all colleagues for their devoted support.

References

Abd El-Karim M S B A, Mosa El Nawawy O A, Abdel-Alim A M (2017). Identification and assessment of risk factors affecting construction projects. HBRC Journal, 13(2): 202–216

Abd El-Razek M E, Bassioni H A, Mobarak A M (2008). Causes of delay in building construction projects in Egypt. Journal of Construction Engineering and Management, 134(11): 831–841

Adeleke A Q, Bahaudin A Y, Kamaruddeen A M, Khan M W A, Yao L, Sorooshian S, Salimon M G (2017). The influence of organizational external factors on construction risk management in Nigerian construction companies. Safety and Health at Work, 8(2)

Aminbakhsh S, Gunduz M, Sonmez R (2013). Safety risk assessment using analytic hierarchy process (AHP) during planning and budgeting of construction projects. Journal of Safety Research, 46 (Supplement C): 99–105

Assaf S A, Al-Hejji S (2006). Causes of delay in large construction projects. International Journal of Project Management, 24(4): 349–357

Ayalew T, Dakhli Z, Lafhaj Z (2016). Assessment on performance and challenges of Ethiopian construction industry. Journal of Architecture and Civil Engineering, 2(11): 1–11

Dziadosz A, Rejment M (2015). Risk analysis in construction project—Chosen methods. Procedia Engineering, 122(Supplement C): 258–265

El-Sayegh S M (2008). Risk assessment and allocation in the UAE construction industry. International Journal of Project Management, 26(4): 431–438

El-Sayegh S M, Mansour M H (2015). Risk assessment and allocation in highway construction projects in the UAE. Journal of Management Engineering, 31(6): 04015004

Fallahnejad M H (2013). Delay causes in Iran gas pipeline projects. International Journal of Project Management, 31(1): 136–146

Forteza F J, Carretero-Gómez J M, Sesé A (2017). Effects of organizational complexity and resources on construction site risk. Journal of Safety Research, 62(Supplement C): 185–198

Gibson G, Walewski J, Dudley G (2003). Life-cycle considerations to optimize risk assessment and management for international projects. In: Proceedings of ASCE Construction Research Congress. Hawaii

Gładysz B, Skorupka D, Kuchta D, Duchaczek A (2015). Project risk time management – A proposed model and a case study in the construction industry. Procedia Computer Science, 64(Supplement C): 24–31

González P, González V, Molenaar K, Orozco F (2014). Analysis of causes of delay and time performance in construction projects. Journal of Construction Engineering and Management, 140(1): 04013027

Hossen M M, Kang S, Kim J (2015). Construction schedule delay risk assessment by using combined AHP-RII methodology for an international NPP project. Nuclear Engineering and Technology, 47 (3): 362–379

Ibrahim M (2011). Risk matrix for factors affecting time delay in road construction projects: Owners' perspective. Engineering, Construction, and Architectural Management, 18(6): 609–617

Koushki P A, Al-Rashid K, Kartam N (2005). Delays and cost increases in the construction of private residential projects in Kuwait. Construction Management and Economics, 23(3): 285–294

Kuo Y C, Lu S T (2013). Using fuzzy multiple criteria decision making approach to enhance risk assessment for metropolitan construction projects. International Journal of Project Management, 31(4): 602–614

Lee M C (2014). Information security risk analysis method and research trends: AHP and fuzzy comprehensive method. International Journal of Computer Science & Information Technology, 6(1): 29–45

Li D, Yang Q, Yu D (2013). On enterprise social responsibility comprehensive evaluation based on two-step fuzzy evaluation method. Modern Economy, 4(1): 66–72

Liu H Y, Guo J, He W T (2014). The research on subject behavioral risk of whole life-cycle water conservation projects. Frontiers of Engineering Management, 1(4): 348

Luu V T, Kim S Y, Tuan N V, Ogunlana S O (2009). Quantifying schedule risk in construction projects using Bayesian belief networks. International Journal of Project Management, 27(1): 39–50

Mahamid I, Bruland A, Dmaidi N (2012). Causes of delay in road construction projects. Journal of Management Engineering, 28(3): 300–310

Mojtahedi S M H, Mousavi S M, Makui A (2010). Project risk identification and assessment simultaneously using multi-attribute group decision making technique. Safety Science, 48(4): 499–507

Nguyen A T, Nguyen L D, Long L H, Dang C N (2015). Quantifying the complexity of transportation projects using the fuzzy analytic hierarchy process. International Journal of Project Management, 33 (6): 1364–1376

Rao G S S, Raghavan S V (2014). Construction risk identification and assessment. Indian Journal of Applied Research, 4(5): 388–391

Saaty T L (1980). The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation. New York: McGraw-Hill International Book Co

Samantra C, Datta S, Mahapatra S S (2017). Fuzzy based risk assessment module for metropolitan construction project: An empirical study. Engineering Applications of Artificial Intelligence, 65(Supplement C): 449–464

Toth T, Sebestyen Z (2015). Time-varying risks of construction projects. Procedia Engineering, 123(Supplement C): 565–573

Wang J, Yuan H (2017). System dynamics approach for investigating the risk effects on schedule delay in infrastructure projects. Journal of Management Engineering, 33(1): 04016029

Wu Z D, Chen M, Xu H J (2010). Risk assessment of oil and gas drilling engineering cooperation project based on fuzzy comprehensive evaluation. In: Proceedings of the 7th International Conference on Innovation & Management

Zeng J, An M, Smith N J (2007). Application of a fuzzy based decision making methodology to construction project risk assessment. International Journal of Project Management, 25(6): 589–600

Zhu J W, Zhou L N, Zhai Z, Wang C (2016). Financing model decision of inter-basin water transfer projects. Frontiers of Engineering Management, 3(4): 396–403

Zou P X W, Zhang G, Wang J (2007). Understanding the key risks in construction projects in China. International Journal of Project Management, 25(6): 601–614