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ASSESSING PROCUREMENT IRREGULARITIES IN THE SUPPLY-CHAIN OF GHANAIAN CONSTRUCTION PROJECTS: A SOFT-COMPUTING APPROACH

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Abstract. This study examines procurement irregularities, as one of the most unexplored threats in the procurement process of construction projects. It also tests the suppositions associated with the contributions of irregularities to corruption in construction procurement. An expert survey is conducted with 62 construction-related practitioners selected via non-probabilistic sampling in the context of a Ghana, to assess the criticalities of the irregularities. Eighteen irregularities were identified within the context selected for this study. A soft computing technique known as the Fuzzy Synthetic Evaluation (FSE) method is employed to examine the identified irregularities. Other relevant techniques including factor analyses, normalization, and descriptive tools are employed to factorize the identified irregularities and test the hypotheses. Out of the 18 irregularities, 11 were revealed to be critical. The findings reveal that the top three irregularities were: payments for uncompleted works, sourcing of proforma invoices from the same supplier and the lack of proper coordination among key departments. Moreover, four constructs were developed using the identified measurement items. They are administrative-specific, procedural, compliance and contract monitoring irregularities. Out of the four, the topmost critical construct turns out to be compliance irregularities. Theoretically, this study advances the scholarship of construction by shedding lights on the irregularities associated with the procurement processes of construction projects. It also contributes to an in-depth understanding of the noted irregularities. In practical terms, this study contributes to the procurement planning and policy-making process, it assists decision makers in putting in place measures to prevent or extirpate the likelihood of any of the irregularities' occurrences.

Keywords: procurement, irregularities, building, civil engineering, projects, corruption, soft computing.

Introduction

Every year, trillions of dollars are expended in purchasing and procurement of goods, works, and services for public projects (Transparency International [TI], 2019). Kim (2016) specifically pointed out that procurement accounts for over 30% of GDP in developing countries and between 10 and 15% in developed economies, highlighting the excessive amount of money expended in public procurement. As a result, the procurement process is widely identified to be vulnerable to corruption (Krishnan, 2010; Le, Shan, Chan, & Hu, 2014a, 2014b; Sohail & Cavil, 2008). According to the annual reports of TI (2019), and the findings of other studies such as Le et al. (2014a, 2014b) the menace of corruption is identified to be worse in developing economies, compared to that of developed countries. This is attributed to the criticalities of the constructs' variances of corruption, such as the causal factors of corruption, the exposure of different contexts to irregularities which are identified to be critical and pervasive in developing countries, as compared to the developed.

With the above in mind, anti-corruption measures are proven to be more effective in the developed countries as compared to the developing (Shan, Chan, Le, & Hu, 2015). Over the years, studies have been conducted to identify some of the rationales behind corruption and their associated forms other than one's greed for money, especially in the context of construction procurement. Owusu, Chan,

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and Shan (2017) presented a conceptual framework in a recent review study on the causal factors of corruption in construction projects. The framework encapsulated 44 causal variables captured under five constructs. Of these constructs, the two constructs: procurement irregularities and the barriers that hamper the effectiveness of anti-corruption measures were identified to be critical contributors to the occurrence and proliferation of corruption. However, the nature of their impacts and the mechanism of their influence are areas, yet to receive the attention they deserve from researchers.

Recently, Owusu and Chan (2019) reviewed and empirically examined the second construct (i.e., the barriers against the effective application of anti-corruption measures). This study addresses one of the remaining gaps on the subject matter. It attempts to review empirically examine the irregularities associated with procurement works within the context of developing countries, using Ghana as the geographical point of focus.

Moreover, while the identified irregularities are proven to be critical in the developing countries, their contribution to the occurrence of corruption remains hypothetical. Therefore, as well as bridging the identified gap by exploring the procurement irregularities in the developing countries, a further step is taken to test the hypothesis of their contribution to the occurrence and proliferation of corruption within the procurement process. Thus, this study intends to explore the construct of procurement irregularities as established by Tabish and Jha (2011), labeled as corruption vulnerabilities or risk indicators by Le, Shan, Chan, and Hu (2014b) in developing countries. Three objectives are hence formulated to achieve the aim of the study. These are: 1) identify the irregularities that are conjectured to render the construction procurement process to corrupt practices; 2) examine the criticalities of the identified irregularities with their associated constructs and 3) test the hypothesis regarding the attribution of corruption occurrence to the identified irregularities.

1. Background

Procurement irregularities refer to systematic loopholes, vulnerabilities or risk indicators that create the favorable conditions, for causal factors of corruption within the procurement process to thrive (Owusu & Chan, 2019; Tabish & Jha, 2011; Le et al., 2014a). Irregularities may also indicate possible presence of corruption (Le et al. 2014). That said, procurement irregularities are not necessarily causes of corruption, neither do they directly trigger the occurrence of corrupt practices but rather induce negative sufficient conditions that make procurement process vulnerable to corruption (Owusu et al., 2017). They can be referred to as indirect systematic loopholes or negative actions of public officials or project parties that trigger causal factors of corruption. In other words, parties involved may not necessarily intend to indulge in corruption. However, due to existing systematic loopholes (irregularities), project parties may become vulnerable. They consequently engage in practices predisposed to threaten the entire procurement process, potentially pushing the procurement process towards corruption (Le et al., 2014a, 2014b; Tabish & Jha, 2011). For instance, the measurement items such as 'work not executed as per original specified design' and 'sufficient publicity not given to a tender' identified in the study of Le et al. (2014) as irregularities may not necessarily be causes of corruption. However, they can serve as signals that have the potency to instigate corruption if proper measures are not undertaken to determine the rationale behind the indicators.

Moreover, contrasting to other topical areas (including forms, causes, and anti-corruption measures) that are more generic in corruption-related studies, procurement irregularities are context-specific (Owusu et al., 2017; Le et al., 2014a). Simply put, the variables captured under this construct vary from institution to institution and from country to country. One of the early works to explore this in construction management was conducted on public procurement operations in India (Tabish & Jha, 2011). The study analyzed irregularities in Indian's public procurement and identified 61 different irregularities in Indian's procurement works. These variables were further categorized into five main components: transparency irregularities, professional standards irregularities, fairness irregularities, contract monitoring irregularities and lastly, procedural irregularities. However, these variables cannot be generalized since almost all of them were specifically skewed to the context of India as identified in the Chief Technical Examiner's reports of India. Also, Le et al. (2014a) conducted a similar study to identify the irregularities in the Chinese construction public sector, and they identified 24 irregularities peculiar to the Chinese public construction sector. The variables can also be used to measure how prone, vulnerable, or weak an organization or a state institution is to the occurrence of corruption with associated liabilities (Shan et al., 2015). Thus, the measurement of corruption is required to attain headway toward its reduction through greater integrity, transparency, and accountability in corruption-free performance. However, this thematic construct of corruption has not been deeply explored due to its context-specific nature. It is, therefore, against this backdrop that this study is conducted in the context of a developing country. Similar to the instances of the aforementioned studies, this study sought to identify the irregularities specific to the Ghanaian procurement context. These irregularities are often reported in the auditor general's (A-G) reports by the A-G of Ghana. The explication of the periodic reports and the identification of the irregularities are presented in the succeeding sections.

2. Procurement irregularities in Ghana

As discussed, the study focuses on the exploration of irregularities in the Ghanaian context, and given the context-dependent nature of the phenomena, factors representing procurement irregularities were extracted from

a series of reports published by the auditor-general of Ghana. The A-G reports were used because that is the first point of contact to retrieve any form of assessment documents on the public sector, including public departments, boards, and ministries. As a result, the desktop search for the needed documents was strictly skewed towards the reports submitted by the auditor general (A-G) to the Parliament of Ghana on the assessments on different institutions of the public sector. Every year the A-G presents various audit reports to the Parliament of Ghana. Among the categories are compliance and regularity audit; performance audit; forensic audit; environmental audit; IT or electronic/computerized systems audit; proposed energy (oil) audit; and disaster management audit and financial audit.

The performance of the audit processes is presented in their respective reports detailing the situations regarding the public-sector organizations and their accounts. However, due to the cumbersome number of the audits performed by the Ghana Audit Service (GAS), this study captures stipulations on the irregularities of both procurement and contract, as well as, their causalities. Therefore, the needed audit reports on public boards, corporations, and statutory institutions, ministries, departments, and other agencies from 2004 to 2018 were downloaded from the GAS website. It should be noted that the latest available report is the 2017 edition. Moreover, whereas some reports provide an account of activities in one financial year of public accounts, other reports present a summary of findings on the activities of two fiscal years. For example, while the report for the year 2014 presents detailed findings of that specific year, the financial report on ministries, departments and other agencies of the central government for the year 2011 presents results in both 2010 and 2011 fiscal years. The search led to the retrieval of 18 identified irregularities identified in construction procurement alone, as tabulated in Table 1.

Table 1. Irregularities in procurement

No.	Irregularities	References (reports)													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Institutions not following correctly the public procurement act regarding obtaining minimum quotations, exceeding authorized threshold limits and unauthorized sole sourcing of suppliers	√			√			√	√	√		√	√		√
2	Lack of adequate supervisory control over procurement transactions and management					√		√	√						
3	Payments for uncompleted works			√			√			√		√			
4	Non-application of sanctions									√					
5	Poor supervision of subordinate officers									√					
6	Disregard for Public Procurement Act regulations							√						√	
7	Procurements not taken on ledger charge			√		√				√					
8	The procurement of goods and services by the administration without adequate recourse to procurements committees of the various public institutions, which diverges from the provided regulations.										√		√		
9	Variations to contract									√				√	√
10	Outstanding mobilization advances owing to non-observance of stipulated regulations						√								
11	Fragmentary procurement								√						
12	Little evidence of value for money spent		√		√			√				√			
13	Sourcing of proforma invoices from the same supplier								√						
14	Overpayment of purchases		√						√					√	
15	Lack of proper coordination among the major departments of the Company and apparent internal control weaknesses reconciliation on Association									√					
16	Lack of consistent monitoring and review of procurement activities	√													√
17	Lack of whole-of-government and corporate procurement planning for significant purchases	√													
18	Lack of audit trails or verification data				√	√				√					

Note: 1 = Ghana Audit Service [GAS](2005a); 2 = GAS (2005b); 3 = GAS (2006a); 4 = GAS (2006b); 5 = GAS (2007a); 6 = GAS (2007b); 7 = GAS (2008a); 8 = GAS (2008b); 9 = GAS (2011a); 10 = GAS (2011b); 11 = GAS (2013); 12 = GAS (2014); 13 = GAS (2016); 14 = GAS (2017).

3. Research methods

As discussed, an extensive desktop search for the procurement irregularities specifically identified in the context of Ghana revealed a list of eighteen procurement irregularities and formed a basis for designing the questionnaire survey, as discussed below.

3.1. Survey

The identified procurement irregularities – the 18-list indicators – were captured in a questionnaire survey. The use of questionnaires as the main data instrument for this study was justified, given that this method offers a valid and reliable source of information quickly, with minimal resources required (Ameyaw et al., 2017). The survey was used, as this method warrants anonymity, and maintains the anonymity of potential respondents, being of outmost importance in conducting research on a sensitive topic – related to corruption (Hoxley, 2008; Chan & Owusu, 2017; Ameyaw et al., 2017). The questionnaire consisted of both open-ended and close-ended questions. Whereas the grading scale approach was adopted for the close-ended or the quantitative section of the questionnaire, the respondents were also asked to provide their views on any procurement irregularities that were not captured in the close-ended section. The 5-point grading scale system, which is also identified as the linguistic terms for the fuzzy synthetic evaluation (FSE) technique, was employed to evaluate the criticalities of the identified irregularities. Following the design of the questionnaire and prior to administering the survey, the questionnaire was pilot tested -with eight experts- to examine the adequacy and relevance of questions, as well as the rationality, technicality, language structure, comprehensiveness and appropriateness of the entire questionnaire. The pre-tests' results confirmed the reliability and statistical concurrence of the experts' responses. The sampling procedure was immediately initiated after the pilot test, as discussed next.

3.2. Sampling

The expert survey technique was employed in this study based on its advantages: 1) it facilitates the solicitation of rich information and reliable data from a preferred source; 2) it is time-efficient as compared to other alternatives; 3) it facilitate the distribution of questionnaires, where experts can recommend other professional colleagues with the same expertise (Ameyaw et al., 2017; Owusu et al., 2017). A non-probabilistic sampling method, namely, purposive sampling technique was used. This entailed soliciting the views of only experts with thorough knowledge on the subject matter. As much as the subject of corruption is regarded as a general social issue, its various manifestations in specific contexts are difficult to explicate (Jain, 2001). As a result, the highly-informed professionals (both industry practitioners and academics) who are involved in the modus operandi of project procurement and management were targeted using a snowballing method. This method does not result in defining a sampling frame, even though it ensures a comprehensive representative of experts on the topic (Darko et al., 2018).

A total of 91 responses were received, out of which 62 responses were regarded as appropriate for further analysis – some questionnaires were not duly completed – with details tabulated in Table 2. The sample size was relatively small, yet it is deemed adequate, compared with other empirical corruption-related studies in construction management. As evidence, Vee and Skitmore (2003), Ameyaw et al. (2017) and Brown and Loosemore (2015) conducted studies with sample sizes of 31, 35 and 23, respectively.

4. Data analysis and findings

The data were first subjected to two pre-tests: data normality, and reliability. As reported in the studies of Darko et al. (2018) and Shan, Hwang, and Wong (2017), these tests are necessary to determine if parametric or nonparametric tools must be adopted for the analysis. The Cronbach's alpha (CA) was used; the alpha values for both the

Table 2. Respondents' data

Construct	Sub-construct	Frequency	Relative frequency	Cumulative frequency
Professional Affiliation	Public	20	32.26	32.26
	Private	30	48.39	80.65
	Both	12	19.35	100.00
	Total	62	100	
Professional Background	Engineer	17	27.42	27.42
	Quantity surveyor	31	50.00	77.42
	Contractor	4	6.45	83.87
	Architect	7	11.29	95.16
	Academics	3	4.84	100.00
	Total	62	100	
Years of experience	Up to 10 years	45	72.58	72.58
	11–20 years	12	19.35	91.94
	21–40 years	5	8.06	100.00
	Total	62	100	
Involvement in procurement stages	Single stage	7	11.29	11.29
	Multiple stages	28	45.16	56.45
	All stages	27	43.55	100.00
	Total	62	100	
Position in organization	Head of Department	5	8.06	8.06
	Director of Works	8	12.90	20.97
	Senior Manager	17	27.42	48.39
	Supervisor	28	45.16	93.55
	Junior staff	4	6.45	100.00
	Total	62	100	

probability and the severity indicators obtained were 0.909 and 0.864, respectively indicating high reliabilities. Nunnally (1978) stipulated that as a rule of thumb, the benchmark for scale reliability for any given set of data should not fall below 0.7.

4.1. Mean index and factor analysis

The mean index analysis in this study is conducted following the lessons by Ameyaw and Chan (2016). This approach was employed to examine the relative importance of the criticality of the irregularities regarding the probability and severity indicators. Having assessed their individual variables' means as assessed by the experts, the impact of variables' irregularities can be ascertained by the square root of the product of the probability and severity means of the irregularities (Ameyaw & Chan, 2016). Therefore, the impact of a given variable is calculated as Eqn (1):

$$Impact\ (I) = (probability \times severity) \wedge 0.5. \quad (1)$$

The descriptive results and the impact evaluation matrices are presented in Table 3.

Afterwards, factor analysis (FA) was used to factorize large number of variables into significantly fewer constructs (Pallant, 2011; Zhang, Le, Xia, & Skitmore, 2016). In FA, there are two key stages: factor rotation and factor extraction. Other significant tests ingrained in FA to check the appropriateness of the data are Bartlett's test of sphericity and the Kaiser Meyer-Olkin (KMO) test (Field, 2005; Chan & Owusu, 2017). Zhang et al. (2016) indicates that any KMO value above the threshold point 0.5 is considered satisfactory for FA to proceed. The KMO value generated for the barriers' dataset was 0.714, indicating an acceptable value. The FA resulted in four representative constructs, as illustrated in Table 4.

4.2. Procurement irregularities constructs

The eighteen variables were captured under four constructs. These were termed as administrative-specific irregularities, procedural irregularities, compliance irregularities and lastly, contract monitoring irregularities, which can also be regarded as probing-specific. The justification for naming the constructs is presented next.

In the study by Le et al. (2014a) in China, the authors relied on the variables used in the study of Tabish and Jha (2011), since the two countries (i.e., China and India) share some socio-economic and demographic commonalities such as population and economic growth among others. Similarly, there were some commonalities in their respective developed constructs even though the two studies had uneven sets of variables (i.e., 61 in the case of India and 24 in the case of China); the identified variables were captured under five similar constructs in both studies. The constructs were: transparency irregularities, professional standards, fairness, contract monitoring, and procedural irregularities. This study, therefore, followed a similar suit in naming the constructs since it is intended to contribute to previous studies as well as address the gaps identified in the earlier studies. Even though eighteen variables were captured under the study, they were categorized into four constructs by the FA technique as listed in the previous paragraphs. While as the procedural and contract monitoring constructs were identified in the previous studies, the other two constructs that evolved in this study were administrative and compliance irregularities. Therefore, even though the theoretical constructs in previous research influenced the labeling of the developed constructs, the second justification to the labeling of the constructs was that they were named by extracting the identical or common themes that existed among the variables in previous research (Owusu, Chan, & Ameyaw, 2019).

4.3. Hypothesis development

As per the aims and objectives, the present study examines both the criticality of the barriers and tests if the identified irregularities contribute to the occurrence of corruption. The constructs developed are procedural-Irregularities, compliance Irregularities, contract monitoring irregularities, and administrative-specific irregularities. As such, the following hypotheses are formulated, to be tested.

H1. Procedural-Irregularities contribute to corruption in project procurement;
H2. Compliance Irregularities contribute to corruption in project procurement;
H3. Contract monitoring Irregularities contribute to corruption in project procurement;
H4. Administrative-specific irregularities contribute to corruption in project procurement.

4.4. Application of the soft computing technique – Fuzzy Synthetic Evaluation (FSE)

The FSE technique is employed in this study to evaluate the effectiveness of anti-corruption measures in the procurement and execution of construction projects. The method is presented in four steps: (1) development of the evaluation index; (2) membership function determination; (3) estimation of weighting functions and (4) developing a multi-criteria and multi-level FSE model, from which the overall criticality index is computed. The following steps are followed to arrive at the overall effectiveness index and the model for evaluating the effectiveness of anti-corruption measures.

4.4.1. Development of the evaluation index

With reference to the four developed constructs for evaluating their contribution to corruption, the EIS can be formulated by defining the irregularities' constructs as the index systems at the first level as (Shao, 2004; Li, Ng, & Skitmore, 2013; Ameyaw, Chan, Owusu-Manu, & Coleman, 2015):

$$I_{pi} = (I_1, I_2, I_3, I_4). \quad (2)$$

Table 3. Criticalities estimations of the irregularities

No	Variables for procurement irregularities	Probability					Severity*					Overall			
		Mean	SD	Sig	N-V	Rank	Mean	SD	Sig	N-V	Rank	SI	Impact	N-V	OR
1	Institution not following correctly the public procurement Acts in terms of obtaining minimum quotations, exceeding authorization threshold limits and unauthorized sole sourcing of suppliers	3.58	1.049	0.000	0.58	8	3.66	1.007	0.000	0.68	5	13.10	3.62*	0.61	4
2	Lack of adequate supervisory control over procurement transactions and management	3.39	1.014	0.004	0.30	16	3.44	1.182	0.005	0.30	12	11.66	3.41	0.25	14
3	Payments for uncompleted works	3.85	0.973	0.000	0.97	2	3.84	1.027	0.000	1.00	1	14.78	3.84*	1.00	1
4	Non-application of sanctions	3.61	1.030	0.000	0.62	7	3.48	1.184	0.002	0.37	6	12.56	3.54*	0.47	8
5	Poor supervision of subordinate officers	3.56	1.182	0.000	0.55	10	3.48	1.184	0.002	0.37	6	12.39	3.52*	0.44	9
6	Disregard for public procurement Acts regulations	3.65	1.202	0.000	0.68	5	3.48	1.225	0.003	0.37	6	12.70	3.56*	0.51	6
7	Procurement not taken on ledger charge	3.63	1.134	0.000	0.65	6	3.31	1.049	0.025	0.07	16	12.02	3.47*	0.35	11
8	The procurement of goods and services by management without adequate resources to procurements committee of the various public institutions, which diverges from the provided regulations	3.47	1.170	0.003	0.42	14	3.69	1.088	0.000	0.74	3	12.80	3.58*	0.54	5
9	Variations to contract	3.45	0.986	0.001	0.39	15	3.39	1.136	0.009	0.21	13	11.70	3.42	0.26	13
10	Outstanding Mobilization advances owing to non-observance of stipulated regulations	3.18	1.248	0.267	0.00	18	3.37	1.059	0.008	0.18	14	10.72	3.27	0.00	18
11	Fragmentary procurement	3.32	1.184	0.036	0.20	17	3.48	1.004	0.000	0.37	6	11.55	3.40	0.23	17
12	Little evidence of value for moneys spent	3.56	1.168	0.000	0.55	10	3.27	1.162	0.068	0.00	18	11.64	3.41	0.25	14
13	Sourcing of proforma invoices from the same supplier	3.87	1.079	0.000	1.00	1	3.77	1.165	0.000	0.88	2	14.59	3.82*	0.96	2
14	Overpayment of purchases	3.58	1.124	0.000	0.58	8	3.35	1.202	0.023	0.14	15	11.99	3.46*	0.33	12
15	Lack of proper co-ordination among key departments of the company and apparent internal control weaknesses reconciliation on Association	3.73	1.104	0.000	0.80	3	3.68	1.037	0.000	0.72	4	13.73	3.70*	0.75	3
16	Lack of consistent monitoring and review of procurement activities	3.66	1.055	0.000	0.70	4	3.45	1.097	0.002	0.32	11	12.63	3.55*	0.49	7
17	Lack of whole-of-government and corporate procurement planning for significant purchases	3.50	1.170	0.001	0.46	13	3.48	1.141	0.001	0.37	6	12.18	3.49*	0.39	10
18	Lack of audit trails or verification data	3.52	1.264	0.002	0.49	12	3.31	1.139	0.038	0.07	16	11.65	3.41	0.25	14

Note: SD = Standard deviation; Sig = Significance; N-V = normalized value; SI = Significance index; OR = Overall rank.

Table 4. Factor analysis of the variables (Irregularities)

Code	Variable	C1	C2	C3	C4	Initial	Extraction
	Administrative-specific						
ASI1	Lack of whole-of-government and corporate procurement planning for significant purchases	0.771				1.000	0.646
ASI2	Sourcing of proforma invoices from the same supplier	0.760				1.000	0.655
ASI3	Little evidence of value for money spent	0.648				1.000	0.637
ASI4	Lack of proper coordination among key departments of the company and apparent internal control weaknesses reconciliation on Association	0.617				1.000	0.473
ASI5	Non-application of sanctions	0.548				1.000	0.539
	Procedural-Irregularities						
PII1	Fragmentary procurement		0.797			1.000	0.754
PII2	Procurement of goods and services by management without adequate resources to procurements committee of the various public institutions, which diverges from the provided regulations		0.766			1.000	0.625
PII3	Procurement not taken on ledger charge		0.624			1.000	0.639
PII4	Variations to contract		0.592			1.000	0.482
	Compliance Irregularities						
CII1	Institution not following correctly the public procurement Acts in terms of obtaining minimum quotations, exceeding authorization threshold limits and unauthorized sole-sourcing of suppliers			0.728		1.000	0.582
CII2	Disregard for public procurement Acts regulations			0.689		1.000	0.563
CII3	Poor supervision of subordinate officers			0.680		1.000	0.597
CII4	Payments for uncompleted works			0.482		1.000	0.467
	Contract monitoring Irregularities						
CMI1	Outstanding Mobilization advances owing to non-observance of stipulated regulations				0.758	1.000	0.780
CMI2	Lack of adequate supervisory control over procurement transactions and management				0.689	1.000	0.687
CMI3	Overpayment of purchases				0.645	1.000	0.509
CMI4	Lack of audit trails or verification data				0.567	1.000	0.608
CMI5	Lack of consistent monitoring and review of procurement activities				0.515	1.000	0.660
Eigenvalues (*EV*)		*5.603*	*2.145*	*1.729*	*1.425*		
Variance (*VA*)		*31.131*	*11.919*	*9.605*	*7.917*		
Cumulative variance (%) (*CV%*)		*31.131*	*43.049*	*52.654*	*60.572*		
Kaiser-Meyer-Olkin measure of sampling adequacy.							*0.714*
Bartlett's Test of sphericity approx. Chi-Square							*464.824*
df							*153*
Sig.							*0.000*

The individual procurement irregularities within each construct as presented in Table 5 are therefore defined as the index system at the second level. This is presented as:

$$I_{asi} = (I_{asi1}, I_{asi2}, I_{asi3}, I_{asi4}, I_{asi5}); \quad (2.1)$$

$$I_{pii} = (I_{pii1}, I_{pii2}, I_{pii3}, I_{pii4}); \quad (2.2)$$

$$I_{cii} = (I_{cii1}, I_{cii2}, I_{cii3}, I_{cii4}); \quad (2.3)$$

$$I_{cmi} = (I_{cmi1}, I_{cmi2}, I_{cmi3}, I_{cmi4}, I_{cmi5}). \quad (2.4)$$

It must be emphasized that the established input variables (also known as the FSE's input variables) apply to both the probability and the severity indicators alike. As presented in Table 5, the identified irregularities within their respective constructs were deemed as representatives for input variables of the FSE assessments.

4.4.2. Membership function determination

The membership grade of both the individual irregularities and their respective constructs can be generated by fuzzy mathematics (Ameyaw et al., 2015). It is again emphasized that the grading scale system employed to assess both the probability and severity of the irregularities were

stipulated by a 2-dimensional, five-level grading scale system as d = (1, 2, 3, 4, 5) where d_1 = very low, d_2 = low, d_3 = neutral, d_4 = high, d_5 = very high for both the extent of probability and severity of the irregularities. Thus, the membership function of a given construct I_{in}, is calculated using the Eqn (3) below (J. H. Chan, D. W. Chan, A. P. Chan, Lam, & Yeung, 2011; Ameyaw et al., 2015; Li et al., 2013; Xu, Chan, & Yeung, 2010).

$$MF_{I_{in}} = \frac{P_{1I_{in}}}{d_1} + \frac{P_{2I_{in}}}{d_2} + \frac{P_{3I_{in}}}{d_3} + \frac{P_{4I_{in}}}{d_4} + \frac{P_{5I_{in}}}{d_5} = \frac{P_{1I_{in}}}{\text{very low}} + \frac{P_{2I_{in}}}{\text{low}} + ... + \frac{P_{5I_{in}}}{\text{very high}}, \quad (3)$$

where MF represents the membership function of a given construct I_{in}; the term I_{in} denotes the nth variable (procurement irregularity) of a given construct i ($i = I_1, I_2, I_3, I_4$); $P_{fI_{in}}$ (f = 1, 2, 3, 4, 5) represents the percentage of the experts who assigned a score of for the individual irregularities (capturing both probability and severity indicators). Lastly, the expression $P_{fI_{in}}/d_i$ connotes the association between $P_{fI_{in}}$ and its respective grading scale rather than the mathematical (fractional) expression; and also, the expression "+" represents a notation rather than the addition expression as applied in mathematics. Therefore, the function in Eqn (3) is further expressed as:

$$MF_{I_{in}} = (P_{1I_{in}}, P_{2I_{in}}, P_{3I_{in}}, P_{4I_{in}}, P_{5I_{in}}). \quad (4)$$

The members in the set of Eqn (2) range between 0 and 1 and their summation must be equal to 1. This is presented in Eqn (5) as:

Table 5. Weightings for the activities and stages for the procurement process

Code	Irregularities	Risk probability				Risk severity			
		Mean	Weighting	Total mean	Construct weighting	Mean	Weighting	Total mean	Construct weighting
ASI1	Lack of whole-of- management and corporate procurement planning for significant purchases	3.50	0.192			3.48	0.197		
ASI2	Sourcing of proforma invoices from the same supplier	3.87	0.212			3.77	0.213		
ASI3	Little evidence of value for money spent	3.56	0.195			3.27	0.185		
ASI4	Lack of proper co-ordination among key departments	3.73	0.204			3.68	0.208		
ASI5	Non-application of sanctions	3.61	0.198			3.48	0.197		
Administrative-specific				18.27	0.285			17.68	0.281
PII1	Fragmentary procurement	3.32	0.239			3.48	0.251		
PII2	Procurement of goods and services by management without adequate resources	3.47	0.250			3.69	0.266		
PII3	Procurement not taken on ledger charge	3.63	0.262			3.31	0.239		
PII4	Variations to contract	3.45	0.249			3.39	0.244		
Procedural-Irregularities				13.87	0.216			13.87	0.220
CII1	Institution not following correctly the public procurement Acts	3.58	0.245			3.66	0.253		
CII2	Disregard for public procurement Acts regulations	3.65	0.249			3.48	0.241		
CII3	Poor supervision of subordinate officers	3.56	0.243			3.48	0.241		
CII4	Payments for uncompleted works	3.85	0.263			3.84	0.266		
Compliance Irregularities				14.64	0.228			14.46	0.230
CMI1	Outstanding Mobilization advances owing to non-observance of stipulated regulations	3.18	0.183			3.37	0.199		
CMI2	Lack of adequate supervisory control over procurement transactions and management	3.39	0.196			3.44	0.203		
CMI3	Overpayment of purchases	3.58	0.207			3.35	0.198		
CMI4	Lack of audit trails or verification data	3.52	0.203			3.31	0.196		
CMI5	Lack of consistent monitoring and review of procurement activities	3.66	0.211			3.45	0.204		
Contract monitoring Irregularities				17.33	0.270			16.92	0.269
Total of construct mean and weight				64.11	1.000			62.93	1.000

$$\sum_{f=1}^{5} P_{f I_{in}} = 1. \tag{5}$$

As explicated earlier, the *MF* of a given construct is generated from the aggregate assessment of the responses from the expert survey using Eqn (4). Thus, using variations to contract (*PII*4) as an example, the results demonstrated that the ratings offered by the experts for the probability indicator as follows; 3% as very low; 13% as low; 32% as moderate, 39% as high and 13% as very high. Thus, using Eqn (1), the *MF* for the variable (i.e., *PII*4) is generated as:

$$MF_{PII4_{(P)}} = \frac{0.03}{\text{very low}} + \frac{0.13}{\text{low}} + \frac{0.32}{\text{moderate}} + \frac{0.39}{\text{high}} + \frac{0.13}{\text{very high}}. \tag{5.1}$$

The generated $MF_{PII4_{(P)}}$ is presented through Eqn (4) as follows (0.03, 0.13, 0.32, 0.39, 0.13). Similarly, the severity indicator for the same variable is presented as follows:

$$MF_{PII4_{(S)}} = \frac{0.10}{\text{very low}} + \frac{0.10}{\text{low}} + \frac{0.18}{\text{moderate}} + \frac{0.47}{\text{high}} + \frac{0.16}{\text{very high}}. \tag{5.2}$$

Again, using Eqn (4), the $MF_{PII4_{(S)}}$ term is presented as (0.10, 0.10, 0.18, 0.47, 0.16). Thus, the same approach is employed to estimate the *MF*s for the remaining variables. The final *MF*s are presented in Table 6. The computation of the variables' *MF*s is the estimation of the constructs *MF*s. The *MF*s for the respective constructs are computed using the computed weightings of the individual variables together with their computed variables as presented in the next section.

4.4.3. Estimation of weighting functions

The weighting function of either a variable or a construct signifies the relative importance as assessed by the survey experts (Ameyaw et al., 2015). Two methods are identified apropos for determining the weighting function. These are the normalized mean method and the analytic hierarchy process (AHP) technique (Lo, 1999; Hsiao, 1998; Ameyaw et al., 2015). The mean method approach was employed in this study to estimate the weightings for both the individual variables and the constructs for this study, since it is regarded as a more straightforward approach and has been employed in various risk assessment studies by Xu et al. (2010), Lo (1999), Ameyaw et al. (2015). Calculating the weighting function using the mean method is conducted using the Eqn (6) below:

$$w_i = \frac{M_i}{\sum_{i=1}^{5} M_i}, 0 < w_i < 1, \text{ and } \sum_{i=1}^{5} w_i = 1, \tag{6}$$

where w_i represents the weighting function for either a variable or a construct i in terms of both probability and severity indicators of the irregularities. M_i in the formula represents the mean index of a specific variable or construct as estimated from the survey. Lastly, analogous to the estimations of the *MF*s, the summation of the mean within a weight function set (Eqn (6)) must be equal to 1, as indicated in Eqn (4). The weighting function set can, therefore, be represented in Eqn (7) as:

$$w_i = \left(w_1, w_2, w_3 ..., w_n\right). \tag{7}$$

Mathematically, the weighting functions (w_i) of both the variables and constructs of the irregularities are computed from the mean values generated from the expert survey ranking using Eqn (6). Again, using $PII4_{(S)}$ (i.e., the severity indicator of variations to construct) as an example, the *WF* is computed as follows:

$$w_{PII4_{(S)}} = \frac{3.39}{3.48 + 3.69 + 3.31 + 3.39} = \frac{3.39}{13.87} = 0.244. \tag{7.1}$$

The remaining variables are as well computed using the same approach. Similarly, at the construct level, the administrative specific irregularity is computed as follows:

$$w_{PII_{(S)}} = \frac{13.87}{17.68 + 13.87 + 14.46 + 16.92} = \frac{13.87}{62.93} = 0.220. \tag{7.2}$$

Similarly, the three remaining constructs of the severity indicator, as well as the other four constructs representing the probability indicators, are computed. The weighting functions for all the variables and the constructs are presented in Table 6 and 7. Lastly, as indicated in the previous paragraph, the summation of the WFs under a similar construct or for all the constructs must equate unity (i.e., 1). Thus, using $PII_{(S)}$ construct as an example $\left(\text{i.e.,} \sum_{i=1}^{5} w_i = 1\right)$ the statement is validated as (0.251 + 0.266 + 0.239 + 0.244 = 1.0).

4.4.4. Developing a multi-criteria and multi-level FSE model

Evaluating the level of procurement irregularities is deemed a multicriteria and a multilevel activity of three key phases. The first phase builds the membership functions (*MF*) and the weighting function of individual variables of irregularities, based on the experts' ratings. Following the establishment of the *MF* and the *WF*, the second phase focuses on the establishment of membership and weighted functions of the constructs (i.e., the four factors of irregularities) and estimates their impacts. The final phase estimates the overall indicator or impact of irregularities.

Therefore, to evaluate the impact of an individual construct, a fuzzy matrix K_1 is first established for every construct, after estimating the membership function of individual variables (irregularities) within their respective

Table 6. Membership functions for the activities and stages for the procurement process

PI Constructs	Risk probability			Risk severity		
	Weighting	MF for Level 3	MF for Level 2	Weighting	MF for Level 3	MF for Level 2
Administrative-specific)			0.07, 0.09, 0.17, 0.46, 0.21			0.08, 0.10, 0.20, 0.44, 0.19
ASI1	0.192	0.10, 0.10, 0.18, 0.47, 0.16		0.197	0.08, 0.11, 0.21, 0.44, 0.16	
ASI2	0.212	0.05, 0.08, 0.11, 0.47, 0.29		0.213	0.06, 0.08, 0.18, 0.37, 0.31	
ASI3	0.195	0.10, 0.08, 0.16, 0.48, 0.18		0.185	0.11, 0.11, 0.27, 0.39, 0.11	
ASI4	0.204	0.05, 0.10, 0.19, 0.40, 0.26		0.208	0.03, 0.13, 0.16, 0.48, 0.19	
ASI5	0.198	0.05, 0.10, 0.21, 0.48, 0.16		0.197	0.11, 0.08, 0.16, 0.50, 0.15	
Procedural-Irregularities)			0.06, 0.13, 0.26, 0.37, 0.18			0.07, 0.11, 0.24, 0.44, 0.14
PII1	0.239	0.08, 0.18, 0.24, 0.34, 0.16		0.251	0.06, 0.08, 0.26, 0.50, 0.10	
PII2	0.250	0.08, 0.11, 0.26, 0.35, 0.19		0.266	0.05, 0.11, 0.15, 0.47, 0.23	
PII3	0.262	0.06, 0.10, 0.21, 0.40, 0.23		0.239	0.06, 0.15, 0.31, 0.39, 0.10	
PII4	0.249	0.03, 0.13, 0.32, 0.39, 0.13		0.244	0.10, 0.10, 0.26, 0.42, 0.13	
Compliance Irregularities)			0.06, 0.10, 0.18, 0.44, 0.22			0.07, 0.09, 0.21, 0.42, 0.21
CII1	0.245	0.05, 0.10, 0.26, 0.42, 0.18		0.253	0.03, 0.10, 0.24, 0.44, 0.19	
CII2	0.249	0.06, 0.15, 0.13, 0.40, 0.26		0.241	0.11, 0.08, 0.21, 0.40, 0.19	
CII3	0.243	0.10, 0.08, 0.18, 0.45, 0.19		0.241	0.10, 0.10, 0.21, 0.42, 0.18	
CII4	0.263	0.03, 0.06, 0.16, 0.50, 0.24		0.266	0.03, 0.08, 0.18, 0.44, 0.27	
Contract monitoring Irregularities)			0.08, 0.11, 0.24, 0.40, 0.18			0.08, 0.13, 0.26, 0.38, 0.15
CMI1	0.183	0.15, 0.11, 0.31, 0.29, 0.15		0.199	0.06, 0.13, 0.29, 0.40, 0.11	
CMI2	0.196	0.06, 0.11, 0.27, 0.47, 0.08		0.203	0.08, 0.15, 0.21, 0.39, 0.18	
CMI3	0.207	0.06, 0.11, 0.19, 0.44, 0.19		0.198	0.06, 0.21, 0.23, 0.31, 0.19	
CMI4	0.203	0.10, 0.11, 0.23, 0.31, 0.26		0.196	0.10, 0.11, 0.31, 0.35, 0.13	
CMI5	0.211	0.05, 0.10, 0.19, 0.47, 0.19,		0.204	0.10, 0.05, 0.29, 0.44, 0.13	

constructs. Thus, using the *MF*s established in Eqn (3), functions of individual variables within their respective constructs, for both probability and severity indicators can be presented in Eqn (8) as:

$$R_i = \begin{vmatrix} MF_{I_{i1}} \\ MF_{I_{i2}} \\ MF_{I_{i3}} \\ \cdots \\ MF_{I_{in}} \end{vmatrix} = \begin{vmatrix} p_{1I_{i1}} & p_{2I_{i1}} & p_{3I_{i1}} & p_{4I_{i1}} & p_{5I_{i1}} \\ p_{1I_{i2}} & p_{2I_{i2}} & p_{3I_{i2}} & p_{4I_{i2}} & p_{5I_{i2}} \\ p_{1I_{i3}} & p_{2I_{i3}} & p_{3I_{i3}} & p_{4I_{i3}} & p_{5I_{i3}} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ p_{1I_{in}} & p_{2I_{in}} & p_{3I_{in}} & p_{4I_{in}} & p_{5I_{in}} \end{vmatrix}, \quad (8)$$

where elements are presented by $P_{fI_{in}}$.

Mathematically, using the variable 'payments for uncompleted works' $CII_{(S)}$ as an example through Eqn (8), the critically level of the given construct is expressed as:

$$R_{CII_{(p)}} = \begin{vmatrix} MF_{CII1} \\ MF_{CII2} \\ MF_{CII3} \\ MF_{CII4} \end{vmatrix} = \begin{vmatrix} 0.05 & 0.10 & 0.26 & 0.42 & 0.18 \\ 0.06 & 0.15 & 0.13 & 0.40 & 0.26 \\ 0.10 & 0.08 & 0.18 & 0.45 & 0.19 \\ 0.03 & 0.06 & 0.16 & 0.50 & 0.24 \end{vmatrix}. \quad (8.1)$$

Therefore, using the established function $R_{i,}$ the matrix $D_{i,}$ can be calculated by adopting the *WF* set: $\{w_i = (w_1, w_2, w_{3,}..., w_n)\}$ of the individual variables within their respective constructs as presented as:

$$K_i = W_i \bullet R_i = \left(k_{in}, k_{in}, k_{in}, \ldots k_{in}\right). \quad (9)$$

Therefore

$$K_i = \left(w_1, w_2, w_3, \ldots, w_n\right) \bullet \begin{vmatrix} p_{1I_{i1}} & p_{2I_{i1}} & p_{3I_{i1}} & p_{4I_{i1}} & p_{5I_{i1}} \\ p_{1I_{i2}} & p_{2I_{i2}} & p_{3I_{i2}} & p_{4I_{i2}} & p_{5I_{i2}} \\ p_{1I_{i3}} & p_{2I_{i3}} & p_{3I_{i3}} & p_{4I_{i3}} & p_{5I_{i3}} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ p_{1I_{in}} & p_{2I_{in}} & p_{3I_{in}} & p_{4I_{in}} & p_{5I_{in}} \end{vmatrix} = \left(k_{i1}, k_{i2}, k_{i3}, \ldots k_{in}\right), \quad (9.1)$$

where K_{in} represents the membership degree of the grading scale d_i, in terms of a given construct. Therefore, following the establishment of $R_{CII_{(p)}}$ the normalization of the matrix using the respective weighting function $W_{CII_{(p)}}$ to generate the fuzzy evaluation matrix for the construct is mathematically presented as:

$$K_{CII_{(p)}} = \left(0.245, 0.249, 0.243, 0.263\right) \times \begin{vmatrix} 0.05 & 0.10 & 0.26 & 0.42 & 0.18 \\ 0.06 & 0.15 & 0.13 & 0.40 & 0.26 \\ 0.10 & 0.08 & 0.18 & 0.45 & 0.19 \\ 0.03 & 0.06 & 0.16 & 0.50 & 0.24 \end{vmatrix} = \left(0.08, 0.11, 0.24, 0.40, 0.18\right). \quad (9.2)$$

Analogous to the mathematical computations above, all the constructs for both the probability and severity indicators are computed following the same approach. The obtained matrices are presented at the third columns of both the probability and sections of Table 6 (labelled, "*MF* at level 2"). With this in mind, $K_{CII_{(p)}} = (0.08, 0.11, 0.24, 0.40, 0.18)$ represents the fuzzy matrix for the probability indicators, of the identified procurement irregularities, which are evaluated by using the established grading system (d = 1, 2, 3, 4, 5) using the Eqn (10) below:

$$CI_i = \sum_{i=1}^{5} K_i \times d^t = (d_1, d_2, d_3, d_4, d_5) \times \left(1,2,3,4,5\right), \quad 1 \le IL \le 5. \quad (10)$$

Therefore, following the establishment of all the constructs, the criticality indexes (*CI*) for all the constructs can be computed through Eqn (10) as presented below:

$$CI_{CII_{(p)}} = (0.08 \times 1) + (0.11 \times 2) + (0.24 \times 3) + (0.40 \times 4) + (0.18 \times 5) = 3.66. \quad (10.1)$$

Similarly, the probability index of the construct is computed as:

$$CI_{CII_{(s)}} = (0.08 \times 1) + (0.13 \times 2) + (0.26 \times 3) + (0.38 \times 4) + (0.15 \times 5) = 3.62. \quad (10.2)$$

Thus, after the estimation of both the probability and severity indicators, the criticality of any of the constructs is computed through Eqn (11) as follows:

$$CI_{CII} = \sqrt{3.66 \times 3.62} = 3.64\,. \quad (11)$$

The computations for all the remaining constructs are presented in Table 8.

4.4.5. Computing the overall criticality index

$K_i \left(i = 1,2,3,4\right)$, representing the newly evaluated matrix, is adopted to represent the fuzzy matrix $\overline{R}$ to evaluate the overall critical levels of irregularities for both the probability and severity indicators. This is presented in Eqn (12) as:

$$\overline{R_i} = \begin{vmatrix} K_1 \\ K_2 \\ K_3 \\ K_4 \end{vmatrix} = \begin{vmatrix} k_{11} & k_{12} & k_{13} & k_{14} & k_{15} \\ k_{21} & k_{22} & k_{23} & k_{24} & k_{25} \\ k_{31} & k_{32} & k_{33} & k_{34} & k_{35} \\ k_{41} & k_{42} & k_{43} & k_{44} & k_{45} \end{vmatrix}. \quad (12)$$

It must be emphasized that K_1 to K_4 represent the individual constructs of irregularities (i.e., 1, 2, 3, 4 or *ASI*, *PII*, *CII*, *CMI*). Mathematically, the matrices representing the probability and severity functions are therefore presented as follows:

$$\overline{K}_{(p)} = \begin{vmatrix} 0.07 & 0.09 & 0.17 & 0.46 & 0.21 \\ 0.06 & 0.13 & 0.26 & 0.37 & 0.18 \\ 0.06 & 0.10 & 0.18 & 0.44 & 0.22 \\ 0.08 & 0.11 & 0.24 & 0.40 & 0.18 \end{vmatrix} \text{ and}$$

$$\overline{K}_{(s)} = \begin{vmatrix} 0.08 & 0.10 & 0.20 & 0.44 & 0.19 \\ 0.07 & 0.11 & 0.24 & 0.44 & 0.14 \\ 0.07 & 0.09 & 0.21 & 0.42 & 0.21 \\ 0.08 & 0.13 & 0.26 & 0.38 & 0.15 \end{vmatrix}. \quad (12.1)$$

Therefore, using Eqn (13), the matrix $\overline{R}$ is again normalized using the weighted function set encapsulating the *WF* of the constructs to arrive at $\overline{K}$. Therefore, the com-

putation of $\overline{K}$ is mathematically conducted as follows:

$$\overline{K_i} = \overline{W} \bullet \overline{R} = \left(w'_1, w'_2, w'_3, w'_4\right) \times \begin{vmatrix} k_{11} & k_{12} & k_{13} & k_{14} & k_{15} \\ k_{21} & k_{22} & k_{23} & k_{24} & k_{25} \\ k_{31} & k_{32} & k_{33} & k_{34} & k_{35} \\ k_{41} & k_{42} & k_{43} & k_{44} & k_{45} \end{vmatrix} = \left(K'_1, K'_2, K'_3, K'_4, K'_5\right), \quad (13)$$

where $\overline{K_i} = \left(K'_1, K'_2, K'_3, K'_4, K'_5\right)$ represents the fuzzy matrix for either or both of the probability and severity indicators of the identified procurement irregularities which are evaluated by using the established grading system (d = 1, 2, 3, 4, 5) using the equation similar to Eqn (14) below:

$$CI_i = \sum_{i=1}^{5} \overline{K_i} \times D^t = (D'_1, D'_2, D'_3, D'_4, D'_5) \times \left(1,2,3,4,5\right), \ 1 \le IL \le 5, \quad (14)$$

where CI represents the irregularities' criticality index i (i represents both probability and severity indicators). It should be noted that just as in the case of Ameyaw et al. (2015), the Eqns from (1) to (14) apply to both the probability and severity constructs. Thus, the overall impact encapsulating both constructs can be computed by the products of the conjugated constructs – calculate the square root of the product as shown as in Eqn (15):

$$OCI = \sqrt{\{\sum_{i=1}^{5} \overline{K_p} \times D^t\} \times \{\sum_{i=1}^{5} \overline{K_s} \times D^t\}}, \ 1 \le OCI \le 5. \quad (15)$$

To compute the overall criticality index of irregularities, the obtained fuzzy evaluation matrices are again normalized using their respective weighted functions to obtain the ultimate fuzzy evaluation matrix of the procurement irregularities:

$$\overline{K}_{(p)} = \left(0.285, 0.216, 0.228, 0.270\right) \times \begin{vmatrix} 0.07 & 0.09 & 0.17 & 0.46 & 0.21 \\ 0.06 & 0.13 & 0.26 & 0.37 & 0.18 \\ 0.06 & 0.10 & 0.18 & 0.44 & 0.22 \\ 0.08 & 0.11 & 0.24 & 0.40 & 0.18 \end{vmatrix} = \left(0.07, 0.11, 0.21, 0.42, 0.20\right) \quad (15.1)$$

and the severity fuzzy evaluation matrix as:

$$\overline{K}_{(s)} = \left(0.281, 0.220, 0.230, 0.269\right) \times \begin{vmatrix} 0.08 & 0.10 & 0.20 & 0.44 & 0.19 \\ 0.07 & 0.11 & 0.24 & 0.44 & 0.14 \\ 0.07 & 0.09 & 0.21 & 0.42 & 0.21 \\ 0.08 & 0.13 & 0.26 & 0.38 & 0.15 \end{vmatrix} = \left(0.07, 0.11, 0.23, 0.42, 0.17\right). \quad (15.2)$$

Thus, the overall criticality index for the procurement irregularities is computed as follows (using Eqns (15.1) and (15.2)) and presented in Table 8:

$$OCI = \sqrt{\left[\left(1\times0.07\right)+\left(2\times0.11\right)+\left(3\times0.21\right)+\left(4\times0.42\right)+\left(5\times0.20\right)\right]} \times \sqrt{\left[\left(1\times0.07\right)+\left(2\times0.11\right)+\left(3\times0.23\right)+\left(4\times0.42\right)+\left(5\times0.17\right)\right]};$$

$$OCI = \sqrt{3.57 \times 3.51} = 3.54. \quad (15.3)$$

From Eqn (15), OCI represents the overall criticality index of procurement irregularities and the subscripts s and p stand for both the severity and probability indicators. This process or stage is called the defuzzification approach (Chan et al., 2017; Osei-Kyei, Chan, & Dansoh, 2019); it transforms the established fuzzy numbers into crisp output, which is employed to facilitate decision making. The defuzzification of both probability and severity constructs are achieved by using the grading scale D^t (Ameyaw et al., 2015; Sadiq & Rodriguez, 2004).

5. Discussion on the findings

5.1. Compliance irregularities

At the construct level, the compliance irregularities construct was identified to be the most critical construct with an overall impact index of 3.64 with both of its probability of occurrence and severity indicators respectively estimated to be 3.66 and 3.62 respectively. Four variables were captured under this contract. Non-compliance to the public procurement act coupled with limited or non-

Table 7. *MF* for stages for the procurement process (for overall probability and severity indicators)

Code	Irregularities' Constructs	Risk probability		
		Weighting	MF at Level 2	MF at Level 1
ASI	Administrative-specific	0.285	0.07, 0.09, 0.17, 0.46, 0.21	0.07, 0.11, 0.21, 0.42, 0.20
PII	Procedural-Irregularities	0.216	0.06, 0.13, 0.26, 0.37, 0.18	
CII	Compliance Irregularities	0.228	0.06, 0.10, 0.18, 0.44, 0.22	
CMI	Contract monitoring Irr	0.270	0.08, 0.11, 0.24, 0.40, 0.18	
Code	Irregularities' Constructs	Risk severity		
		Weighting	MF at Level 2	MF at Level 1
ASI	Administrative-specific	0.281	0.08, 0.10, 0.20, 0.44, 0.19	0.07, 0.11, 0.23, 0.42, 0.17
PII	Procedural-Irregularities	0.220	0.07, 0.11, 0.24, 0.44, 0.14	
CII	Compliance Irregularities	0.230	0.07, 0.09, 0.21, 0.42, 0.21	
CMI	Contract monitoring Irr	0.269	0.08, 0.13, 0.26, 0.38, 0.15	

Table 8. Overall descriptors and hypothesis validation

No	Risk probability			Risk Severity			Overall				
CT	Index	LI	CE	Index	LI	CE	Impact	RK	LI	N-V	Hypothesis
ASI	3.66	High	0.26	3.55	High	0.25	$\sqrt{3.66\times3.55}=3.61$	2	Critical	0.864*	Accepted
PII	3.47	High	0.24	3.48	High	0.25	$\sqrt{3.47\times3.48}=3.48$	3	Critical	0.273	Rejected
CII	3.66	High	0.26	3.62	High	0.26	$\sqrt{3.66\times3.62}=3.64$	1	Critical	1.000*	Accepted
CMI	3.47	High	0.24	3.38	Neutral	0.24	$\sqrt{3.37\times3.38}=3.42$	4	Neutral	0.000	Rejected
Total	14.26		1.00	14.03		1.00					
OI	3.57			3.51			$\sqrt{3.57\times3.51}=3.54$		Critical		

Notes: LI = Linguistic; CE = Coefficient; RK = Rank; N-V = Normalized value; OI = Overall index.

compliance of contractual stipulations regarding payment of non-executed works were noted as the top two critical irregularities as compared to the other two. While there are standardized procedures to facilitate the procurement process, embedded in the public procurement act, the A-G indicated this to be one of the most critical concerns in the public sector. Similarly, the experts also highlighted this to be one of the most critical irregularities that have the potential to create room for corruption to flourish and cause other financial, performance and standardization irregularities in a given public domain.

The other critical concerns are '*disregard for public procurement act*' and '*regulations and the payment for uncompleted works*'. Similar to the first to irregularities, the issue of this disregarding stipulated act is antonymous to compliance. Thus, in the first scenario, whereas public procurement officials may choose to follow some parts of procurement policies (like partial compliance as defined by Worthy, John, and Vannoni (2017)) the cause of disregard is directly synonymous to non-compliance. As such, the harm that this specific irregularity may lead to is likely to be greater than in the former case. Similar compliance-related irregularities were identified under the regulatory irregularities in the studies of Tabish and Jha (2011) indicating the criticality of this factor and the need to extirpate its occurrence, influence, and proliferation in the procurement process as well as other activities involved in public procurement.

5.2. Administrative irregularities

Administrative irregularities can be defined as the potential organizational risks that transpire as a result of a weakened internal and external structures, depreciated organizational morality, professional and ethical standards within an organizational setting that endangers the workflow, productivity and overall institutional structures to two known and unknown corruption occurrence (Owusu et al., 2017; Le et al. 2014a, 2014b). Analogous to the compliance irregularities construct, the administrative irregularities construct was identified to be one of the critical constructs made of 5 individual irregularities. Even though past studies have not captured the administrative irregularities as a construct, both studies of Tabish and Jha (2011) and Le et al. (2014a) identified professional standards irregularities as one of the five pressing constructs identified in the context of India and China respectively. However, some of the variables captured under the construct of professional standards irregularities are somewhat similar to that captured under administrative irregularities in this study. For instance, limited disclosure of money spent, unrealistic preparation of sound cost estimates and unrealistic high rated or highly valued items which are not adequately verified or monitored existed under a common construct of all the three mentioned studies.

The remaining variables captured under this construct are sourcing or procuring of proforma invoices from the same supplier with a criticality impact of 3.82 and the lack of proper coordination among key departments and personnel within an institution, obtaining a criticality index of 3.70. Also, non-application of sanctions to undisciplined work ethics and the lack of whole management and corporate procurement planning for significant purchases with a critical impact index of 3.49 were captured under this construct. According to the A-G, these are critical administrative irregularities that have ensued within the administrative structures of the public procurement board for an appreciable period. Moreover, they agreed to this concern, justifying the criticality of the loopholes identified within the administrative structures of the public procurement system with the developing countries and the need to help check and extirpate these irregularities to limit the occurrence of other unlikely events such as corruption among others.

Moreover, a recent study conducted by Owusu, Chan, DeGraft, Ameyaw, and Robert (2018) on the measures established to extirpate corrupt, practices in construction project management captured one of the constructs as administrative measures out of 6 constructs. This study, therefore, recommends that practical deduction can be made from the findings of Owusu et al. (2018) as it remains the most up-to-date review study of anti-corruption measures in this context. It would as well be needful for researchers and other anti-corruption advocates to draw strategic measures specifically skewed to limit or extirpate the occurrence and impact of administrative irregularities in the public procurement system of developing countries.

5.3. Procedural irregularities

Procedural irregularities represent one of the two constructs in this study captured similarly by both studies of Tabish and Jha (2011) and Le et al. (2014a). Any form of risk posed to any task encapsulated in the process of the sequence of getting the specified work done can be termed as procedural irregularities. In the context of public procurement, the term lends itself to the distortion, risk, or threat posed against the established modus operandi of transacting an official or established procurement process. The explication of this term is needful to establish a common ground to discuss the variables captured under this construct. Tabish and Jha (2011), however, defined this term from the perspective of non-compliance, which has already been captured in our previous construct. While the concept of compliance can be captured under this construct, it must be emphasized that procedural irregularities can manifest in different forms other than non-compliance. For instance, per the four variables captured under this construct in this study, the act of fragmentary procurement or variation to a contract may not necessarily be non-compliance to established procurement process but can, however, pose a threat to the supply chain of the procurement process. Variations to contract take place as a result of different causal factors, including force majeure (Bing, Akintoye, Edwards, & Hardcastle, 2005). And this does not necessarily mean non-compliance to procedural stipulations.

However, if variations to a contract are not effectively handled, they may serve as a threat or susceptible grounds for corruption to flourish such as inflation of the amount to cover the varied part of the given contract (C. Stansbury & N. Stansbury, 2008). This is one of the rationales for emphasizing the definition of procedural irregularities. As presented earlier, the mentioned procedural irregularities (that is, fragmentary procurement and variations to contract obtained criticality indexes of 3.40 and 3.42 respectively indicating moderate criticalities. However, the experts demonstrated their consent for their severity impact of the fragmentary procurement and the probability impact of the variations to contract, which per their views, are considered critical and need practical rectification measures to extirpate their respective concerns. However, apart from the two irregularities, the other two rather had appreciable levels of critical impact indexes. They include procurement not taking on ledger charge and the procurement of goods and services by management without adequate resources to the procurement committee of various public institutions which diverges from the provided regulations. These two irregularities had their respective impact indexes to be 3.47 and 3.58 respectively, indicating the respective criticalities. The variables regarding the procurement of goods and services by management without adequate resources which as well diverges from provided regulation can as well be regarded as an administrative or non-compliance irregularity. This shows that even though some variables are specifically skewed towards a construct, they can as well be considered under other constructs indicating the relationship of the variables. There is, therefore, the need to pay critical attention to how the respective stages within the procurement process can be effectively structured to limit the occurrence of these irregularities or the unlikely outcomes that are bound to happen should the irregularities happen.

5.4. Contract monitoring irregularities

The construct of contract monitoring irregularities was as well identified as one of the constructs captured in the literature (Tabish & Jha, 2011; Le et al. 2014a). Previous studies defined this construct to be the contractual laxities, that ensue as a result, non-compliance to contractual stipulations or agreement. Therefore, it can be established that this is one of the main limitations of previous works on this subject matter – attributing almost all the constructs to non-compliance. However, as established, this study postulates that not all the irregularities emerge or take place as a result of non-compliance. While non-compliance may be regarded as a direct causal factor to allow the occurrence of any of the irregularities, it must be emphasized that other forms of irregularities other than non-compliance can cause different forms of irregularities to emerge as explained in the previous section.

For instance, the topmost critical variable under this construct, which is the lack of continual stringent monitoring and the review and evaluation of procurement activities may not be an issue of non-compliance as reported in the previous instance (Osei-Tutu, Badu, & Owusu-Manu, 2010; Tanzi, 1998). However, as identified by the experts, this variable was revealed to have high criticality indexes for both the probability and severity indicators. This highlights the need to raise awareness on the development of sterner contract monitoring mechanisms to extirpate the criticality of the identified irregularities. As mentioned, five irregularities were captured under this construct. However, regarding the remaining four, only one variable was identified to be critical, and that was the overpayment of purchases with an index of 3.46. The remaining three are: the lack of inadequate trails or verification data, lack of adequate supervisory control over procurement transactions and management, and the outstanding mobilization advances incurred as a result of either limited or non-observance of stipulated regulations. These variables can be attributed to administrative flaws especially regarding the need to verify any given data on the specifications and any other information of purchases made and the need to ensure adequate supervisory control on procurement transactions. This will enable early detection of both unidentified and unknown irregularities to facilitate the strategy formulation of effective measures to extirpate them.

As per the stipulations presented by Worthy et al. (2017), the use of the term non-compliance as frequently used in past studies is highly debatable. The term non-compliance refers to zero adherence according to Worthy

et al. (2017). However, there are instances where the recorded irregularities may instigate or propagate as a result of partial compliance, lack of awareness, or absolute ignorance of certain demands or stipulations required of them. In such instances, the primary problem may not be attributed to non-compliance or adherence. Therefore, this study is intended to inform its audience about the correct use of the term non-adherence because the degree of relevance attached to the various forms of compliance (i.e., from noncompliance to concordance) and the measures required to check the specificity of the various levels of compliance.

6. Practical implications

For the world of practice, this study points to the crucial role of irregularities, as a stepping stone for policy makers and practitioners to promote the development of effective strategies to mitigate or extirpate irregularities. Discussion on the nature and root causes of irregularities and their impacts are invaluable for project stakeholders, procurement experts, contract administrators and anti-corruption activists. At the industry and organization levels, the study contributes to the development of a more holistic and stringent measures for estimating corruption, the respective causal factors and potential irregularities likely to distort the order of procurement processes. At the project level, the ability to extirpate these irregularities by project managers will enhance the smooth execution of the procurement process and facilitates meeting project objectives with reducing corruption.

Conclusions

The occurrence and proliferation of corruption in the procurement and management of construction projects are propelled by corruption constructs, which include causes of corruption, irregularities, and the barriers that hamper the effectiveness of anti-corruption measures. This study is unique within the construction domain, presenting a strong case: in order to holistically examine the concept of corruption – within any given context – examining the causes of corruption is far from adequate. The contextual irregularities as well as the factors that obstruct the effective application of anti-corruption measures are of similar importance. This study therefore extends previous research on identifying the factors that cause corruption in project procurement and management, in revealing an area hitherto unexplored and unmapped. The study therefore contributes to the body of knowledge with revealing this overlooked area – procurement irregularities in the context of project procurement and management in a developing country. Moreover, this study examines the contextual irregularities in Ghana and demonstrates the criticality of them. This makes the study stand out, as no similar empirical assessment has been conducted on this topic. The study further advances the body of knowledge on the topic, through identifying the most influential variables and introducing four constructs: administrative irregularities, procedural irregularities, compliance irregularities, and lastly contract monitoring irregularities. As another insight provided by the findings reported here, the study tests several hypotheses to assess variables' contribution to the occurrence of corruption, and confirmed two constructs to be significantly critical towards rendering the entire procurement process to the occurrence and proliferation of corrupt practices.

With the above in mind, the novelty presented by this study lies within the identification and the empirical examination of the irregularities prevalent within the procurement process, as well as, confirming that these irregularities contribute to the prevalence of corruption. In terms of methodology, the present study benefits researchers through demonstrating a use case of applying soft computing techniques (i.e., fuzzy evaluation method) in examining the irregularities prevalent within the procurement process. Furthermore, the study provides a sound basis for future research, to continue this trend of corruption-related research in different fields.

The primary limitation of this study is the necessity of exercising caution in generalizing the findings of this study to other developing countries, as well as a relatively small sample size for the respondents. As a result, more context-based research in different contexts is needed, to facilitate the identification of factors or irregularities that are identical in specific contexts and contribute to the development of effective strategies for extirpating specific irregularities in different contexts. Future studies can also explore the strategies needed to extirpate the prevailing irregularities (Neupane, Soar, & Vaidya, 2014; Nurmandi & Kim, 2015). On the other hand, a deeper exploration of the constructs developed in this study can be conducted to determine their relational attributes (i.e., how one construct affects the other). For instance, how administrative-specific irregularities can influence either compliance or contract monitoring. Lastly, apart from the recommendation of conducting similar studies in different contexts to determine the criticality of the variables under those domains, there is the need to specifically examine how the identified irregularities affect or obstruct the respective stages of the procurement process. However, despite the limitations encountered, this study can serve as a relevant source of reference or foundation both in the general approach of the study as well as the methodology adopted for developing and extending the research on the subject matter.

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