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An approach to assessing human factors related occupational safety using behavioural observation-based indicators: The case of a construction site in Nigeria

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Abstract

Globally, the construction industry is regarded as one of the most dangerous where workers often face safety and health risks throughout the process of task and activities execution. Safety violations through unsafe behaviours are major contributors to these risks. This research aimed to develop a quantitative model that assesses the level of workers' safety on a construction site based on behavioural observation. A construction firm in Southwest Nigeria was identified and studied. Data on tasks performed by the workers on the number of unsafe behaviours (N) and the durations in which they lasted (D) was collected. Based on this, the level of safety adherence (LSA), the initiated and sustained number of safety violations (I-NSV and S-NSV) and the probability of unsafe acts occurrence and zero unsafe acts (PUA1 and PUA2) indicators were developed and used in assessing the safety level of the project. An evaluation of different levels of N and D was also undertaken to provide further insight into the requirements for attaining an improved systems safety level. The results obtained indicated that the LSA was 0.35. The I-NSV and S-NSV results were 41 and 118 unsafe acts respectively while the PUA1 and PUA2 values were 1.00 and 0.00 respectively. Evaluation results showed that LSA increases were directly related to S-NSV decreases caused by corresponding decreases in D, while improved project safety levels could be achieved through I-NSV mitigation. The study concluded that the safety level of the construction site was low and recommended improved safety strategy implementation for attaining improved project safety level. The model is useful for measuring construction projects' safety levels based on workers' safety violations and the study outcome could be used to set improvement targets and relay feedback for safety behaviour improvement in construction firms and related organisations.

Keywords: Construction industry, Safety violation, Unsafe acts, Behavioural observation, Safety performance indicators

1. Introduction

The role of the construction industry occupies a strategic position globally as it is a significant contributor to the economic development of many countries in the world [1, 2]. Although not the highest to the Nigerian economy, the sector is nevertheless crucial for its role as a provider of infrastructure and employment. Within the current decade, the Nigerian construction industry has employed over 6 million people [3] and has contributed to the country's gross domestic product (GDP) [4-6] albeit not significantly.

Unfortunately, by the nature of its labour-intensive activities, and low-skill labour force composition [7, 8], the Nigerian construction industry like its global counterparts is characterised by the prevalence of hazards and accident occurrences [8-11]. Although sparse data exist on construction industry-related accidents in Nigeria as a result of poor reporting and documentation culture, the industry does exhibit accident occurrence characteristics such as high incidences and severities similar to those of developing economies [12-14]. For example, Idoro [15] reported that over 16 worker-related accidents were recorded during activities involving registered construction firms. A study carried out by Ikechukwu [16] revealed that over 50% of the masons in some local construction sites selected for the study had been involved in one form of accident or another.

The consequences of these accidents not only end in pain, physical and psychosocial damage, loss of livelihood, and even death to the workers, they also can lead to productivity decreases and delays in activities, thereby posing a menace to project completion in terms of time and production costs.

Having realised this construction sector linked accident consequences, safety practices should be a fundamental part of management activities with the primary goal being to guarantee workers safety on construction sites. It is believed that the industry will be better effectiveness-wise if practices and regulations are directed at protecting workers and communities where these projects are executed. One way of achieving this is through the use of safety performance monitoring and measurement (SPMM). SPMM is a means of verifying project safety performance and validating safety risk control effectiveness [17-20]. Given the knowledge that accident causes are generally credited to unsafe acts and practices by workers [7, 21] on the one hand, and unsafe working conditions attributed to management actions/inactions [22, 23] on the other, SPMM can provide insight into the safety level of construction projects and reveal the dynamic interaction between management safety strategies and actions and workers responses to them.

Concerning construction accidents in Nigeria, a literature survey on works relating to SPMM was conducted by the authors. The results obtained show that there have been several investigations made on the use of SPMM in unearthing accident causal factors in

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this sector to propose accident preventing or mitigating solutions. The methodologies used in most of the studies revolve around the application of descriptive, exploratory, and inferential statistics in the analysis of subjective information gathered from stakeholder questionnaires and interview responses. Some of the causal factors revealed include lack of proper worker education [24], poor organisation and improper documentation [25], size/level of construction project [15], poor safety policy implementation [24], poor management compliance [3, 15, 26, 27], unsafe acts and other human factors [28-30], fatal accidents arising from poor safety culture [15, 30, 31], and poor management-worker communication [29, 32].

Despite the relevance of the results obtained by these studies in guiding stakeholders on construction workplace safety improvement, the authors assert that a gap exists in the literature regarding the use of on-field observer-based information in the assessment of the extent of the worker safety performance in Nigerian construction firms. This is because for an accident to occur, there must be pre-existent potential accident causal activities (unsafe acts) or unsafe conditions called hazards [33-35]. It is widely believed that more than 70% of accidents that occur are triggered by hazards that originate from unsafe acts/behaviours [21, 36]. Unsafe acts can take place in situations where unsafe conditions exist but are unidentifiable. They can also become prevalent when workers have come to the acceptance of working under the risk of unsafe conditions or unsafe acts that take place irrespective of the existent working conditions [37]. Given the dynamic conditions of the construction workplace, the adoption of behavioural-based safety (BBS) as a means of safety management for accident prevention/mitigation through the improvement of worker awareness and behaviour for unsafe acts elimination is key.

BBS is a practical safety management technique that is used for accident identification and prevention. BBS advocates believe that unsafe behaviour is the main accident cause. In other words, accident frequency could be decreased by correct behaviour [38, 39]. It is believed also that behaviours can be estimated and enhanced by techniques such as observation, analysis, and feedback [40]. The observation of workers' safe and unsafe behaviours may be done by safety managers or safety auditors. Observers note unsafe individual behaviours by referring to a behaviour checklist developed by safety managers. BBS has been proven to be an effective safety management strategy in several industries [37, 41-43] and remains very relevant as the construction industry keys into the zero-incident, zero-injury philosophy [44, 45].

One of the key principles for achieving an effective BBS programme involves focusing on a worker's observable behaviour [46]. Thus, for the assurance of safety and wellbeing in the construction workplace, constant observing of safety metrics is core, keeping in mind the end goal which is to eliminate potential risks in the system effectively. A behavioural observation (BO) methodology tends to study how often individuals carry out safe and/or unsafe activities at work with respect to time [47, 48]. As a result of its simplicity, Ismail et al. [38] suggested that by watching each other's behaviour, human safety behaviour, safety awareness, and in effect safety performance can be improved. In combining the suggestions and outcomes of the works of Altmann and Haynes et al. and Oostakhan et al. [37, 47, 48], a summary of the steps involved in the use of BO in BBS management is presented

i. Identification of unsafe behaviours from workers.
ii. Observation of the identified behaviours over a certain period. This is usually done using sampling and/or work-study techniques [49, 50]
iii. Presentation of feedback in the form of an SPMM indicator
iv. Based on iii, safety programmes may be modified or re-launched to increase desired behaviour or for continuous improvement.

We believe that a need exists regarding the use of BO techniques in the provision of information for decision-making on workers' safety improvement in the Nigerian construction sector, hence the motivation for the study. We aim to develop a quantitative measure that provides information on the extent of safety adherence/violation by construction workers in Nigeria pivoted on the application of the behavioural based safety (BBS) philosophy using BO principles. The study was carried out using a building construction project handled by a local contractor.

The development of the workers' safety performance model will help to provide adequate and relevant information for proactive decision-making by management and related stakeholders for safety improvement in the Nigerian construction sector.

2. Materials

2.1 Symbols and notations

The symbols and notations of the quantities used in the study are presented in Table 1.

2.2 Site selection and determination of activities and tasks

Firstly, a preliminary study of some construction sites in a city in south-western Nigeria was conducted. The study followed the form of personal contacts and discussions with the respective project stakeholders to ascertain sufficient in-house support and interest in the study.

Subsequently, a construction site located in the suburb of the city was selected as a case study. The construction project was a storey building consisting of twenty classrooms. The construction activities undertaken at the selected site during the period of the study revolved around pillar and lintel casting, column casting, masonry, and decking. Each of these project activities consisted of different tasks. The schedules for the activities were made to overlap each other to speed up the construction time. A chart of the observed activities with their respective tasks is shown in Figure 1. The grouping of all the activities by the similarity of tasks was carried out. In all, fourteen tasks were identified (Table 2).

2.3 Pre behavioral observation activities

Before starting the BO process, there was a need to determine the number of observations to ensure an effective study. As such, a one-on-one interview was conducted with the site supervisor to generate information on the average expected number of workers per day during the construction process (W_d), the daily workhour duration (T_d), the number of breaks between work (N_b), and the length of the break periods (T_b). Information regarding the supervisor's assessment of the type of potential accidents that could occur as a result of unsafe acts exhibited by workers while undertaking tasks was also obtained.

Based on the information obtained from the interview, it was decided to conduct the observations within a study window (T_s) of 8 weeks (48 days).

Table 1 Abbreviations, symbols, and notations

SN	Symbol/Notation	Definition	Dimension
1	Col.	Column	--
2	LSA	Level of safety adherence	--
3	PUA	The probability to commit an unsafe action	--
4	SV	Safety violation	--
5	I-NSV	Initiated number of SVs	--
6	S-NSV	Sustained NSV	--
7	d	Margin of error of observation	Dimensionless
8	θ_{Aq}, θ_{Vq}	Safety adherence and safety violation for level task/system	
9	$f\{u_r\}$	Frequency of committing SV type r	Dimensionless
10	β_j	Total duration of observation of task type j	hr
11	μ	Unit observation interval	hr
12	λ_I, λ_S	Probability distribution parameters for initiated and sustained unsafe acts respectively	Dimensionless
13	$\bar{T}_{ij}^{o}$	Average time expended on observing worker i within μ	hr
14	ϕ	The fraction of work window expended on work.	Dimensionless
15	N_b	Number of breaks between work	Dimensionless
16	T_b	length of the break periods	hr
17	W_d	Average expected number of workers per day	day^{-1}
18	T^o	Total behavioural observation period	day
19	$N_{obs}\{T_s\}$	Total observations available within the T_s	Dimensionless
20	T_d	Daily workhour duration	hr
21	t	Value of the t-distribution corresponding to the chosen significance level	Dimensionless
22	p	Estimate of the population proportion	Dimensionless
23	N_{obs}^{*}	Minimum number of observation intervals required for work sampling study	Dimensionless
24	T_{ij}^{o}	BO period for worker i undertaking task j	hr
25	T_j^o	Total time spent observing all workers at task j	hr
26	u_{irj}	SV type r, committed by worker i while undertaking task j	Dimensionless
27	$f\{u_{irj}\}$	Frequency of committing u_{irj}	Dimensionless
28	$t\{u_{irj}\}$	Duration of time in which u_{irj} is initiated and sustained	hr
29	$N^o\{w_j\}$	Total number of workers observed to have committed u_{irj}	Dimensionless
30	$N^o\{u_j\}$	Total number of observed SVs committed at task j	Dimensionless
31	$t\{T_j^o\}$	Period of sustained violation by the set of workers undertaking task type j	hr
32	β	Number of operation hours	hr
33	γ_q^I, γ_q^S	Number of I-NSV and S-NSV respectively committed on tasks /system	Dimensionless
34	ω_q	Daily duration of unsafe actions at task/within the system	hr
35	$N^*\{u_j\}$	Normalised number of initiated unsafe acts committed at task j	Dimensionless
36	$t^*\{u_j\}$	Normalised time of sustained unsafe acts initiated at task j	hr

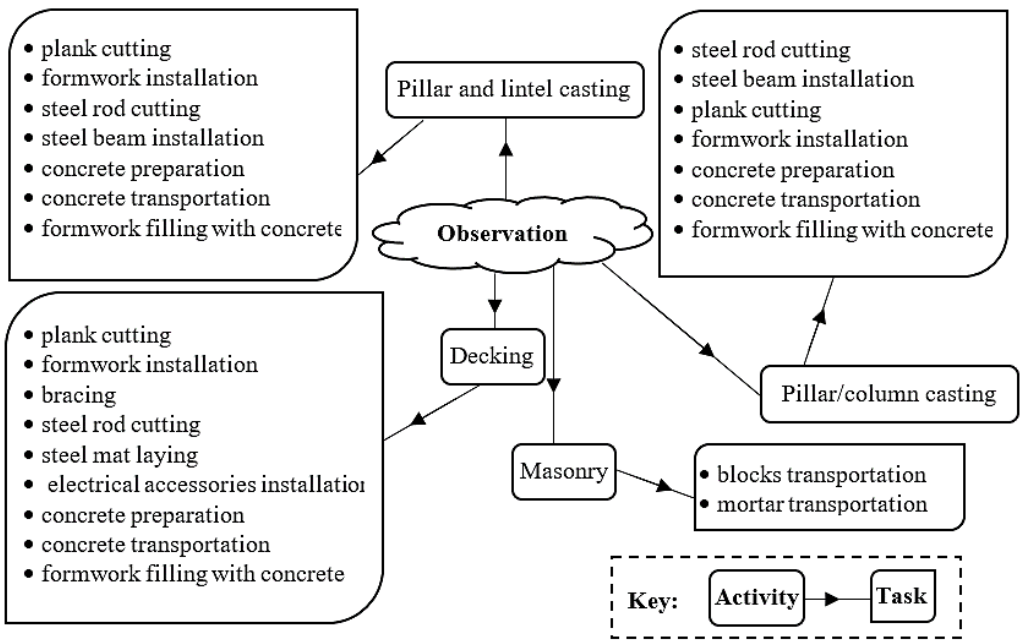

Figure 1 Identified construction activities and corresponding tasks

Table 2 Definition of tasks carried out at the selected construction site

SN	Task (Notation)	SN	Task (Notation)
1	Formwork Installation (T1)	8	Steel mat laying (T8)
2	Steel rods cutting (T2)	9	Electrical accessories installation (T9)
3	Steel beams installation (T3)	10	Blocks transportation (T10)
4	Concrete/mortar preparation (T4)	11	Plumbing accessories Installation (T11)
5	Concrete/mortar Transportation (T5)	12	Masonry (T12)
6	Formwork Filling (T6)	13	Planks/bamboo cutting (T13)
7	Bracing (T7)	14	Steel rods transportation (T14)

The minimum number of observation intervals required for the study (N_{obs}^{*}) was then determined by adapting the Bartlett et al. [51] model (Equation 1-3) at the value corresponding to the 95% confidence interval of the t-distribution. The estimate of population proportion (p) and the margin of error values were set at 0.5 and 0.05 respectively [52].

To increase the effectiveness of the random process as well as to deal with the uncertainties in the work schedules and task execution, we introduced the unit observation interval (μ) rule which essentially requires that a task that may have been previously observed could be observed again if the time difference between the last observation and that of the desired observation equals or exceeds a unit observation interval. In our case, μ was chosen as 1 hour. A decision was made to undertake the BO on more than one task within μ with the minimum and maximum observation interval for a task set at 10 minutes and 30 minutes respectively and the average time expended on one observation within μ (δ) fixed at 20 minutes (0.333 hours).

$$N_{obs}^{*} = \begin{cases} N_{obs} & \{N_{obs} \leq 0.05 N_{obs}\{T^{o}\}\} \\ \dfrac{N_{obs}}{(1 + [H_{w}^{-1} N_{obs}])} & \{otherwise\} \end{cases} \quad (1)$$

$$N_{obs} = \frac{(t)^{2} p(1-p)}{(d^{2})} \quad (2)$$

$$N_{obs}\{T_{s}\} = \phi W_{d} T_{s} T_{d} \bar{T}_{ij}^{o^{-1}} \quad (3)$$

Where N_{obs}: Initially computed total number of hourly observations, t: value of the t-distribution corresponding to the chosen significance level, d: Margin of error of observation, p: Estimate of population proportion, T^{o} : Total behavioural observation period, $N_{obs}\{T^{o}\}$: Total observations available within the T^{o}, $\bar{T}_{ij}^{o}$: Average time expended on one observation within observation window (μ), ϕ: Fraction of work window actually expended on work.

Based on the information, the minimum number of observations was determined. Eventually, 140 observation hours (equivalent to about $1.52N_{obs}^{min}$) were expended on the BO exercise with 8 to 9 observations made daily. The obtained minimum number of observation intervals alongside and related details are shown in Table 3.

Table 3 Work sampling input and output for behavioural observation exercise quantities

Input			Output		
SN	Quantity	Value	SN	Quantity	Value
1	t	1.96	1	N_{obs}	385 observations
2	d	0.05	2	$N_{obs}\{T^{o}\}$	19833 observations
3	p	0.50	3	N_{obs}^{min}	277 observations
4	$\bar{T}_{ij}^{o}$	0.33 hours	4	$T_{obs}^{min} = \bar{T}_{ij}^{o} N_{obs}^{min}$	92.33 observation hours
5	ϕ	0.91	5	N_{obs}^{*}	140 observation hours

2.4 Behavioural observation exercise for safety violations detection

The following assumptions were made before the BO process

i. Each task observed was performed by a different worker under the same working conditions.
ii. Each worker exhibited the same behaviour when under observation and when not under observation.
iii. The behaviour of the workers observed within the N_{obs} represents the overall behaviour of the population of workers within the entire period of executing the project.

We like to point out that the second assumption was necessary because of the possibility that one worker undertaking a task could be observed more than once within the observation window as the emphasis was not placed on workers per se, but rather on how the tasks were being undertaken.

The BO exercise was then carried out by randomly selecting and observing workers over chosen observation intervals (T_{ij}^{o}) as they performed their tasks in order to identify different types of suspected unsafe acts/SVs committed by them. Once these violations were observed, there were recorded as violation type r committed at task j (u_{irj}) alongside the frequency in which the violation type was committed ($f\{u_{irj}\}$). Also, the length of time in which the act was sustained by the observed worker ($t\{u_{irj}\}$), and the total number of workers observed to have committed the violations for every task done ($N^{o}\{w_{j}\}$) were also recorded

At, the end of the exercise, the suspected SVs list was modified to an actual violations list after the recorded activities had been verified by a team made up of the observer(s) and the site supervisor(s) as being actual violations. It is worth noting here, that the personal details of the workers engaged in the violations were not recorded.

2.5 Analysis of violations and development of the safety violations indicator

On the completion of the observations, the number of observed SVs committed, the length of sustained violation by the set of workers undertaking task type j $(N^o\{u_j\}$ and $t\{u_j\})$ and their corresponding windows of observation (T_j^o) were computed (Equations 4-6). Following this, $N^o\{u_j\}$ and $t\{u_j\}$ were normalised to conform to a common observation window (Equation 7). μ was chosen as the common observation window in the study. Using the normalised data form, analyses were done to obtain three safety indicators namely, the level of safety adherence (LSA), the SV rate (NSV) and the probability to commit an unsafe action (PUA) using models developed in this section.

$$N^o\{u_j\} = \sum_{i}^{W_{obs}} \sum_{r=1}^{R} f\{u_{rj}\} \tag{4}$$

$$t\{\mu_j^o\} = \sum_{i=1}^{W_{obs}} \sum_{\mu=1}^{N_{obs}^*} t\{u_{irj}\} \tag{5}$$

$$T_j^o = \sum_{i=1}^{W_{obs}} \sum_{\mu=1}^{N_{obs}^*} T_{ij}^o \tag{6}$$

$$A^* = \frac{A\mu}{T_q^o} \quad \left\{A^* = N^*\{u_j\} \middle| t^*\{T_j^o\}; A = N^o\{u_j\} \middle| t\{T_j^o\}\right\} \tag{7}$$

$$\forall j, t\{T_{ij}^o\} \leq T_{ij}^o, T_{ij}^o \leq T_j^o\ , T_j^o \leq\ T^o, \mu = 1, (k \geq 0;\ integer)$$

2.5.1 Level of safety adherence indicator

For the entire workers undertaking task j in task observation window T_j^o, the level of safety violation was formulated as the ratio of the sum of the normalized lengths of violation and the unit observation window (Equation 8). The construction system's level of SV was determined as the ratio of the sum $t^*\{\mu_j^o\}$ and μ (Equation 9).

$$\theta_{Vj} = \frac{t^*\{\mu_j^o\}}{\mu} \tag{8}$$

$$\theta_{VS} = \frac{t^*\{\mu_S^o\}}{\mu} = \frac{\sum_{j=1}^{J} t\{\mu_j^o\}}{\sum_{j=1}^{J} T_j^o} \tag{9}$$

For any of the safety indicators described by equations 8 and 9, the level of safety adherence was obtained using equation 10.

$$\theta_{Aq} = 1 - \ \theta_{Vq}\ \{q = j|\mathrm{S}\} \tag{10}$$

θ_{Aq} is an index that indicates the measure of the component/system's level of safety control. Thus as θ_{Aq} increases, the safety level is considered to increase. Absolute control is established when $\theta_{Aq} = 1$. On the other hand, a lower θ_{Aq} value indicates poor safety adherence.

2.5.2 Number of safety violations

The number of safety violations (NSV) is an indicator that provides an estimate of the number of SVs that are regularly being committed in the work environment. The Initiated NSV (I-NSV) and the sustained NSV (S-NSV) are the two NSV forms that were formulated. The I-NSV (γ_q^I) was developed to provide information on the number of unsafe acts initiated by workers while attending to a task. The S-NSV (γ_q^S) is meant to provide an assessment of the number of unsafe acts that occur when an I-NSV is sustained over a time interval.

To this end, γ_q^I was obtained as the product of the rate of SV initiation (I-SVR) and the daily window of construction operation β (Equations 11-12). In formulating the γ_q^S, we describe with equation 13 the normalised interval that accounts for non-SV activities for different tasks/system (ε_q^*). Then, by applying the concept of the interval between successive events [53], the initiation/re-initiation of unsafe acts was determined as the ratio of ε_q^* and $N^*\{u_j\}$ (Equation 16). The S-NSV was subsequently derived as the ratio of β and γ_q^{*S} (Equation 17).

$$\gamma_q^I = \beta\lambda_I \tag{11}$$

$$\lambda_I = N^*\{u_j\} \tag{12}$$

$$\varepsilon_q^* = \frac{\varepsilon_q}{\beta}\ \{q = j|\mathrm{S}\} \tag{13}$$

$$\varepsilon_q = \beta - \omega_q \tag{14}$$

$$\omega_q = \beta t^*\{T_q^o\} \tag{15}$$

$$\gamma_q^{*S} = \begin{cases} \dfrac{\varepsilon_j^*}{N^*\{u_j\}} & \{q = j; \forall j\} \\ \dfrac{\varepsilon_S^*}{\bar{N}^*\{u_j\}} & \{q = S\} \end{cases} \tag{16}$$

$$\gamma_q^S = \frac{\beta}{\gamma_q^{*S}} \; \{q = j|\mathrm{S}\} \tag{17}$$

$N^*\{u_j\}$: Normalised number of initiated unsafe acts, ω_q: Duration of unsafe actions

It should be noted for equation (13) that in situations where ε_q^* was equal to zero, we replaced the zero value with 0.001. This was necessary to,

i. Deal with the problem of infinite divisibility in situations where a SV was sustained over an entire window of observation
ii. Provide stakeholders with information on the number of SVs in the firm in a clearer and more relatable format rather than a value of ∞.

2.5.3 Probability of unsafe actions indicator

The PUA indicators (PUA1 and PUA2) provide information on the probability of committing at least one SV within a shift of construction operation and the probability of obtaining zero-SV incidences while undertaking different tasks within the daily work window. The indicator is useful in providing information regarding safety concerns regarding zero accident targets. The safety indicator formulation was adapted from model concepts provided by Duzgun et al. [54] and Charles-Owaba et al. [55]. In our case, we make the following assumptions about the probability of SV (p_q):

i. It is a function of the number of unsafe acts initiated by the workers, the period spent on the task in the sustenance of the violation, and the length of exposure of the workers to the task.

ii. It follows a Poisson distribution given that the unsafe act events are random and discrete, whereas the state space (window of operation/observation) is continuous (equation 18) [53, 56]

$$p_q = 1 - e^{-\lambda_S \beta} \tag{18}$$

We defined the probability distribution parameter (λ_S) as the rate at which unsafe acts are being continually committed or simply put, the sustained safety violation rate (S-SVR). It represents the workers' characteristic to commit unsafe acts (C_q) [equation 19]. The lower the value of λ_S, the lower the number of SVs and vice versa. C_q was designed to capture the efforts made by the project stakeholders at ensuring that SVs are prevented from occurring. The final forms of PUA1 and PUA2 were obtained as described by equations 20 and 21 respectively.

$$\lambda_S = C_q = \left(\gamma_q^S\right)^{-1} \{q = j|\mathrm{S}\} \tag{19}$$

$$p_q\{\beta_q \leq \beta\} = 1 - e^{-\beta C_q} \tag{20}$$

$$p_q\{N\{u\} = 0\} = \frac{{C_q}^0 e^{-C_q}}{0!} \tag{21}$$

2.6 Models application and analysis

The LSA, NSV and PUA were applied to the construction project data generated from the BO process to determine for the observed tasks and the system; the level of SV/adherence, the number of violations that take place from sustained unsafe activities, and the probability of a SV occurring. Also, the impact of initiated and sustained safety violations on the safety level at the site by investigating the correlation that exists between θ_{Aj}, γ_q^I, and γ_q^S. To avoid issues relating to normality distribution of and ties in variables [57], the Spearman rank correlation coefficient (r_s) was used. Their effect θ_{Aj} was investigated based on the null (H_o) and alternative (H_1) hypotheses that:

H_o: The safety adherence level does not have a significant effect on the respective NSV forms during site activities.

H_1: The safety adherence level has a significant effect on the respective NSV forms during site activities.

At 95% confidence interval, the effect of the NSV forms was considered significant and the null hypothesis was rejected if the p-value from the correlation analysis was at most 0.05, otherwise, the null hypothesis was accepted.

Furthermore, a sensitivity analysis was also undertaken on the generated data to observe the effect of changes on some of the variables on the system's safety level. This involved varying the worker exposure length (β), ω_s, λ_I, and λ_S by values of -20, -60, -80, -95, and -99%, respectively and observing the effect of the varied reductions on the LSA, SNSV, and PUA.

3. Results and discussion

3.1 Construction site activity pattern and pre-behavioural observation analysis result

The outcome of the interview with the site supervisor revealed that the number of breaks that workers are allowed to take (N_b) was 1 with a total duration (T_b) of 1 hour (Table 4). The daily number of working hours (T_d) was 10. T_d disagrees with the 8 hrs/day standard recommended by the international labour organisation [58] and exceeds the average number of daily construction work hours in the US [59, 60] by more than 40%. The implication of this is that such long hours of work have the potential of causing fatigue [61, 62] which may trigger losses in concentration and subsequent SVs.

Table 4 Results obtained from the interview with the construction site supervisor

Parameter	W_d	β	N_b	T_b
Value	15	10	1	1

3.2 Observed safety violations

It was observed from the BO exercise that a total of 584 violations were committed from 24 SV types producing an average violation frequency of 24.333. Some of the SV types observed included putting nails in the mouth during carpentry tasks, working at heights while standing on unstable ladders, running on staircases while carrying a load, and work tool abuse. The three most frequent acts of violation were poor lifting posture/positions (165), not wearing nose masks in the highly dusty environment (78), and not wearing safety boots (69). The three least frequent violations were; working on a broken ladder, wearing slippery slippers, transporting long objects without alerting nearby traffic, and engaging in horseplay while carrying a load which all had one violation each. The description of the violations and their corresponding frequencies are presented in Table 5.

Table 5 Types of safety violations at the construction site under study and their corresponding frequencies

r	**Observed SV types (u_r)**	**Frequency** $f\{u_r\}$
1	Bad lifting posture	165
2	Not wearing a nose mask	78
3	Not wearing safety boots	69
4	Not wearing gloves when mixing concrete	63
5	Not wearing hard hats for protection from the sun	57
6	Putting nails in mouth	39
7	Disregard for human traffic during formwork installation at heights	19
8	Not wearing hard hats while working on scaffolds	14
9	Reaching too far to the sides while working on ladders	14
10	Working from an unstable ladder	12
11	Running while carrying a heavy load	9
12	Using the body as support while cutting planks	8
13	Worker carrying overload	7
14	Running on the staircase while carrying a load	6
15	Horseplay while working on a ladder	5
16	Abuse of work tool (machete)	4
17	Putting binding wire in the mouth	4
18	Inappropriate balance on a ladder while receiving a heavy load	3
19	Placing steel beams in an upright position without support	2
20	Working in the sun without wearing a shirt	2
21	Working on a broken ladder	1
22	Wearing slippery slippers	1
23	Transporting long objects without alerting nearby traffic	1
24	Engaging in horseplay while carrying a load	1
	Sum: 584 Average = 24.333	

Viewing the violations with respect to the nature of tasks undertaken, it can be observed from Table 6 (Col. 3) that more time was expended in observing some tasks (T_j^o) than others.

For example, the task of formwork installation ($T1$) [T_1^o], was much larger than that of plumbing accessories installation ($T11$) [T_{11}^o].

This action was intentional because the workers assigned to $T1$ [$N(w_1) = 89$] were larger in number than those undertaking $T11[N(w_{11}) = 1]$. However, when the ratio of T_j^o to $N(w_1)$ is considered (Col 5), it can be seen that the time spent in observing each worker at a task are generally the same with mean and standard deviation values of 0.33 and 0.04 hours respectively. This implies that a proportionately equal time was spent observing the workers. The mean observation value also agrees with the mean observation period value of 0.33 hours adopted at the pre behavioural observation stage of the study.

Also, it was observed that the largest number of SVs was committed during formwork installation ($T1$) while the least violations were produced during plumbing accessories installation ($T11$) and steel rods transportation ($T14$) [Col. 5, Table 6]. However, when viewed from the perspective of the number of violations per worker (Col. 6), it can be seen that the number of violations per worker (2) was highest in $T11$ and lowest (0.62) in electrical accessories installation ($T9$). On average, at least every worker at one time or another had been involved in an act of SV.

Table 6 Results of safety level indication analysis for tasks done on the construction site under study

j	$N\{w_j\}$	T_j^o	$t\{u_j\}$	$N\{u_j\}$	$\frac{T_j^o}{N\{w_j\}}$	$\frac{N\{u_j\}}{N\{w_j\}}$	$N^*\{u_j\}$	$t^*\{u_j\}$	ε_j^*	LSA θ_{Aj} (θ_{Vj})	I-NSV γ_j^I	S-NSV γ_j^S	100|(A-B)|/A	PUA1 (p_j) $\{\beta_j \le \beta\}$	PUA1 (p_j) $\{N\{u\} = 0\}$
T1	89	34.22	18.76	127	0.38	1.43	3.7	0.55	0.45	0.45(0.55)	37	82	121.44	1.00	0.00
T2	3	0.95	0.87	4	0.32	1.33	4.2	0.91	0.09	0.09(0.91)	42	479	1040.00	1.00	0.00
T3	32	11.67	8.85	53	0.36	1.66	4.5	0.76	0.24	0.24(0.76)	45	186	313.46	1.00	0.00
T4	49	14.27	11.62	78	0.32	1.59	5.4	0.75	0.25	0.25(0.75)	54	212	292.29	1.00	0.00
T5	64	17.30	10.97	84	0.25	1.31	4.8	0.67	0.33	0.33(0.67)	48	147	205.89	1.00	0.00
T6	24	7.92	2.16	17	0.30	0.71	2.1	0.30	0.70	0.70(0.30)	21	30	43.82	1.00	0.05
T7	20	6.67	5.04	30	0.32	1.50	4.5	0.79	0.21	0.21(0.79)	45	210	367.16	1.00	0.00
T8	63	20.88	15.78	90	0.34	1.43	4.3	0.73	0.27	0.27(0.73)	43	162	277.16	1.00	0.00
T9	13	4.33	1.54	8	0.33	0.62	1.8	0.35	0.65	0.65(0.35)	18	28	55.02	1.00	0.06
T10	19	5.87	3.20	27	0.31	1.42	4.6	0.55	0.45	0.45(0.55)	46	101	120.37	1.00	0.00
T11	1	0.33	0.33	2	0.33	2.00	6	1.00	0.00	0.00(1.00)	60	600000	999900.00	1.00	0.00
T12	36	12.90	10.70	53	0.36	1.47	4.1	0.82	0.18	0.18(0.82)	41	226	452.18	1.00	0.00
T13	7	1.92	1.09	9	0.27	1.29	4.7	0.44	0.56	0.56(0.44)	47	83	77.20	1.00	0.00
T14	2	0.78	0.78	2	0.39	1.00	2.6	1.00	0.00	0.00(1.00)	26	260000	999900.00	1.00	0.00

SD: Standard Deviation; A: I: NSV; B: S-NSV; DI: Derived Index; NA: Not-Applicable

Table 7 Results of safety level indication analysis for the construction site under study

	$N\{w_S\}$	T_s^o	$t\{u_s\}$	$N\{u_s\}$	$\frac{T_s^o}{N\{w_s\}}$	$\frac{N\{u_s\}}{N\{w_s\}}$	$N^*\{u_S\}$	$t^*\{u_S\}$	ε_s^*	LSA $\theta_{AS}(\theta_{VS})$	I-NSV γ_j^I	S-NSV γ_j^S	100|(A-B)|/A	PUA1 (p_s) $\{\beta_j \le \beta\}$	PUA1 (p_s) $\{N\{u\} = 0\}$
Total	422	140	91.44	584	NA	NA	57.3	9.62	4.39	NA	573	41952	NA	NA	NA
Mean	30.14	10	6.53	41.71	0.33	1.38	4.1	0.69	0.31	NA	41	2996.6	NA	NA	NA
SD	NA	NA	NA	NA	0.038	NA	1.14	0.21	0.21	NA	11.49	6942.5	NA	NA	NA
DI	NA	NA	NA	NA	NA	NA	NA	0.65	0.35	0.35 (0.65)	41	118.2	188.31	1.00	0.00

SD: Standard Deviation; A: I: NSV; B: S-NSV; DI: Derived Index; NA: Not-Applicable

It was clear from the results that the potential to trigger unsafe conditions into accidents existed in the site. The workers' actions during the BO exercise seemed to indicate that many of them lack awareness and had poor knowledge concerning what actions are risky and the consequences that could potentially occur from their unsafe behaviours. There is a need for improved safety consciousness by the management towards developing an improved safety culture that can influence perception as it concerns its importance to management.

3.3 Level of safety indications

It was observed that the level of safety adherence in the system as indicated by the system's LSA was low ($\theta_{VS} = 0.35$) [Table 7]. Among the 14 tasks undertaken at the site, only three tasks namely Formwork Filling ($T6$), $T9$, and Planks/bamboo cutting ($T13$) with LSA values of 0.76, 0.65, and 0.56 exhibited safety adherences above the LSA marks above 0.5 (Col. 8, Table 6). $T11$ and $T14$ exhibited no safety adherence whatsoever as the LSA values for both tasks were 0. This implied that the workers responsible for both tasks continually committed unsafe acts throughout the tasks.

For a ten-hour daily shift of activities, the number of initiated violations that occurred in the system as indicated by the I-NSV was 41 on average (4.1 per hour) [Table 7]. $T9$ initiated the least SVs (18) while the highest I-NSV occurred with $T11$. When the daily number of workers in the site of 15 is considered (Table 4), the daily average I-NSV per worker is approximately equal to γ_s^I(Table 7). The implication of this is that about 4 unsafe acts are initiated every hour by a worker on the site.

The initiated accidents when sustained at various intervals while undertaking tasks resulted in a much larger number of SVs across all observed tasks as revealed by the S-NSV [Table 6 Col 12]. For example, the respective S-NSV values for Steel rods cutting ($T2$) and Steel mat laying ($T8$) with I-NSV values of 42 and 43 respectively, were 479 and 162. The impact of sustaining SVs after their initiation increased the number of unsafe acts during tasks by as much as 43.82% at the least and over 900,000% at the most and a system mean increase of 188.31% [Table 6, Col 13]. $T14$ was particularly worthy of note as the value of its daily I-NSV (26) ranked as one of the least when compared to the other tasks, however, its sustained violation value of 260,000 was second only to $T11$ in terms of SVs among tasks.

This could imply some or all of the following,

i. The workers may lack appropriate knowledge and awareness on how to conduct their tasks safely.
ii. Poor or unavailable protection equipment
iii. Inadequate correctional and compliance resources in the form of task supervision to ensure that all tasks are done according to expected safety requirements.

Regarding the PUA1, it was observed for all tasks in the system, the probability of committing a safety violation in course of construction work at the site was 1.00 [Table 6, Col 14] indicating the highest likelihood of SVs occurring among tasks and within the system. Also, the general probability of not experiencing any safety violations for all tasks was zero implying that the probability of safety violations not occurring in the system within the daily work window was non-existent.

3.4 Comparison of the relationship and effect of safety adherence on initiated and sustained safety violations

The obtained Spearman correlation coefficient (r_s) for the test between I-NSV and S-NSV revealed an insignificant ($p - value = 0.2453$) low positive correlation (Table 8). This inferred that initiated SVs had little or no influence on sustained SVs during work activities and both are relatively independent events. As such, for construction site managers concerned with creating a safe work environment, limiting the number of initiated unsafe acts is a first step towards ensuring this. However, in situations where these acts cannot be entirely eradicated, then implementing effective monitoring and control strategies that prevent further escalation of such SVs becomes key.

A similar insignificant relationship ($p - value = 0.3990$) but a low negative correlation coefficient ($r_s = -0.2448$) was observed to exist between I-NSV and LSA. This also implied that initiated unsafe acts alone did not significantly affect the extent of safety adherence in the worksite. However, the LSA/S-NSV relationship ($p - value = 0.0000, r_s = -0.9746$), was adjudged to be highly significant and strongly negatively correlated implying that unsafe act sustenance was influenced by the level of safety adherence. It was clear from the results that if efforts are geared at reducing unsafe acts initiation and sustenance, then the likelihood of committing safety violations will be lowered and in effect, a safer work environment will be created.

Table 8 Results of correlation test for the site safety level indicators

SN	Tested Indicator pair	r_s	$p - value$
1	I-NSV/S-NSV	0.3326	0.2453
2	I-NSV/LSA	-0.2448	0.3990
3	S-NSV/LSA	-0.9746	0.0000

3.5 Effect of parameter changes on safety level in the construction site

The results of the simulation analysis (Figure 2) provided insight into various possibilities that exist in construction projects if attention is focused on the reduction of the safety level influencing factors considered in the study.

3.5.1 Influence of changes in the duration of worker exposure

Changes in the duration of time the workers (DWE) are exposed to tasks were observed to have an insignificant effect on the LSA. This is expected given the constant pressure to deliver assumption on which the model was built. Thus if the management implements a policy in which workers are not put under any undue pressure, the likelihood of increased SV rates will be low. However, increased reduction in the DWE may not be economically profitable for both the management and the workers given that the current daily window of activities exists within the required standard [50]. Furthermore, decreasing the DWE may lead to increased pressure on the workers to deliver and may consequently increase the number of SVs.

The reduction of the currently implemented DWE from 20-80% showed no effect on the probability of SV occurrences in the system as the PUA1 value remained unchanged from its current value of 1.00. However, beyond the 80% reduction mark (DWE < 2 hours), PUA1 steadily declined to 0.69 (obscured by the SVR curve in Figure 2). This revealed that shortening the length of work activities does have the effect of reducing the rate of SVs. Although implementing a less than two hours DWE may not be feasible when project completion times are considered, the observed results suggest that it may be possible to improve the safety level and prevent potential accidents at the site by splitting the total DWE into smaller intervals with periods of rest set in-between them for the workers. Adequate breaks are beneficial to workers as they help ease fatigue and improve performance [63]. It was also observed that there was no noticeable effect of DWE reduction on the probability of the system not experiencing zero unsafe acts (PUA2).

3.5.2 Effect of reduction in the duration of safety violation

A direct relationship was observed between the progressive decrease of the time spent on SVs and the LSA. However, its effect on PUA1 and PUA2 was insignificant (Figure 2).

The LSA is an indicator that provides information on the time expended on already initiated unsafe actions in the system. As such, once sustained unsafe actions (S-NSVs) are reduced or terminated, the system's decreased levels of violation will be reflected by a corresponding increase of the LSA.

This is further clarified by Figure 3 which shows the effect of DSV reduction S-NSV values. The lack of influence of the DSV on the probabilistic safety level parameters is expected. This is because the rate of unsafe action parameter which is the most significant influencer of the Poisson distribution-based models is a function of safety initiation and sustenance.

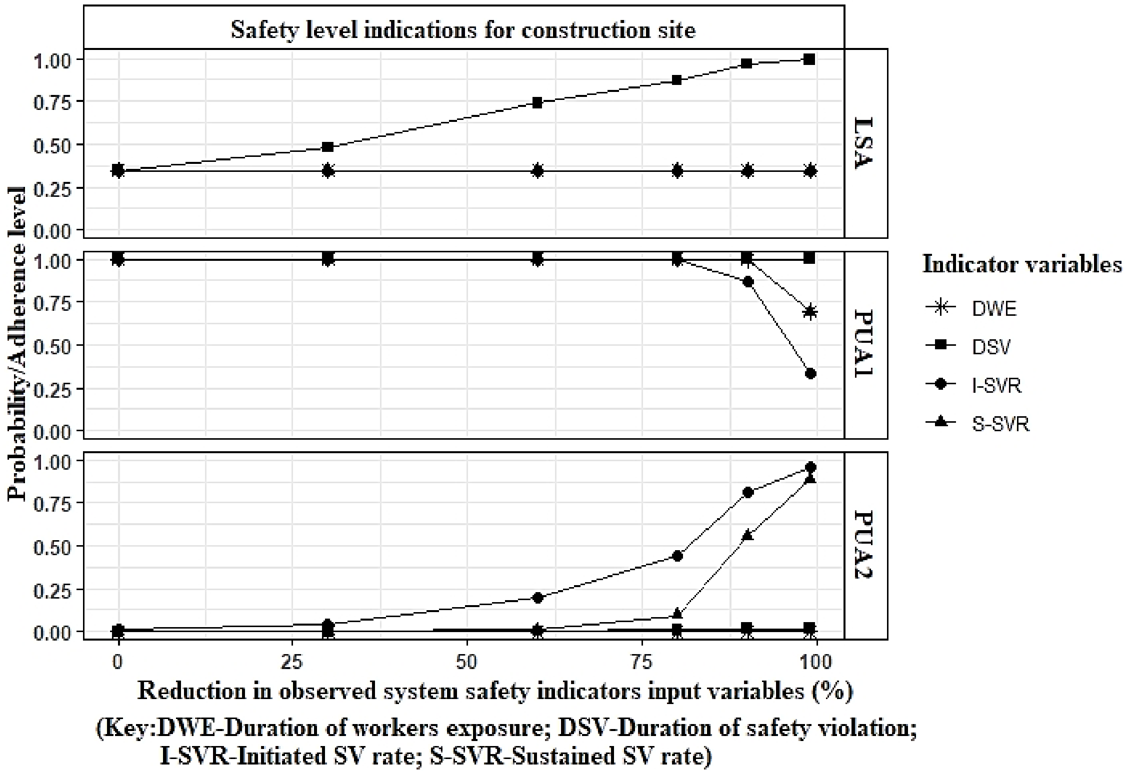

Figure 2 Sensitivity analysis results for construction site safety level indicators

SV sustenance is dependent on both the DSV and triggering of unsafe actions, but the number of initiated violations (I-NSV) is not DSV dependent. This infers that the DSV reduction is only as effective as the smallest I-NSV in the system.

Thus, as long as initiated unsafe acts exist in the system, PUA1 and PUA2 values will tend towards their extreme limits reflecting that elements of violations still exist in the system despite any degree of adherence. This situation is particularly beneficial for management with a drive for achieving zero accident targets as it means that more effort has to be made towards completely preventing all unsafe acts initiation and in effect eliminate all accidents.

3.5.3 Effect of reduction in safety violation rates

As observed from Figure 2, the safety violation rates (I-SVR and S-SVR) exhibit some similarities.

One of such is the ineffectiveness of their varying values on the LSA of the system. As earlier highlighted, the LSA exists only if at least one unsafe act initiation has occurred and does not depend on the number of SV initiations, but rather on the time spent in sustaining the initiation. In that regard, the adherence level of a system for the I-SVR cannot be determined with the use of the LSA indicator. Also, LSA is a function of the S-SVR and as such, dependent on the values of the LSA to describe the magnitude of accidents that exists per unit time in the system due to sustained SVs.

Another similarity exhibited by I-SVR and S-SVR is their influence on the PUA indicators. Regarding the PUA1, it can be observed from Figure 2 that at the current I-SVR and S-SVR value reduction range of 80-99%, the probability of unsafe act occurrence in the system began to decline from the maximum value to 0.69 and 0.34 respectively. As regards PUA2, the probability of zero SVs steadily increased at all levels of the respective I-SVR and S-SVR percentage reductions. This shows that the safety level of the system under study is strongly dependent on the number of initiated and sustained unsafe actions in the system. Thus, if unsafe act initiation and sustenance rates are reduced through the proper implementation of adequate safety prevention strategies, the probability of accidents occurring as a consequence of unsafe actions will be correspondingly reduced.

Another behaviour worth noting from Figure 2 is the degree of response of the PUA indicators to I-SVR and S-SVR values. Changes in I-SVR were observed to cause a greater effect on the site's safety level than those of the S-SVR. This indicated that although it is necessary to tackle and eliminate sustained violations, it is even more important to eliminate their initiations since SV initiations serve as the foundation for which other forms of safety violations are built.

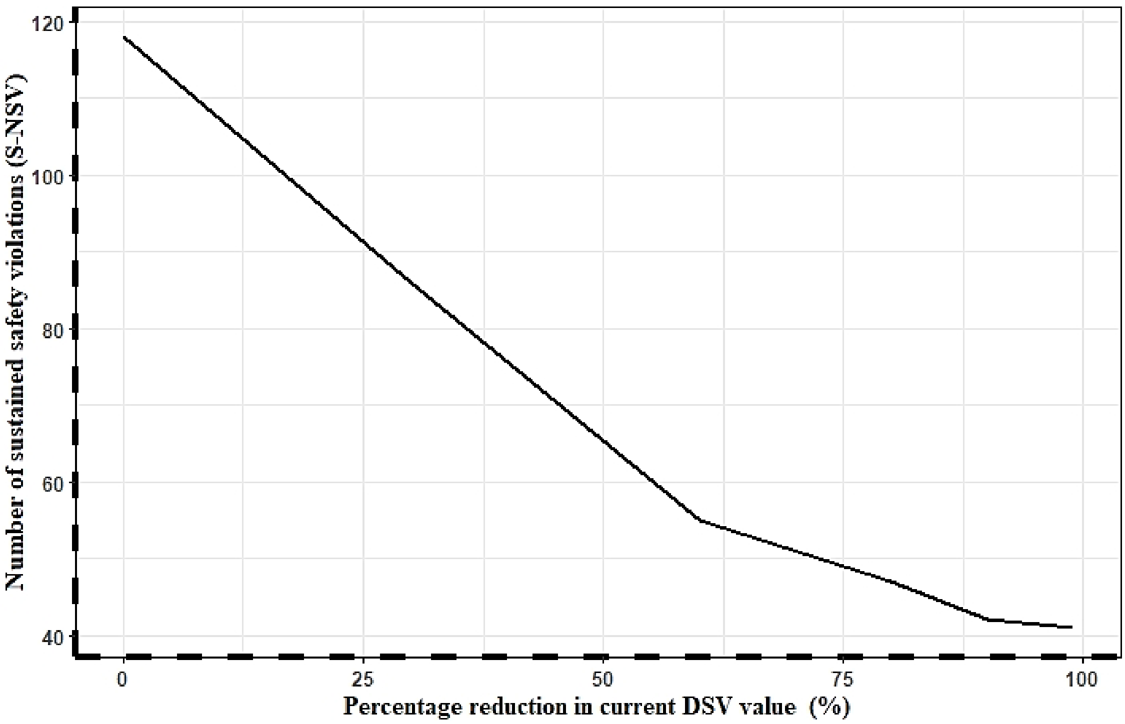

Figure 3 Effect of changing SV duration on the number of sustained SVs in the construction site

4. Conclusion

This study aimed to develop quantitative measures that provide information in the assessment of human factor influenced safety level in construction activities using a project site in Nigeria as a case study. To this end, adoptions and adaptations from the concepts of behavioural observation and Poisson probability distribution were utilised. Three quantitative safety indicators (LSA, NSV, and PUA) that are dependent on the observations of the number and interval of safety violations by members of the workforce were developed. The models when collectively utilised can provide insight into a construction work site's safety level. The application of the models on the unsafe behavioural observation data of a construction site in South-West Nigeria showed that the level of worker's adherence to safety which varied from one form of a task to another was generally low as indicated by the LSA. Also, given the current level of compliance in the organisation, the safety violations are likely to be persistent as indicated by the PUA.

The study suggests that more efforts should be made to cause a reduction in the number of initiated and sustained safety violations in the system. Such efforts should include the development and implementation of safety compliance strategies including awareness creation, task-specific safety education, and improved supervision. Also, it is recommended that more focus be directed at eliminating safety violation initiations as they serve as the bedrock on which all other forms of safety violations occur.

There are some limitations in this study that could be addressed in future research. First, the study was conducted using a single local-contractor scale construction site. Even though the safety behaviour of the workforce observed at this site may be similar to those of other local-contractor scale construction projects, the results obtained in this study may not be completely reflective of the overall safety level of the Nigerian construction industry. As such, for validation and evaluation purposes, future research could be focused on the application of our methodology in estimating the safety levels of other local-contractor-scaled projects, as well as those of other project scales that are predominantly practiced in the country [15].

Secondly, the BO conducted did not consider the contexts in which the safety behaviour of the workers was observed. This subject is an important one which if properly understood, can help in the reduction of targeted unsafe conditions and improvement in workers safety behaviour in organisations such as the one studied given that the correct solution approaches are implemented. Besides, this knowledge can find relevance in human reliability analysis (HRA) investigation, specifically in the area of the nominal human error probability (HEP) determination for construction activities. This is an area where information is sparse and is thus worth considering as a future research prospect.

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