Human Factor Analysis Framework for Ghana's Mining Industry*

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Abstract

In an attempt to incorporate human factors into technical failures as accident causal factors, researchers have promoted the concept of human factor analysis. Human factor analysis models seek to identify latent conditions within the system that influence the operator's action to trigger an accident. For an effective application of human factor analysis models, a domain-specific model is recommended. Most existing models are developed with category/subcategory peculiar to a particular domain. This presents challenges and hinders effective application outside the domain developed for. This paper sought to propose a human factor analysis framework for Ghana's mining industry. A comparative study was carried out between three dominated accident causation models and investigation methods in literature; AcciMap, HFACS, and STAMP. The comparative assessment showed that HFACS is suitable for incident data analysis based on the following reason; ease of learning and use, suitability for multiple incident analysis and statistical quantification of trends and patterns, and high inter and intra-coder reliability. A thorough study was done on HFACS and its derivative. Based on recommendations and research findings on HFACS from literature, Human Factor Analysis, and Classification System – Ghana Mining Industry (HFACS-GMI) was proposed. The HFACS-GMI has 4 tiers, namely; External influence/factor, Organisational factor, Local Workplace/Individual Condition and, Unsafe Act. A partial list of causal factors under each tier was generated to serve as a guide during incident coding and investigation. The HFACS-GMI consists of 18 subcategories and these have been discussed. The HFACS-GMI is specific to the Ghanaian Mines and could potentially help in identifying causal and contributing factors of an accident during an incident investigation and data analysis.

Keywords: Human Factor Analysis, Causal Factor, Causation Model, Mining Industry

1 Introduction

The mining sector since its commencement has been regarded as a hazardous profession and always at war with nature and its forces. Illness, injuries, and accidents are seen as part of the job, leaving safety practitioners and researchers with the tough task of identifying the latent and active failures within the system in the hope to prevent or mitigate future occurrences(Patterson and Shappell, 2009). As a safety-critical domain, the strategy adopted across the world is to control the accident frequency and severity through technological advancement (Amegbey *et al.*, 2008). Although the sector has seen an improvement in safety, it is still recognized as one of the most high-risk professions across the world (Mitchell *et al.*, 1998; Coleman and Kerkering, 2007). The sector only employs 1% of the global workforce but account for 8% of work-related fatalities (Stemn, 2018). In South Africa, the mining industry recorded 51 fatalities in 2019 which is the lowest figure in the history of the industry (Farmer, 2020). The South African mines also recorded 2406 and 2447 injuries in 2019 and 2018 respectively (Farmer, 2020). From 2004 to 2019, the United State mining sector on average recorded 44 fatalities each year and rated second-highest concerning the fatality rate recorded in the private sector in 2007(Poplin *et al.*, 2008; Garside, 2020). In Ghana, the sector records on average 5 fatalities and 51 serious injuries every year (Stemn, 2018). These alarming figures are a clear indication that causal factors identification and analysis focused research is required in the mining industry.

It is acknowledged that, without much understanding of accident causation models and theories, accidents will continue to occur within a complex sociotechnical system (Hollnagel, 2016). Understanding accident models and theories help in the identification of causal and contributing factors to accidents and inform apt system reforms and accident countermeasure development (Salmon *et al.*, 2012). Development of appropriate countermeasures can only be achieved through incident investigation and analysis. Incident investigations and analyses are critical in ensuring one understanding of the underlying factors that contributed or initiated the accident as well as indicating the weakness in a system where safety can be improved (Salmon et al., 2012). For this to occur, the organisation must put in place a well-structured procedure and process to ensure comprehensive incident data collection, quality investigation and analysis, and implementation of lessons and recommendations from the investigation and the analysis process (Stemn *et al.*, 2018). Effective implementation of the lessons and recommendation within a system enable double-loop learning and present opportunities for improving the system safety (Stemn *et al.*, 2020).

An accident occurs within a complex socio-technical system as a result of the interaction between technological, environmental, human, and organisational factors (Rasmussen, 1997; Reason, 2008). Losses occur when there is a failure in the defence or barriers at the technological, environmental, or organisational level which is

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mostly triggered by the human factors as depicted in Fig. 1.

Human factor has received significant attention in the field of incident investigation and analysis for the past ten years due to its contribution to the occurrence of accident (Newbold, 1926; Reason, 1990; Gordon *et al.*, 1996; Reason, 2000; Patterson and Shappell, 2010; Liu *et al.*, 2018). Human factor according to the International Ergonomics Association is the interactions among humans and the sociotechnical component of a system taking into consideration ways to optimize human well-being and improve the system's overall performance (Shappell and Wiegmann, 2013). The subcategory of the human factor which is given much attention in the industrial setting is the error component (Brehmer, 1993; Maiti and Bhattacherjee, 1999; Amegbey et al., 2008; Hosseinian and Torghabeh, 2012). Error in this context refers to events in which a planned sequence of mental or physical activities fails to achieve its expected outcome (Reason, 1990). Much attention is given to human error as it is the trigger of accidents. Adopting newton's law of inertia to safety, a deficiency or failure within a system will remain latent unless acted upon by an external force (human error) which results in an accident.

Recent models and studies on accident causation tend to look at accident/incidents taking into account the whole system and how the component within the system interact with each other(Reason *et al.*, 2006; Von Thaden *et al.*, 2006; De Landre *et al.*, 2007; Shappell and Wiegmann, 2013). These shift the focus from a single element of accident causation (Human error) to system failures and deficiencies. These recent models and studies focus on the system or organisational approach to accident investigation and prevention to eliminate failures and deficiencies rather than identify culprits at the operating end.

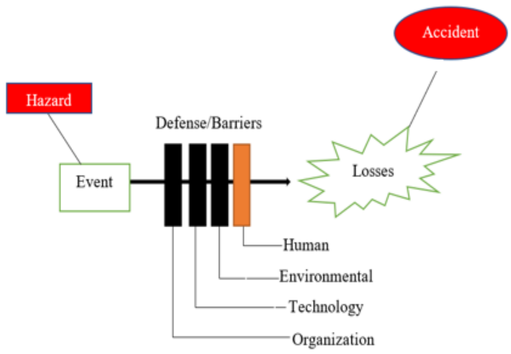


Fig. 1 System Component Interactions

This study seeks to identify opportunities for improving the safety performance within the Ghana Mining industry through effective incident investigation by proposing a human factor Analysis framework for the Ghanaian Mining Setting.

1.1 Human Error Taxonomies

In an attempt to move from the concept of technological malfunction in accident causation, human error was introduced as the cause of accidents within the industrial setting in the mid-twentieth century. This concept of human error considers the system as error-free and needs to be protected from humans at the operating end (Woods *et al.*, 2010). With this assumption, the basic cause of accidents was associated with human error and the only way to prevent accidents or minimize its consequence is to improve the individual at the sharp end. In view to understand the contribution of human factor/error in accident causation, many human error models have been proposed. These models address human error from five perspectives; the psychosocial perspective (Helmreich and Foushee, 1993), the cognitive perspective (Rasmussen, 1982; Wickens and Flach, 1988), the ergonomic perspective (Edwards, 1988), the behavioral perspective (Petersen, 1978) and the epidemiological perspective (Suchman, 1961).

However, recent models and researches on accidents have shifted the focus from human failure to system failures or deficiencies. (Woods *et al.*, 2010). System approach models and studies seek to reveal the latent conditions(Reason, 1990), such as poor illumination, poor standard operating procedures, manufacturing defects, poor design, and maintenance failure, that created the conditions causing the operator to trigger the accident. With this line of research, human error is not considered as the basic cause of an accident but, rather as an outcome of a latent condition within the system. The system approach model, which seeks to understand the role of human error in accident causation and has gain must popularity and attention in safety literature is the Swiss-Cheese model.

Swiss Cheese Model (SCM)

In an attempt to explain why and how an accident occurs within a complex system, Reason (1990) succeeded in his study on accident occurrences within complex systems and proposed the Swiss Cheese Model (SCM). The SCM represents the planes/levels; senior management/decision-maker, line management, precursor/precondition, production activities, and defences, of an organisation or a system as a slice of cheese and the deficiencies or failures; poor communication, poor equipment design, and maintenance, violation of safety procedure, in each plane/level as the holes within the cheese slice as shown in Fig. 2. The holes in the slice (deficiencies in the planes) are the active and latent failures that cause nearly all accidents within an organisation (Reason, 2000), which is mostly triggered by the operator or the individual at the sharp end. The system becomes susceptible to an accident when the hole in each plane in the system line up. Active failures are acts committed by the operator or the individual at the operating level resulting in an accident, which is mostly referred to as the immediate cause of the accident. Latent conditions are error provoking conditions or situations that create long-lasting holes or weaknesses in the defence of the system (Reason, 2000). These conditions remain dormant within the system until it combines with an active failure and a trigger to create an accident opportunity.

In the mid-1990s, the SCM mark I was modified (SCM Mark II) to reduce the four productive levels to three, organisation, workplace/task, and individual, with an extension of the defences plane from one to three as shown in Fig. 3. The modification was necessary, to give specific and detailed understanding with regards to how each level of the system contribute to the occurrences of accident (Reason *et al.*, 2006). The SCM II introduces a latent path leading from the organisation level directly to the defence planes. This pathway account for accidents such as Challenger and Piper Alpha accident, in which there was no immediate active failure, (Reason et al., 2006).

While the SCM I and SCM II give a conceptual idea on how an accident occurs, they failed to give a clear and detailed explanation of the stages in the development of organisational accident/incident and how to investigate these accidents to find the causes and deficiencies within the system.

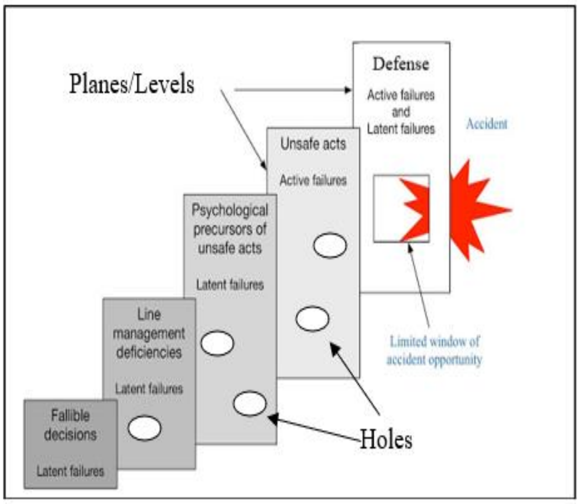


Fig. 2 SCM Mark I (Reason *et al.*, 2006)

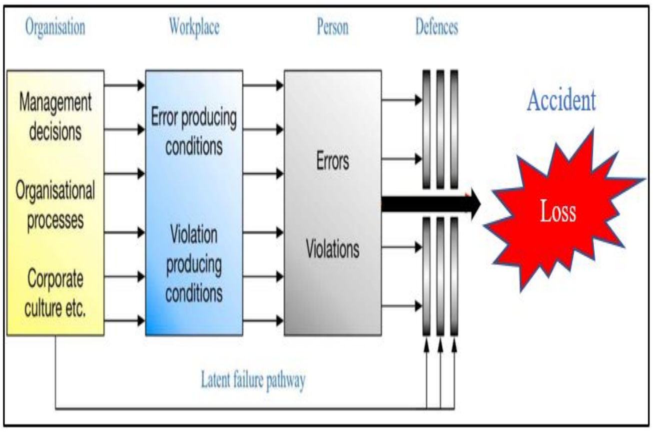


Fig. 3 SCM Mark II Adapted (Reason *et al.*, 2006)

To fill this gap, Reason in 1997, developed the third version of the SCM (see Fig. 4), taking into account the path or direction to find causes and investigate accidents (Reason, 2016). With the SCM III, the top rectangular block indicates the main elements of an accident/incident whereas the triangular shape below illustrates the system producing the event. The red arrow indicates the direction for accident causation and the black indicate the step to investigate an event. The SCM III focuses on the barriers, controls, defences, and safeguards within the planes of the system.

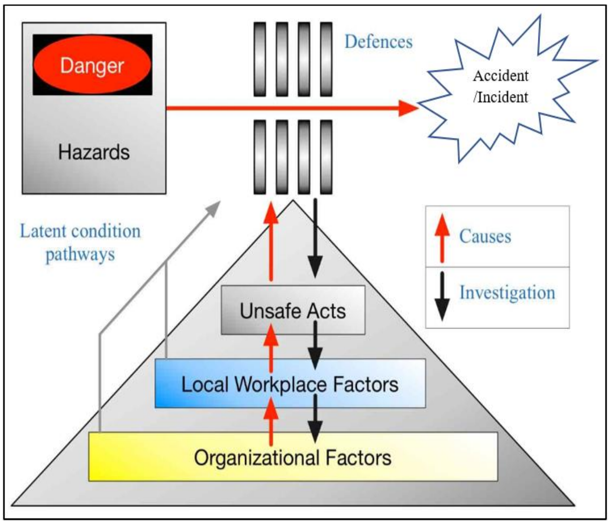


Fig. **4 SCM III Adapted (Reason, 2016)**

1.2 Human Factor Accident Causation Models

Whenever an accident/failure occurs within a socio-technical system, it is the organisation's concern to find out in detail exactly which defence fails. To meet this hard-hitting task, researchers over the years have developed conceptual models to unravel the mysteries of accident causation. Some of these models aid in understanding how incidents occur in theory whereas others are very useful in accident/incident investigation. These models help investigators to gain a detailed understanding of the causal and contributing factors of an accident so that effective corrective actions can be recommended and implemented. Examples of human factor accident causation models and investigation methods that dominate the literature include risk management framework and AcciMap (Rasmussen, 1997; Rasmussen and Suedung, 2000; Svedung and Rasmussen, 2002), Human Factor Analysis and Classification System (HFACS) (Wiegmann and Shappell, 2003) and Systems Theoretic Accident Model and Processes Model (STAMP) (Leveson, 2004)

1.2.1 Risk Management Framework and AcciMap

Rasmussen (1997) proposed a risk management Framework for accident investigation and analysis, popularly known as AcciMap as a contribution to understanding accident causation in a typical sociotechnical system. With the rapid advancement and complexity in technology, organisations are left with no option but to develop complex structures to ensure their safe operation. The operation of these structures is mostly influenced by dynamic environmental conditions such as economic and political pressure, legislation, market competition, and increasing awareness of safety which in the long run influences the work practice and human behaviour (Rasmussen, 1997). Existing causal model although study or consider the rapid technological advancement and its complexity, they fail to assess the influence of these dynamic environmental conditions in the operation of these complex systems. Rasmussen (1997) argued that the complex system together with the dynamic environmental conditions should be considered as one entity during risk management and how decisions and actions at each level interact to influence the performance of the system. The AcciMap model gives a graphical representation of system-wide failures, decisions, and actions contributing to the occurrence of an accident. The AcciMap method focuses on six organisational level: government policy and budget; regulatory bodies and associations; company planning and budgeting; physical processes and actor activities; and equipment and surroundings and analyses how these levels interact with one another to shape the occurrence of an accident. The risk management framework and AcciMap method, have been used widely to analyse accident (Johnson and De Almeida, 2008; Debrincat *et al* 2013; Salmon *et al* 2014; Underwood and Waterson, 2014; Newnam and Goode, 2015; Kee *et al* 2017; Zhang *et al* 2018). Fig. 5 shows a graphical representation of the AcciMap method.

1.2.2 HFACS

Until Reason (1990) proposed the swiss cheese model, industries for centuries have always embrace human error as a sequential theory. The introduction of the SCM in 1990, changed the industrial perspective of human error, and industries began to examine it systemically. Although, the SCM became popular and was extensively applied across industries, the absence of taxonomies of active and latent failures within the levels of the SCM limited its usefulness for accident analysis in some industries such as aviation (Wiegmann and Shappell, 2003). To address this gap, Wiegmann and Shappell (2003), developed taxonomies for each level within the SCM I and name the proposed "SCM I with taxonomies" Human Factor Analysis and Classification System (HFACS). Currently, in the field of accident causation, HFACS is one of the most extensively applied tools for human factor analysis(Harris and Li, 2011). The HFACS serve as a practical tool for investigators, analyst, and safety professionals (Wiegmann and Shappell, 2003), which enable them to systematically categorized the causes of accident/incidents. The HFACS structure is hierarchical, with nineteen causal factors categorized under four levels of failure. Deficiencies within the four levels include an active failure: unsafe act; and latent conditions: precondition for unsafe act; unsafe supervision and organisation influences, with each upper level influencing the subcategories at the lower levels as illustrated in Fig. 6.

1.2.3 STAMP

With the essential changes in the aetiology of accident due to technological advancement, Leveson (2004) argues that existing accident causation models fail to take into account accidents/failures that may result from the use of digital systems and software. Leveson argues that digital systems and software introduces new failure modes and must be accounted for in accident investigation and analysis to prevent future occurrences. Existing accident causation models mostly focus on the electromechanical component and how it is protected against human failure. Leveson (2004) is of the view that this changes and advancement in technology stretches the limit of the current model and proposed the System-Theoretic Accident Modelling and Process (STAMP) model which take into account digital system and software failure, cognitive complex human activities and societal and organisational influence during risk assessment, incident investigation and incident data analysis. Whereas existing accident models are event-based, the STAMP model is a constraint-base. With the STAMP model, accident occurs as a result of inadequate control of component failures, dysfunctional interaction and external disturbance. To prevent accident within a socio-technical system, safety constraints are imposed from the upper level on the lower levels on mechanisms and factors that influence human behaviour to trigger an accident. The model assesses the socio-technical system as hierarchical levels of control with each level imposing safety constraints on the level below. The STAMP model proposed the following taxonomy of control failure: (1) inadequate control of action; (2) inadequate or missing feedback; (3) inadequate execution of control of actions (see Fig. 7). Due to the model's origination from the engineering setting, current applications such as Ouyang *et al.* (2010) have introduced the "mental model flaw" to account for human structure in the system.

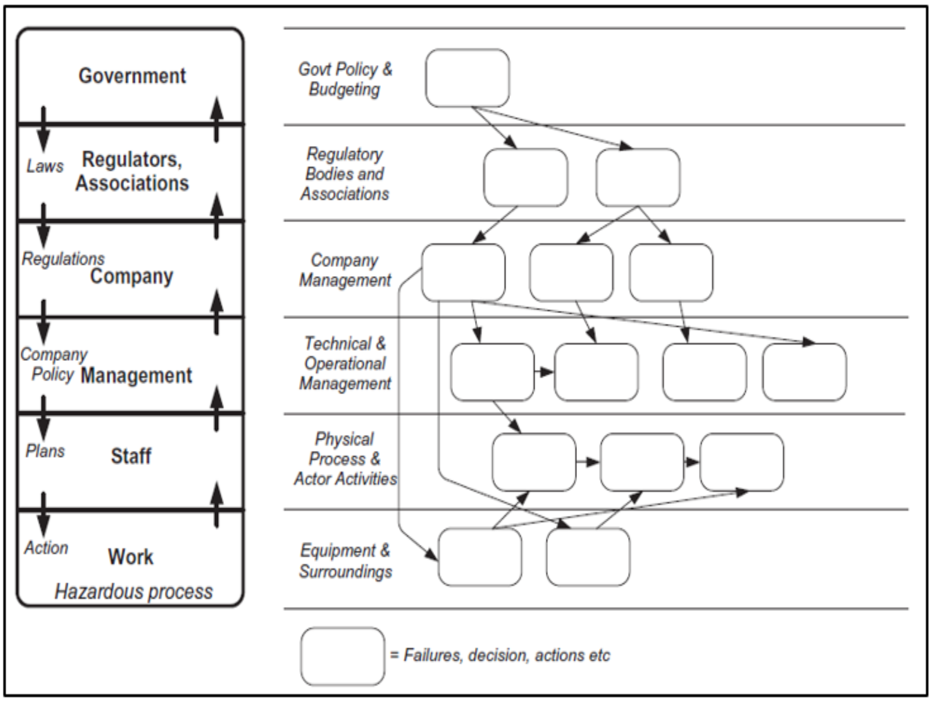


Fig. 5 Risk Management Framework and AcciMap Method (Salmon *et al* 2012)

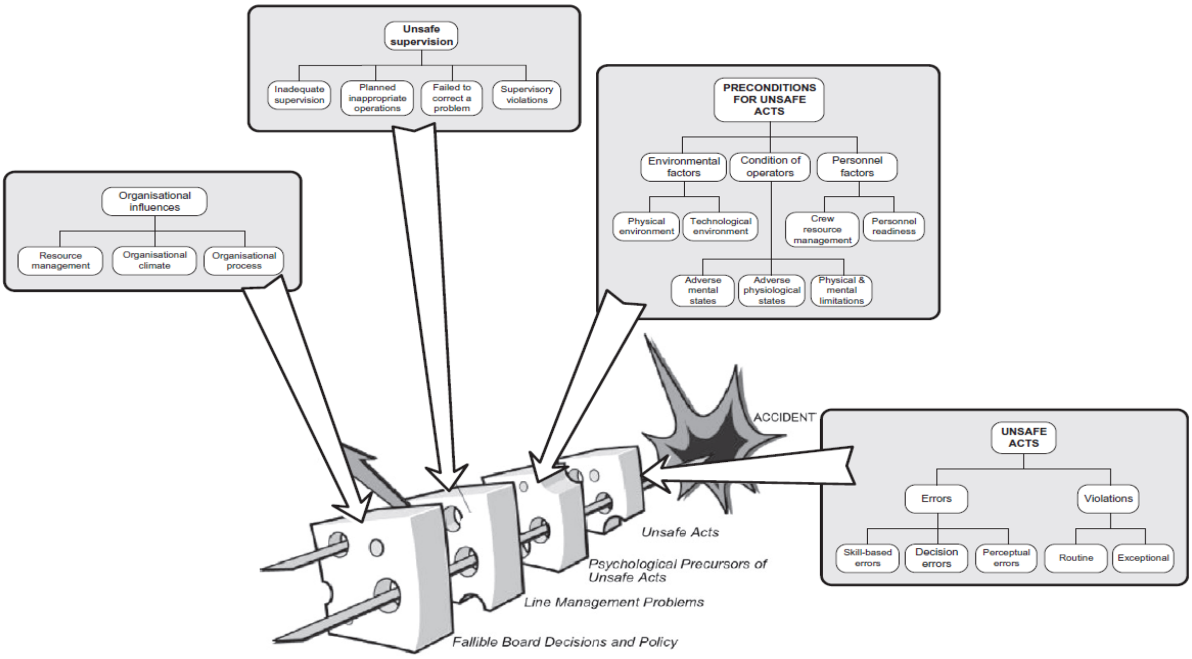


Fig. 6 HFACS Taxonomies Overlaid on SCM I (Salmon *et al* 2012)

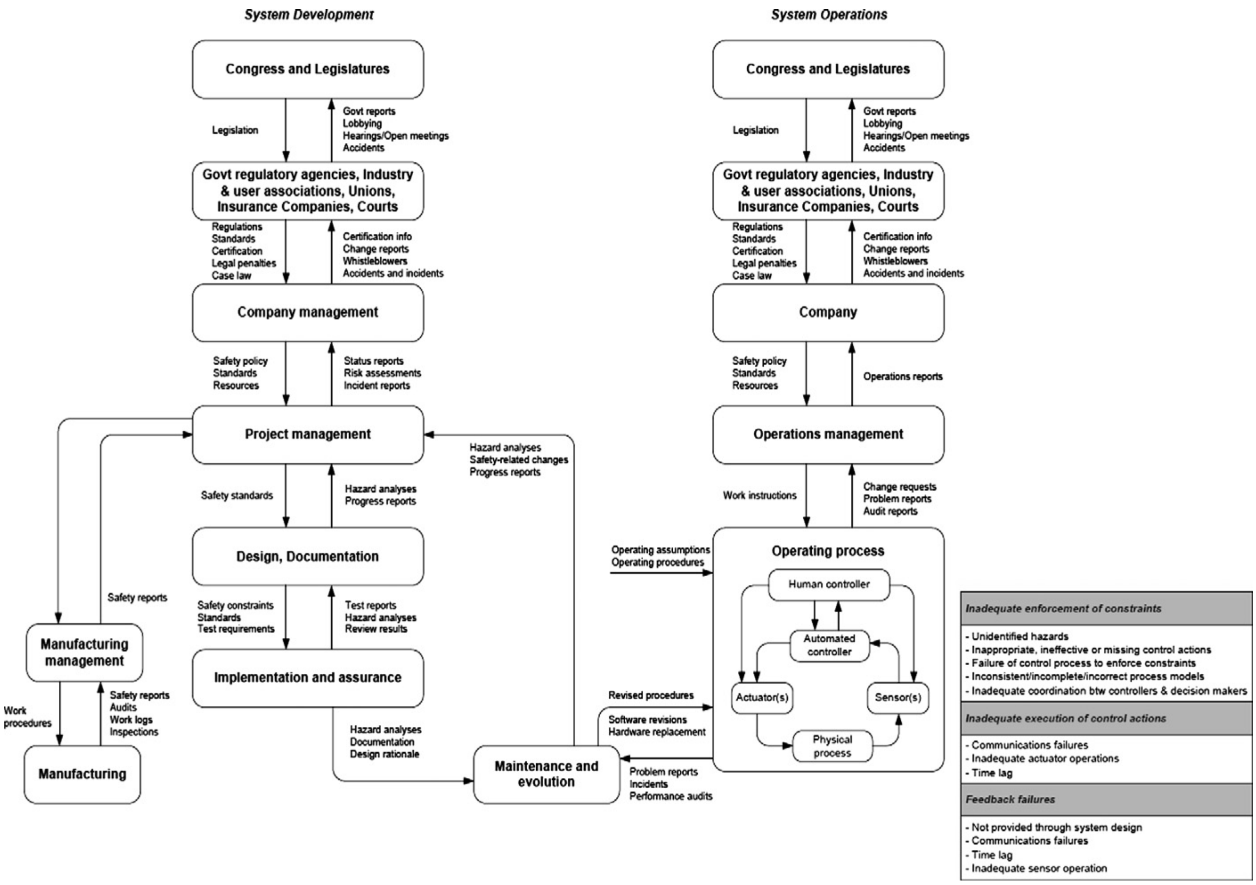


Fig. 7 STAMP Taxonomies and Socio-Technical Safety Control Structure (Salmon *et al* 2012)

2 Resources and Methods Used

2.1 Comparison of AcciMap /HFACS /STAMP

With the recent shift from finding a single cause of accidents to understanding the failures in a dynamic complex system such as organisational or management deficiencies, accident theory/model has also evolved from the chain model (Domino theory); and human behaviour and actions model (cognitive reliability and error analysis model) to system analysis model (such as AcciMap, STAMP, and HFACS). The system analysis models allow the investigator to consider both blunt end factor (management level, government, and regulatory agencies) and sharp end factor (operator acts) that contributed to the occurrences of the accident and also analyse the relationship or influence between the blunt end and the sharp end. The application or use of a particular system analysis model for accident analysis or investigation depends on three variables namely usability/ease of learning, the validity of its analysis, and reliability of its analysis. The usability of a system-based model is mostly influenced by the features of the model, the characteristic of the investigator/analyst, the type of incident under investigation or analysis, and the technical, organisation, and physical environment of the socio-technical system (Cathy and Nigel, 1996). Considerable knowledge is required for novice users in the application of AcciMap, HFACS, and STAMP for incident analysis. Effective application of the STAMP model for accident analysis requires in-depth knowledge and understanding; and control theory concept (Igene and Johnson, 2019) as compared to AcciMap and HFACS. Despite the easier use of the AcciMap as compare to the STAMP model, guidelines are required for correct identification and placement of contributing factors at the appropriate level and mapping causal relationships between them (Igene and Johnson, 2019). The taxonomic nature of the HFACS enables easy application and ease of learning, compare to AcciMap, although it has its root from the aviation setting (Salmon *et al* 2012; Zhang *et al* 2018). HFACS has been successfully applied in the mining sector (Patterson and Shappell, 2009; Lenné *et al* 2012; Liu *et al* 2018) with little or no alteration for accident analysis in the identification of causal factors of an accident. Little is known about the applicability of the AcciMap and the STAMP in the mining industry. Even though the AcciMap and STAMP are quite flexible in their application as compare to the HFACS (Salmon *et al* 2014; Underwood and Waterson, 2014), they cannot statistical quantify the relationship among contributory factors (Wang *et al* 2018; Zhang *et al* 2018) and not suitable for multiple accident data analysis (Salmon *et al* 2012; Zhang *et al* 2018; Igene and Johnson, 2019).

The AcciMap, STAMP, and HFACS were all developed with the objective of modelling a socio-technical system when a failure occurs to determine the contributing factors. Each model although applied a different methodological approach for incident analysis, they were all developed based on a recognized accident causation theory or principle and have been adopted in different domains for incident data analysis (Salmon *et al* 2012; Underwood and Waterson, 2014). Most practitioners or researches measure the validity of a model by comparing the output to set recommendation from multiple analysts or expert opinion (Igene and Johnson, 2019), little of such study exist for the validation of the Accimap, STAMP, and HFACS model.

Reliability of a model is referred to as the extent to which the model upon its repeated application or trail yields the same result (Carmines and Zeller, 1979). Reliability in this context is measured or determined in two ways; intra-rater and inter-rater reliability. Inter-rater reliability measures the degree of agreement of the outcome of different analysts classifying failure within a system whereas intra-rater reliability measures the consistency of an analyst over time in classifying failure within a system (Olsen, 2013; Ergai *et al* 2016). The HFACS due to its taxonomic nature, measure both high inter and intra-reliability as compare to the AcciMap and the STAMP(Salmon *et al* 2012). Research on the reliability of the HFACS models has been successful and exhibited an acceptable level of reliability (79%) (Ergai *et al* 2016) whereas other works measured lower reliability, 52% (O'connor, 2008), 39.9% (Olsen and Shorrock, 2010) and 35.6% (Olsen, 2011). Few studies exist on the reliability of the STAMP and AcciMap model. Goncalves Filho *et al.* (2019) in their inter-rater reliability study of the STAMP and the AcciMap observed high reliability with the STAMP (68%) than the AcciMap model (38%), which is below the benchmark of 70% as suggested by Baysari *et al.* (2011), Olsen (2011), Olsen and Shorrock (2010) and Wallace and Ross (2006). The summary of the comparative assessment between AcciMap, HFACS, and STAMP are presented in Table 1.

From the comparison analysis, HFACS is recommended for incident/accident analysis in the Ghanaian mining industry base on the following reasons:

(i) Ease of learning and use due to its taxonomic nature
(ii) Suitable for multiple accident/incident data analysis and statistical quantification of patterns and trends among contributing factors (Li and Harris, 2006; Tvaryanas *et al* 2006).
(iii) High inter and intra-coder reliability as compared to the STAMP and AcciMap model.

Table 1 Comparison Summary of HFACS/AcciMap/STAMP

Category	Sub-category	Model/Tool		
		AcciMap	**HFACS**	**STAMP**
Usability/Ease of learning	Novice	×	√	×
	Expert/Specialist	√	×	√
	Multiple incident Analysis	×	√	×
	Trends and path Analysis	√	√	×
	Statistical Quantification	×	√	×
	Flexibility	√	×	√
Reliability	Inter-rater	√	√	√
	Intra-rater	×	√	×

√= Yes ×= No

3 Results and Discussion

3.1 HFACS and Its Derivatives

While the HFACS framework was initially developed and applied successfully in military aviation for accident analysis, other industrial settings have also successfully applied the HFACS framework in their domain for accident analysis with little or no alteration. Most alterations/modifications made were to address the deficiency in the HFACS framework, not taking into account the influence of external factors such as government and regulatory bodies in accident occurrences. These include the marine, HFACS-MA (Chen *et al* 2013); coal mining, HFACS-CM (Liu *et al* 2018) and HFACS-IM (Patterson and Shappell, 2010); railway, HFACS-RR (Reinach and Viale, 2006); oil and gas, HFACS-OGI (Theophilus *et al* 2017); and aviation, HFACS-ADF (Inglis *et al* 2010)and HFACS-ME (Rashid *et al* 2010). Fig. 8 shows the key modifications made to the original HFACS framework for use in several different domains or sectors.

Although the issues of external influences or factors have been addressed in most of the derivatives, most of the subcategories such as misinterpretation of traffic calls and hypoxia are not applicable outside the aviation industry. Salmon et al. (2012) and Olsen and Williamson (2017) argue that for effective usage and achievement of high reliability outside the military aviation setting, the HFACS framework should be made domain-specific. The HFACS framework is underpinned by the SCM mark I, though the layers from SCM mark I have been modified (Reason *et al* 2006), reducing the levels/layers from four to three in the SCM mark III. Modification of the HFACS framework base on the SCM mark III could result in a reduction in the size of the coding system, which is acknowledged as a key factor to attaining high reliability(Olsen and Williamson, 2015; Olsen and Williamson, 2017). Based on these reasons, a modified HFACS framework, HFACS-GMI, is proposed for the Ghana Mining Industry.

3.2 HFACS-GMI Framework

The framework proposed is a derivative of the HFACS proposed by Wiegmann and Shappell (2003). The modified framework by the authors was based on the SCM III proposed by James Reason, with input to better correlate to the Ghanaian mining industry.

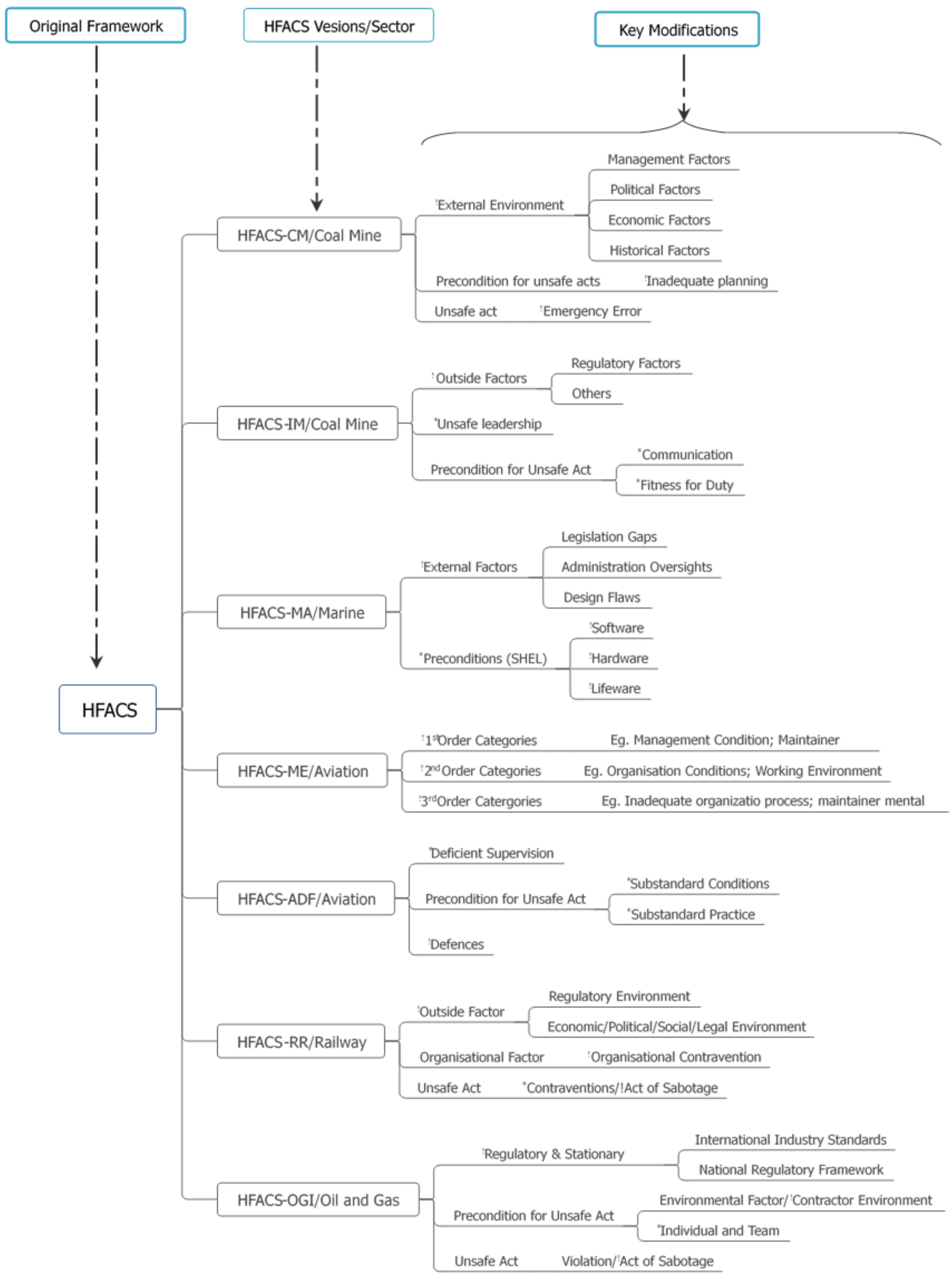
The modified framework, Human factor Analysis, and Classification System – Ghana Mining Industry (HFACS-GMI) have 4 tiers, namely; External influences/Factors, Organisational Factor, Local Workplace/Individual Conditions, and Unsafe Act. The addition of external factors/influences was based on recommendations proposed by several scholars (Reinach and Viale, 2006; Patterson and Shappell, 2010; Salmon *et al* 2012; Liu *et al* 2018; Igene and Johnson, 2019). The organisational factors level was adopted from the original framework with some alterations including renaming; organisational climate to corporate climate, resource management to management decision, and organisational processes to operational processes. A new tier, local workplace/individual conditions, was introduced. At this tier, the term 'leadership' was preferred to 'supervision' because, in the mining setting, there are some peoples who are not supervisors (e.g. site foreman and shift boss) but oversees the activities of the worker and also to eliminate instance where coders may refer to the term supervision as the operator's immediate supervisor (Patterson and Shappell, 2010) during incident data analysis. With the Unsafe act tier, the category of the error was changed to slip, lapse, and mistake. The violation term was also renamed to contravention. Fig. 9 shows the proposed HFACS-GMI framework, thick lines, and short dashes indicating the category and subcategory under each tire respectively.

3.3 Description of HFACS-GMI Tiers

3.3.1 External Influences/Factors

Research on accident investigation and analysis has proven that factors contributing to accidents go beyond the organisational factor or level (Chen *et al* 2013). Companies or organisations do not operate in isolation but within a certain environment govern by regulations, laws, and standards. These factors as well as the conditions within which the organisation operate can influence their activities and considered as a contributing factor to a mishap as shown in the Deepwater Horizon blowout of 2010 investigations finding (Theophilus *et al* 2017). These external influences/factors include; political/economic factors, national regulatory factors, and international industrial standards.

In the Ghanaian setting, the mining sector is regulated under the Minerals and Mining Regulation, 2012, with health and safety under LI 2182. This LI 2182 (Health, Safety, and Technical) is enforced by the Inspectorate Division of the Minerals Commission. The LI 2182 mandates the Inspectorate division to regulate and give guidance on the health and safety of the workers.



!= New category; *=Rename category

Fig. 8 Key Modifications to the HFACS Framework

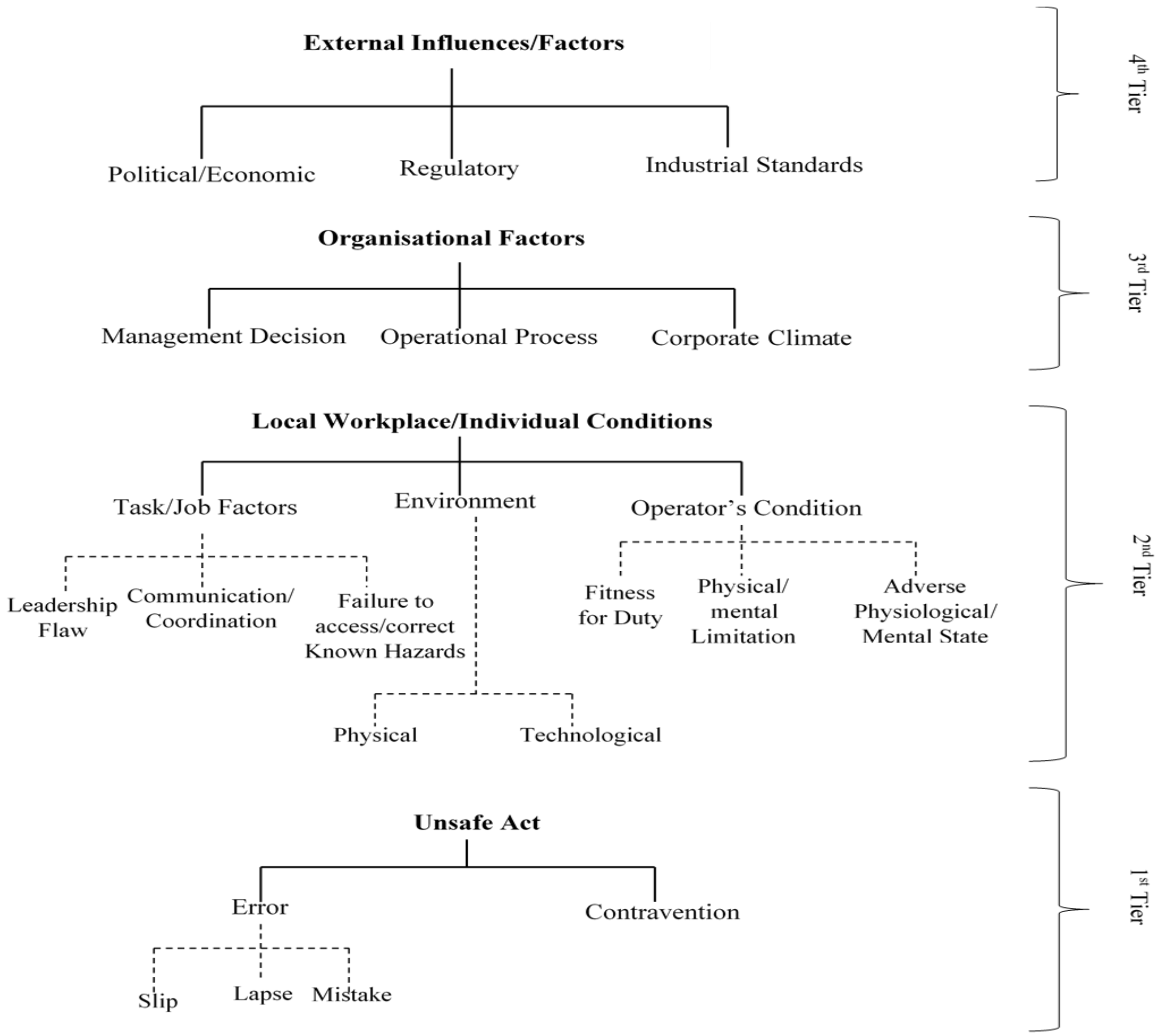


Fig. 9 Human Factor Analysis and Classification System-Ghana Mining Industry (HFACS-GMI) Framework

Lapses in the responsibility of the Inspectorate Division could result in suboptimal enforcement of the regulation and inadequate guidance on health and safety concerns which could be a major contributing factor to accidents occurred within the mines.

The Mines for effective management and control of work-related hazards have adopted some international standards such as the ISO 45001 and ISO 31001. These industrial standards give guidance on the management and control of health and safety issues and concerns within the workplace as well as measures for effective implementation. Deficiencies within the standards could affect the management and control of workplace hazards. Apart from this, there are also standards and guidelines from industry peak bodies such as the Ghana Chamber of Mines, International Council for Mining and Metals, which can affect the safety of a mine and contribute to the occurrence of accidents.

In terms of political factors, the absence of occupational health and safety law and national industrial standards for workplace health and safety could be one of the causes of safety-related mine accident. Some sections of the adopted standards do not fit into the Ghanaian industrial setting and this affects their effective implementation in the management and control of work-related accidents. Economic factors such as reduction in gold prices, high taxation, and royalty can force the mines to reduce their investment in safety in order to cut down costs. The economic pressures can also result in the lay-off of employees in order to reduce costs. This increases the workload of the worker and increases the risk of work-related accidents.

3.3.2 Organisational Factors

The organisational factor is the third tier of the framework. These deficiencies and failures are latent conditions provoke by the highest levels of the organisation. Identification of these causal factors during incident investigation and analysis is quite difficult because top management mostly presides over investigation activities and are not ready to assign the blame to the organisation for fear of liability. Three causal factors are considered under this tier: Management decision, Operational process, and Corporate climate. Management decision refers to the corporate decision and priority concerning the allocation of the company's resources and maintenance of its assets such as its human resource and equipment. Corporate climate refers to the organisation's policies, culture, and structure which reflect the working atmosphere of the organisation at any given time. The structure refers to the organogram and the order of command employed within the organisation. The culture reflects the fundamental beliefs, values, norms, attitude, and customs that resides within the framework of the organisational system. The policies refer to written and unwritten procedures that govern all activities and operations within the organisation. Operational processes refer to the day-to-day processes (e.g. operational tempo and schedules) and procedures (e.g. Standard Operation Procedure (SOP)) that governs the operations of the organisation.

3.3.3 Local Workplace/Individual Conditions

These are error provoking or violation-producing conditions within the organisation. These latent conditions influence the behaviour and actions of the operators to engage in an unsafe act that triggers an accident. Causal factors consider under this tier are; Task/job factors: leadership flaw, communication/coordination and failure to access/correct known hazards; Environmental factors: physical environment and technological environment; and Operator's conditions: fitness for duty, physical/mental limitation, and adverse physiological/mental state.

People with leadership roles within the mines are often tasked with the responsibility of providing employees with the opportunity to operate safely and also ensure a good culture with respect to established law and regulations. Leadership flaw in the context refers to the act of leaders that allows the breeding of violation and oversights within the organisation. Communication and coordination are means through which management relay instruction, procedures, and information to its employees and also means for getting feedback from the employees. Poor communication and coordination could result in a misperception of a given instruction or procedure and a breakdown in the organisational pathway and teamwork toward the achievement of its safety goal. Failure to access/correct known hazards is referred to instances where a supervisor allows for unnecessary risk due to improper assessment of the hazards associated with operation/activity or failure to correct a known hazard that could provoke an unsafe act or situation.

The Physical environment refers to the ambient and working surroundings such as the lighting, noise levels, and workshop layout, of the operator whereas the technological environment, focuses on equipment design and control, display/interface features, automation, and checklist outline issues-related.

Fitness for duty is referred to the individual readiness, both physical and mental, to perform his or her duty without any influence such as drug and alcohol, or factors that can reduce the individual functional capability which can contribute to the risk of failure within an organisation. Physical/mental limitations account for those situations and instances where the task allocated to the employee exceeds his capabilities. Adverse physiological/mental state refers to medical (e.g. acute illness or injury) or mental (e.g. fatigue) conditions that preclude safe performance of the essential duties of the job.

3.3.4 Unsafe Act

These are the active failures within the organisation and are often observed at the sharp end. They are referred to as the actions and decisions of operators that directly influence or trigger the occurrence of an accident within a socio-technical system. Under this tier, slip, lapse, and mistake, and contravention are considered as causal factors. Slips refer to failure of attention, memory, or technique. This type of error mostly happens with little or no conscious response during highly automated tasks. Lapse error occurs when there is a distraction of the sensory input visual, auditory, and olfactory, and the operator makes decisions based on the misinterpreted input. Mistakes are mostly knowledge-based errors that occur when the operator selects an incorrect/wrong procedure for a situation/task, or when solving a problem. Contraventions are intentional bending of rule and regulation or application of short-cut by the operator in the execution of his duties. Short-cuts are habitual deviations from the set rules and regulation and are most tolerable by management except when it yields an undesired outcome. Rule-bendings are isolated deviations from the set rule and are not acceptable by management.

3.4 Exemplars of Causal Factors

A list of causal factors under each tier was generated to be used as a guide during incident data coding and investigation. Most mines in Ghana have a list of causal factors that serve as a guide during incident investigation in the identification of the possible causes of an accident. These lists were obtained from the mining industries, in addition to some possible causal factors of accidents within the mining sector from literature (Patterson, 2009). The authors then had a brainstorming section on grouping the list of causal factors under the tiers of the HFACS-GMI framework. Tables 2, 3, 4, and 5 show a partial list of causal factors considered under each tier.

Table 2 A list of External influences/factors Nano-codes

Regulatory	**Political/Economic**
(i) Regulator's failure to oversee site activities	(i) Economic pressure to forgo-safety practice
(ii) Infrequent/ inadequate inspections	(ii) Workforce decrease due to economic pressure
(iii) Inadequate/ambiguous regulations	(iii) Political pressure
(iv) Inadequate enforcement of regulation	(iv) Fear of prosecution/legal pressure
(v) inadequate communication/coordination	(v) Workload increase due to economic pressure

Industrial Standards
(i) Deficiency in standard
(ii) Standard applicability to sites

Table 3 A List of Organisational Factors Nano-Codes

Management Decisions	**Operational Process**
(i) Inadequate staff training	(i) Lack of SOP
(ii) Inadequate contractor selection	(ii) improper attempt to save time
(iii) Excessive cost cutting	(iii) Outdated SOP
(iv) Improper/inadequate PPEs	(iv) Inadequate performance feedback
(v) Inadequate adjustment/repair/maintenance	(v) Improper work schedules
(vi) Inadequate staffing/manning	(vi) Unclear definition of instruction/procedure
(vii) Inadequate monitoring of compliances	(vii) Inadequate job hazard analysis

Corporate Climate
(i) Unclear chain of command
(ii) No accountability of SOPs
(iii) Inadequate enforcement of policies
(iv) Uneasy access to workplace policies
(v) Unclear/undefine organisational custom/values
(vi) Inadequate organisational communication
(vii) Conflicting assignment of responsibility

Table 4 A List of Local Workplace/Individual Conditions Nano-Codes

Leadership Flaw (i) Inadequate instructions, orientation and training (ii) Failure to ensure competency (iii) Inadequate identification/evaluation of loss exposure (iv) Encourage rule-bending/short-cuts (v) Failure to provide appropriate PPE (vi) Inadequate work planning or programming (vii) Disregarding of SOP	**Communication/coordination** (i) Lack of teamwork (ii) Misinterpretation of instructions (iii) Inadequate communication of hazards (iv) Lack of coaching (v) Unavailable/ineffective communication method (vi) Inadequate communication between work peers (vii) Inadequate vertical communication between workers and leader (viii) Standard terminology not used
Failure to access/correct Known Hazards (i) Inadequate hazard identification/assessment (ii) Failure to stop/correct unsafe acts or situation (iii) Failure to enforce/update SOPs, policies and procedures (iv) Failure to correct reported hazard (v) New process introduced without adequate training (vi) No or inadequate rest periods (vii) Poor pairing of crew members	**Physical Environment** (i) Poor housekeeping (ii) Temperature extremes (iii) Inadequate or excess illumination (iv) Inadequate ventilation (v) Slippery floor, walkway, roadways (vi) Confined spaces (vii) Congestion or restricted action/motion
Technological Environment (i) Inadequate guards and barriers (ii) Defective/dysfunctional tools and equipment (iii) Inadequate warning system (iv) Poor man-machine interfaces (v) Inadequate consideration of human factors or ergonomics (vi) Inadequate equipment and tool maintenance (vii) No installed or missing safety devices	**Fitness for Duty** (i) Inadequate rest requirement (ii) Use of illicit drug/alcohol (iii) Overexertion of duty (iv) Lack of sleep (v) Lack of physical fitness
Physical/Mental Limitation (i) Visual/vision/hearing deficiencies (ii) Memory failure (iii) Low learning aptitude (iv) Emotional disturbance (v) Temporary disabilities (vi) Inappropriate height, weight, size and strength reach	**Adverse Physiological/Mental State** (i) Fatigue due to task load or duration (ii) Fatigue due to mental task load or speed (iii) Exposure to health hazard (iv) Constrained Movement (v) Conflicting/confusing demands/directions

Table 5 A List of Unsafe Act Nano-codes

Slip (i) Inadvertent operation of incorrect control (ii) Improper lifting/loading (iii) Poor reaction time (iv) Incorrect application of procedure (v) Omitted steps in a procedure (vi) Wrong isolation of equipment (vii) Failure to lower equipment attachment when parked	**Lapse** (i) Misinterpretation of safety signs/warning (ii) Under/over estimation of object's weight (iii) Misjudge surface/weather condition (iv) Misjudge work depth/height
Mistake (i) Working at height without fall restraint/arrest (ii) Failure to use PPE properly (iii) Horseplay (iv) Serving equipment in operation (v) Wrong response to emergency situations (vi) Failure to identify hazard/risk (vii) Operating equipment without authority	**Contravention** (i) Failure to use provided PPEs (ii) Fear to wear seatbelt (iii) Disregard of SOP, procedures and policies (iv) Entry into unauthorized area (v) Operating equipment without training/authorization (vi) Operating/equipment at speed greater than the set limit (vii) Violation of training rules and procedure

4 Conclusions

This study sought to propose a classification system for investigation, analysis, and coding of incident data within the Ghanaian Mining Industry. A comparative study between AcciMap, STAMP, and HFACS reveal that the HFACS is most suitable for multiple incident data analysis and coding as well as quantify trends and pattern between causal factors. The comparative analysis also revealed that the HFACS yields high inter and intra-rater reliability than AcciMap and STAMP. HFACS-GMI was proposed after a thorough study of the original HFACS framework and its derivatives and consideration of recommendations proposed by several scholars. A partial list of causal factors nano-codes were generated to serve as a guide during incident coding and investigation. The HFACS-GMI is now at the developmental stage and requires a demonstration of its applicability, usefulness, and acceptance in the Ghanaian Mines. There is ongoing work that is seeking to contribute to that effect.

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