Applicability and Usefulness of the HFACS-GMI*

[1]T. Joe-Asare*, [1]E. Stemn, [1]N. Amegbey
[1]University of Mines and Technology, Box 237, Tarkwa, Ghana

Joe-Asare, T., Stemn, E. and Amegbey, N. (2021), "Applicability and Usefulness of the HFACS-GMI", *Ghana Mining Journal*, Vol. 21, No. 2, pp. 33-45.

Abstract

To present information such as causes of accidents and their consequences on the Ghanaian mining industry in the safety literature, classification schemes for incident analysis within the safety literature were studied. Human Factor Analysis and Classification Scheme (HFACS) emerged suitable for incident analysis. Base on its suitability for incident analysis within the Ghanaian Mining Industry (GMI), a derivative of the HFACS, namely HFACS-GMI, was proposed. This research seeks to study the usefulness and the applicability of the HFACS-GMI. Collectively, 56 incident investigation reports were obtained from an open cast gold mine in Ghana and analysed using the HFACS-GMI. Two cases, an equipment damage incident and an injury incident, were used to demonstrate the coding processing in identifying the causal factors. The analysis shows that most mishaps are associated with adverse workplace/operator conditions (151 references), with the physical environment (72.2%) being cited as the major causal code under the tier. Management decision showed a major contribution (74.1%) to mishap under the causal codes. Most cases were attributed to mistake error (57.4%) followed by the contravention (51.1%) of set rules and procedures with the operator's act tiers. Inadequate work standards (27.8%) and failure to ensure competency (24.1%) under the operational process and leadership flaw causal codes, respectively, were identified as the most cited nanocode. Management decision is critical in a mishap and should be given much attention in developing accident prevention strategies. The study has demonstrated that HFACS-GMI is very useful and applicable for incident analysis within the mining industry and is recommended to study causal factors across the mines.

Keywords: Mining, Human Factor Analysis and Classification Scheme-Ghanaian Mining Industry

1 Introduction

For the past century, accidents have been attributed to human error with limited focus on the system and other factors. Although failures were attributed to operator errors, mechanical and engineering problems/failures were the focal point in ensuring system safety (Shappell and Wiegmann, 2013). With this assumption, attention was focused at the design stage to ensure high system reliability and efficiency in addressing safety-related issues. Unfortunately, this theory of accident causation fails as it neglects factors that influence the operator at the sharp end to engage in an unsafe act, and the system continues to record accidents. To address this gap, accident analysis models/schemes such as Human Factor Analysis and Classification System (HFACS) (Wiegmann and Shappell, 2003), Systems Theoretic Accident Model and Process (STAMP) (Leveson, 2004) and AcciMap (Rasmussen, 1982) were developed to look at accident from a broader perspective by considering how each level within the socio-technical system influence the operator's act to trigger an accident. With this line of research, domains such as the USA, Australia and China have embraced the new shift and demonstrated the applicability of these models and presented topics such as the causes of accidents within a socio-technical system within their industrial setting (Patterson and Shappell, 2010; Salmon *et al.*, 2012; Gong and Li, 2018; Liu *et al.*, 2018; Zhang *et al.*, 2018).

Within the Ghanaian industrial setting, little is known on how the various levels within the socio-technical system contribute to accident occurrence. To address this issue and present information such as the causal and contributory factors of accidents in the Ghanaian mines, a comparative study was done among accident analysis schemes in the safety literature (Joe-Asare *et al.*, 2020). HFACS emerged suitable from the analysis, and a derivative Human Factor Analysis and Classification System-Ghana Mining Industry (HFACS-GMI) was proposed for incident analysis within the Ghanaian mines. This study seeks to evaluate the usefulness and applicability of the proposed incident analysis scheme through a detailed analysis of incident investigation reports obtained from an open cast gold mine.

2 Resources and Methods Used

2.1 Classification Scheme

The HFACS-GMI is a four-tier scheme: operators act, local workplace/individual conditions, organisational factors, and external influence. Table 1 gives a brief description of the HFACS-GMI casual categories.

2.2 Data

Incident investigation reports used in this study were obtained from a surface mine (Mine A) in Ghana. The Mine consider for the study is a metalliferous mine, with gold being its commodity of interest. It operates on two shifts, day (6: 00 am to 5: 00 pm) and night (6: 00 pm to 5: 00 am). The mining activity is characterised by blasting, load and haul, ore

*Manuscript received August 13, 2021
Revised version accepted December 15, 2021
https://dx.doi.org/10.4314/gm.v21i2.5

crushing and grinding, and mineral processing. Accident manuals of the mine were also collected to study the method underlying their investigation processes and influencing their search for causes. In all, fifty-six (56) investigation reports and two (2) accident manuals were obtained from the Mine. Investigation reports obtained were for incidents that had occur on mine between the years of 2016 and 2019.

2.3 Method Underlying investigation Processes at the Mine

The methods used at Mine A during incidents investigation in searching for causal factors is the ICAM tool. The causation model underlying this method is the complex linear model, the swiss cheese model (Reason, 2016), focusing on the first four socio-technical system levels (Stemn and Joe-Asare, 2021). The ICAM tool has gained much popularity in the mining industry as it extends the search for causal factors from error and violation to latent conditions within the system or organisation (De Landre *et al.*, 2006). The method used at the Mine organises causal factors into three elements: individual/team action, task/environmental conditions, and organisational factors, in answering how the accident happened and evaluating the performance of controls or defences. The method's structure is fixed attached with a checklist of causal factors to select from it.

2.4 Investigation Reports Analysis

Reports obtained from the mines were given reference identification numbers, and a thorough review was done on each to check its completeness. Reports which presented detailed information about the incident and identified all possible causes of the event were considered complete. After the review, two (2) of the reports were not complete and were not included in the coding process. Descriptive data, including time of the incident, age of the persons involved, total experience at current mine and total mining experience, were extracted from the fifty-four (54) reports.

The HFACS-GMI framework was fitted in Nvivo 12 data analysis software, and the investigation reports were coded onto the classification scheme. A consensus classification was adopted for the coding process through a round-table discussion by the three researchers. The first is a postgraduate research assistant and a PhD student, the second is a lecturer and an expert in incident investigation and risk management, and the third is a professor in Mining engineering and an expert in mine safety/human factors. Each HFACS-GMI causal code was counted once per case. With the operator's act, causal code could be either one of the errors subcode or violation, while both can occur. A demonstration of the coding process is presented below for an injury and equipment damage case. The two cases selected for the demonstration were because each report presents a detailed description of the causal factors identified. Tables 2 and 3 present the causal factors identified by the Mine during the investigation process using the ICAM tool. A summary of the emerging codes for case 1 and case 2 is presented in Table 4.

2.4.1. Case 1 (Equipment Damage)

Incident Description

On 04/04/2019, at about 0730 hours, an employee was operating a hoist to charge steel balls from the steel ball kibble into a chute. In the process of hoisting the loaded kibble, the rope on the hoist got removed from the hoist hook, causing the loaded kibble to fall onto the chute opening. This resulted in some of the steel balls spilling out. No injury was sustained.

Causal Description

The wire rope pulled out from the hoist hook due to the rope's excess tension from an overhang of the kibble while the operator drove the kibble, which over travelled above the upper limit switch and further made contact with the overhead crane beam. The safety limit switch failed to actuate because there has been earlier work on the rope without a corresponding adjustment to the limit switch settings by the maintenance team.

Table 1 Brief Description of HFACS-GMI Causal Codes

Tier	Causal Codes
Operator's act	*Slip*: failure of attention, technique or memory while undertaking an assigned task, e.g., failure to recognise hazards. *Mistake*: Knowledge base-error where a planned procedure fails to achieve the intended outcome, e.g., inadequate risk assessment. *lapse*: sensory input errors influencing operator's decision, e.g., misinterpretation of signs. *Contravention*: intentional or unintentional violation of set standard operation procedures, e.g., failure to use given PPE.
Local workplace condition	*Leadership flaw:* inadequate supervision or oversight by leader responsible for ensuring safe working operation, e.g., poor supervision and checking. *Communication and coordination*: how information is communicated from management to employees and vice visa and among employees. It also considers how employees coordinate to achieve the set goal. *Failure to access/correct known hazards*: situations where management fails to correct or access known hazards and put in measures before the commencement of an activity. *Physical environment*: immediate working condition of the operator and its influence on his activities, e.g., poor housekeeping, illumination. *Technological environment*: relate to issue with the design of equipment and its display/interface and component integrity, poor man-machine interface. *Fitness for duty*: employee's physical and mental readiness to perform his daily duties, e.g., use of illicit drug/alcohol. *Physical/Mental limitation*: allocation of a task beyond the capability of the employees, e.g., limited experience. *Adverse physiological/mental state*: condition either mental, e.g., stress or medial, e.g., impairment due to drug, that hinders the employee's safe operation.
Organisational factors	*Management decision: the* decision of management on resource allocation, human resource development, equipment purchase and maintenance and mine design, e.g., excessive cost-cutting, inadequate design of haul road. *Operational process*: processes and procedures that govern the organisations' day-to-day activities to achieve its vision, e.g., inadequate work standards. *Corporate climate:* working atmosphere of the mine, including the structure, policies and the culture, e.g., chain of command, policies enforcement.
External influence	*Political/Economic*: how government policies and the economic terrain, e.g., cost of doing business and market demand influence the operation of the mines, e.g., workforce reduction due to economic pressure or low market demand. *Regulatory*: how regulatory acts and bodies influence the activities of the mines., e.g., inadequate inspections. *Industrial standards*: how international standards adopted by the mines influences their operations, e.g., standard applicability to site.

Table 2 ICAM Analysis for Case 1

Board Theme	Causal Factors
Organisation/System Factors	*Inadequate Maintenance Management* There was evidence of the annual electrical and mechanical maintenance by the OEM for the hoist system; however, there was no evidence of a monthly preventative maintenance (PM) program for the hoisting systems' electrical and mechanical integrity in the process plant. The limit switch failure was a result of changes in the settings due to the previous work on the wire rope, which could have been anticipated ahead of time if such monthly PM's were being carried out as required. *Procedure* There is no procedure available to conduct the monthly preventative electrical and mechanical maintenance integrity of the hoisting system (overhead equipment) in the entire process plant.
Task/Environmental Conditions	*Inadequate Communication* It was revealed during the investigation that the wire cable/rope kinked some weeks prior to the incident occurrence and was worked on by some other plant involved persons without the feedback of such activity to other related disciplines. *Inadequate Training* It was revealed that the involved person had checked satisfactorily for some of the electrical and mechanical elements without having a full understanding of its functional integrity and inherent risk associated with the electrical and mechanical elements of the hoist pre-use checklist. Information revealed that the involved person had received training on overhead crane field assessment, which was facilitated by a Metallurgical trainer who may have limited knowledge in the mechanical and electrical operations of the overhead crane hoist system.
Individual/Team Actions	*Procedure Non-compliance* The involved person failed to comply with the hoisting inspection checklist, requiring involved persons to test the hoist by lifting the kibble without load. The involved person indicated that while inspecting the hoist, he failed to remove the hoist, which was hooked overnight to the loaded kibble, before testing. The involved person also revealed left the wire rope hanging overnight with the hoist hooked to the kibble containing the steel balls for the mill charging exercise. *Inadequate Supervision* It was established that the supervisor did not conduct a Planned Task Observation (PTO) on the involved person to determine whether or not he is applying all the aspects of the Ball Mill Grinding Media Charging Procedure the correct way. *Equipment Use* It was established that the involved person became inattentive while operating the hoist pendant *Control* together with the *emergency stop* buttons, which he could have applied upon noticing the hoist was travelling over the upper limit.
Absent/Failed Defences	*Safety Device failure* The safety limit switch failed to actuate because there has been previous work on the rope without a corresponding adjustment to the limit switch settings.

Table 3 ICAM Analysis for Case 2

Board Theme	Causal Factors
Organisation/System Factors	*Training* It was established that the involved mechanics and the other mechanics had not been trained by the company on the use of an overhead crane, slinging and lifting of items at the workshop though their job requires that they use such lifting gears. The team used an overhead crane and a 10-tonner fibre sling for the lifting. The company has no structured training plan for the workshop crew involved in slinging and lifting. *Risk Management* The culture of people operating the overhead crane at the workshop without training and authorisation influenced the involved person together with his team to operate the crane.
Task/Environmental Conditions	*Task planning and restricted workplace* The position of the involved person at the time of the incident was very restrictive. The task was not properly planned with all the resources (competent rigger and certified overhead crane operator. Non-availability of rigger and crane operator and JHA form at the workshop. *Hazard Analysis* There was no task-specific risk assessment (JHA) done before the commencement of the task, and the supervisor resorted to the use of Take-5 instead. The Take5 identified falling object as a hazard with "Lifting equipment must be in good condition" and "proper communication" as controls but was not adequate to unearth the inherent risk on the task. *Competency/experience/skill for task* Although the involved person and the other mechanics have at least 15 years of experience, none have received training on the use of overhead crane and lifting.
Individual/Team Actions	*Non-Compliance to Procedure* The team failed to comply with the Safe Lifting of equipment procedure, work instructions and warning signs posted at the workshop to warn untrained and uncertified mechanics from operating equipment. *Ineffective supervision* The foreman thought it was routine and simple because the skid was off the chasses and did not need attention. Foreman recognised the hazards associated with the task in the Take-5. He, however, did not display responsibility to ensure that the controls were adequately provided and the resources required are provided.
Absent/Failed Defences	*Control system* The team did not know the weight of the hoist cylinder and the weight the overhead crane was allowed to lift. *Inadequate knowledge of the potential hazard* The foreman/supervisor failed to ensure adequate identification of hazards and possible elimination of such hazards but assume it to be a simple task.

Case 1 Causal Factors Coding References

Lapse

Misinterpreted/misread equipment: It was revealed that the involved person had checked satisfactorily for some of the electrical and mechanical elements without fully understanding its functional integrity and inherent risk associated with the electrical and mechanical elements of the hoist pre-use checklist.

Contravention

Procedure Non-compliance: The involved person failed to comply with the hoisting inspection checklist, requiring involved persons to test the hoist by lifting the kibble without load. The involved person indicated that while inspecting the hoist, he failed to remove the hoist, which was hooked overnight to the loaded kibble, before testing

Leadership Flaw

Inadequate supervision: supervisor failed to conduct PTO to ensure that the correct procedure is followed.

Failure to ensure competency: Employees complete the checklist without having a full understanding of its functional integrity. This was attribute to the training facilitated by personnel with limited knowledge in mechanical and electrical operations.

Adverse Physiological/Mental State

Inattention: operator lost attention while operating the hoist pendant control together with the emergence button, which he could have applied upon noticing the hoist was travelling beyond the upper limit.

Communication/Coordination

Inadequate vertical communication between worker and leader: The supervisor fails to communicate modification on equipment to the worker:

Technological Environment

Electrical system failure/design flaw: safety limit switch failed to activate when the hoist travelled beyond the upper limit.

Physical/Mental Limitation

Limited experience/proficiency: the worker involved in the incident has inadequate electrical and mechanical operations training.

Management Decision

Inadequate preventive maintenance: The investigation reveals that there was no evidence of a monthly PM program for the electrical and mechanical integrity of the hoisting systems in the process plant.

2.4.2 Case 2 (Medical Treatment Injury)

Incident Description

On 16th November 2018, 1345hours, a mechanic sustained a contusion on his right foot. He was working with three other mechanics on a dump truck. The team were in the process of fixing a hoist cylinder when it slipped off the web sling they were using. A part of the hoist made contact with one of the mechanics' right foot.

Causal Description

The direct cause of the accident was due to the fact that slings holding up a hoist cylinder was inadequately strap, causing the hoist cylinder to slip and fell on the right foot of one of the mechanics while they were fixing a hoist cylinder of a dump truck.

Table 4 Summary of Case 1 and Case 2 Coding

Case 1		**Case 2**	
Codes	Ref.	Codes	Ref.
Operator's act - ***2***		*Operator's act* - ***2***	
Lapes	1	Mistake	1
Contravention	1	Contravation	1
Workpace/individual condition - ***5***		*Workplace/individual conditions* - ***5***	
Leadership flaw	2	Leadership flaw	3
Adverse Physiological/mental state	1	Physical/mental limitation	1
Communication/coordination	1	Failure to assess/correct known hazards	1
Technological environment	1	*Organisational factors* - ***4***	
Physical/mental limitation		Management decision	2
Organisation factors - ***1***		Operational processes	1
Management decision	1	Corporate climate	1

Case 2 Causal Factors Coding References

Mistake

Inadequate risk assessment: the team failed to conduct a specific risk assessment for the task, and the supervisor resorted to the use of Take-5 but failed to control the risk adequately.

Contravention

Non-Compliance to Procedure: the team failed to comply with the safe lifting of equipment procedure and warning signs posted "No operation by untrained and uncertified worker".

Leadership Flaw

Failure to ensure competency: Although the daily routine job of the involved persons requires lifting gears, none of the workers has received training on using an overhead crane, slinging, and lifting items.

Inadequate supervision: the foreman recognised the hazards associated with the task but failed to display responsibility to ensure that the identified hazards were adequately controlled.

Inadequate work planning/programming: the supervisor underestimates the complex nature of the task and therefore did not properly plan with all the resources like a competent rigger and a certified overhead crane operator.

Physical/Mental Limitation

Lack of competency: the involved persons have not been trained on the use of various lifting gears though their work requires the use of such equipment.

Failure to Access/Correct Known Hazards

Inadequate hazards identification/assessment: the supervisor knew the hazards involve with the task but failed to adequately assess them and put in the necessary measures to control them. Management Decision.

Inadequate staffing: Non-availability of rigger and crane operator at the workshop section

Inadequate Human Capacity Development: All mechanics at the workshop have not been trained on the use of lifting gears.

Operational Process

Inadequate work standards: there is no Job Hazard Analysis (JHA) form in the workshop section.

Corporate Climate

Poor Safety Culture: The culture of people operating the overhead crane at the workshop without training and authorisation influenced the involved person together with his team to operate the crane.

3 Results and Discussion

3.1 Incident/Employee Characteristics

This section gives a brief description of the age of the employee involved in the incident, the total and current mine experience and the time of occurrence of the incident.

3.1.1 Age of Involved Employees

A qualitative description of the ages of the employees involved in the accident is shown in Table 5. The young category (30 to 39) was mostly involved (33.3%) in an accident within the mines. Out of the 54 accidents, 24.1% of the employees involved were between the ages of 40 to 49. The younger age category (18 to 29) accounted for 7.4% of the incident recorded. The aged (≥ 50) category had the same percentage as the middle-aged category, 24.1%. Six of the report had no records on the age of the employee involved in the accident.

From the safety literature, several studies have been undertaken on the relationship between age and work-related accident. Some found relationships between age and occupational accident, e.g. (Salminen, 2004; Ghosh and Bhattacherjee, 2007), whereas other studies concluded no correlation exists, e.g. (Bennett, 1982). Examination of Table 5 indicated that young miner (30 to 39) are more likely to engage in an accident. Maiti and Bhattacherjee (1999), Ivaz *et al.* (2020) and Sari *et al.* (2004) made similar observations. Younger miners are less likely to be involved in a mine accident, which contradicts the observation made by Salminen (2004). This difference in observation could be a result of socio-cultural difference or the nature of the data used. Data used in this study covers both injuries and equipment damage incident, whereas data used by Salminen (2004) only focus on injury incident.

3.1.2 Mine Experience of Employees

Regarding the mine work experience of the employees involved in the accident (see Table 6), the majority of the employees (55.5%) involved in an accident within the mines are novices, with current mine experience of less than two years. Current mine experience refers to the number of years the miner has been with the mine under study, whereas total mining experience refers to the miner's total mining operation exposure (in years).

Table 5 Age of Employees Involved in the Accidents

Qualitative Description	Age of employee	Count
Younger	18 to 29	4
Young	30 to 39	18
Middle Aged	40 to 49	13
Aged	≥ 50	13
	Unknown	6

Table 6 Mine-Work Experience of Employees

Qualitative Description	Year	Current Mine Experience	Total Mining Experience
Novice	< 2	30	7
Minimum experience	2 to 10	21	19
Average experience	11 to 20	2	12
Above-average experience	≥ 21	0	11
	Unknown	1	5

Table 7 Work Shift of Accident Occurrence

Shift	***Day(n=35)***												***Night(n=19)***											
Hours	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0	1	2	3	4	5
Count	0	1	3	4	6	2	3	5	2	3	2	4	0	2	1	0	1	4	1	5	0	3	1	1

38.8% of the employees involved in an accident have current mine experience between two to ten years. 3.7% of the employees involved current mine experience ≥ 11 years. Regarding the total mine experience, most of the employees (35.2%) have minimum experience in mine operations. The novice category in the total mine experience is less likely to be involved (13%) in an accident. One report had no data on employee's current mine experience, and five reports had no information on employees total mine experience.

With much exposure to the mining terrain, a worker becomes aware of hazards associated with the mining operations and how to minimise/control them and work safely. The results (Table 6) indicate that work experience (current experience) is inversely proportional to the mine accident. Therefore, employees with less experience are more likely to be involved in an accident. Several studies in the safety literature recorded similar observations. For instance, in their study, Kecojevic *et al.* (2007) observed that mineworkers with less experience are most vulnerable to an equipment-related accident. However, Stemn (2018), in his analysis of incident data, could not conclude on the relationship between work experience and accident due to high missing information (32.2%) on involved employees work experience. Nevertheless, his data on workplace experience incident that employees with less than five years working experience are most likely (40%) to involved in a mine accident. On the contrary, Maiti and Bhattacherjee (1999) observed that novice and above-average experienced workers are at the same risk of involving in an accident. Comparing current and total mine-work experience, there is a deviation from studies in the literature. Mineworkers with less total mining experience are less likely to be involved in a mine accident. Workers with more mining experience may be complacent in their daily activities and may not take adequate time to identify and assess associated hazards with their work. Most of the workers have had the opportunity to work in different mines. Due to their mine-work experience, the mine may not take adequate time to induct on the job and the associated hazards with the new environment.

3.1.3. Work Shift

Time of injury occurrence with respect to the work shift is presented in Table 7. It is estimated that 64.8% of the incident occurred within the day shift, with most of the incidents (17.5%) occurring at 10 am. With the night shift, 26.3% of the incident occurred at 1 am.

Observing the time of accidents according to the work shift, most of the accidents occurred within the day shift, which contradicts the phenomenon that human nature is less active at night and workers on the night shift are more prone to accidents due to lack of concentration and fatigue (Ivaz *et al.*, 2020). Ivaz *et al.* (2020) observed that 65% of mine accident occurred during the night shift, which contradicts the observation made in the study. The mine has most of the activities within the day shift and a high percentage of the workforce working during the day shift. Also, the mines restrict some activities to the day shift. This could account for the high incident records during the day shift. Stemn (2018) also support the observation that majority of mine accident occurring the day shift.

3.2 HFACS-GMI Analysis Outcome

Table 8 gives a detailed description of the causal factors accounting for the accident that occurs within the mine. Since one incident might be associated with more than one causal code, the count/reference of the cases may be more than 100%. As seen in Table 8, the majority of causal factors are associated with workplace/operator's conditions (151 references). Organisational factors accounted for the second-highest causal factor (83 references) to an accident within the mine, followed by the operator's act (82 references). With external influence, only one case identified a regulatory factor as an accident causal factor. With regard to the causal codes, management decision is most often cited as a causal factor followed by the physical environment. Within the operator's act tier, the mistake was often cited, followed by the contravention.

3.2.1. Operator's Act

Some scholars cite this category as the major contributor to a mishap (Patterson and Shappell, 2010; Verma and Chaudhari, 2017), whereas others see it as a trigger of an accident (Joe-Asare *et al.*, 2020). The operator's act category was associated with 82 references of the cases, which place third among the HFACS-GMI tiers. This observation contradicts studies in the safety literature (Patterson and Shappell, 2010; Verma and Chaudhari, 2017), identifying operator's act in nearly all cases. This difference in observation could be attributed to socio-cultural differences and the model used at the mines during the investigations process to identify causal factors. Also, the model underlying the HFACS derivatives is the swiss cheese model mark I, which does not account for the latent failure pathway. The swiss cheese model mark I hold the assumption that accident occurs as a result of unsafe actor of the operator at the sharp end, which could account for the identification of unsafe act category nearly in all cases.

The causal codes were further categorised to give a detailed and systematic classification of the causes (see Table 9 (a, b and c). with regard to mistake error, inadequate risk assessment and failure to identify hazards/risk conditions were often cited. However, procedural non-compliance accounted for most of the contravention references. This could be attributed to leadership flaw, specifically inadequate supervision. Poor risk perception was often associated with the slip error. Inadequate induction of workers on the job and inadequate knowledge of the potential hazards associated with the work environment could account for the high record of this subcategory. Misinterpreted/misread equipment accounted for the lapse error reference.

Table 8 Reference and Percentages Associated with Causal Codes Categories

HFACS-GMI Tiers	Causal codes	Reference	n (54) (%)
4th Tier External influence	Political/economic factors	0	0
	Regulatory factors	1	1.9
	Industrial standards	0	0
3rd Tier Organisational factors	Management decision	40	74.1
	Operational process	30	55.6
	Corporate climate	13	24.1
2nd Tier Workplace/operator's conditions	*Task/Job Factors*		
	Leadership flaw	36	66.7
	Communication/coordination	15	27.7
	Failure to access/correct known hazards	10	18.5
	Environment		
	Physical	39	72.2
	Technological	18	33.3
	Operator's condition		
	Fitness for duty	3	5.6
	Physical/mental limitation	13	24.1
	Adverse physiological/mental state	17	31.5
1st Tier Operator's act	*Error*		
	Slip	21	38.9
	Mistake	31	57.4
	Lapse	2	3.7
	Contravention	*28*	*51.9*

Table 9a Exemplars of Slip Error

Slip subcategories	Reference
Poor risk perception	10
Wrong application of procedure	4
Loss of Concentration	3
Sleeping on the Job	2
Improper lifting	1
Improper position for task	1
Total	**21**

Table 9b Exemplars of Mistake Error

Mistake Subcategories	Reference
Failure to identify hazards/risk conditions	12
Inadequate risk assessment	12
Failure to conduct a risk assessment	5
Failure to take action on known Hazard	1
Failure to take action on known Hazard	1
Total	**31**

Table 9c Exemplars of Contravention

Contravention subcategories	Reference
Procedural non-compliance	15
Operating vehicle beyond the set speed limit	7
Failure to wear seatbelt	2
Operating equipment without training/authorization	2
Failure to Adhere to Instruction	1
Failure to use provided PPEs	1
Total	**28**

3.2.2 Local Workplace/Operator's Condition

These are unsafe act provoking conditions that increase the likelihood of an accident occurrence. This tier is further classified into task/job conditions, operator's environment and operator's condition. Under this category, the physical environment was cited as the error provoking condition, accounting for 72.2% of the cases. Leadership flaw was found to be responsible for 66.7 of the cases. Regard the operator's conditions, adverse physiological/mental state was cited as the major causal factor (31.5%) in the cases. Exemplars for leadership flaw, communication/coordination, technological environment, physical environment, physical/mental limitation and adverse physiological/mental state are present in Table 10a, 10b, 10c, 10d, 10e and 10f, respectively. Failure to access/correct identified hazards (9.3%) and inadequate hazard identification/assessment (9.5%) were identified as the exemplars for the failure to assess/correct known hazard causal code. Use of illicit drug/alcohol (3.7%) and lack of sleep (1.9%) was identified as the exemplars accounting for the fitness for duty causal code.

Leaders are to ensure adequate training, supervision and oversight of employees in the performance of their operations safely. The cultural setting is just that, with minimum leadership, employees turn to deviate from the set rules and SOP or are most likely to comment errors. Leaders failed to ensure adequate employee training within the mines and cited as a major contributor to an accident under this category. Inadequate supervision and work planning/programming had the second-highest contribution to the accident under the leadership flaw causal code. Due to high work overload, the leaders do not have enough time to supervise and adequately plan given tasks. Uneven/slippery surfaces were found to be the dominant exemplar under the operator's environment causal code. Complacency and fatigue were found to be mostly associated with adverse physiological/mental state. Due to the nature of the mining job (12 hours per shift), fatigue is seen as part of the job and a major contributor to mishap if not properly managed.

3.2.3 Organisational Factors

These are deficiencies in the organisational process that influence the occurrence of an accident. These latent conditions are challenging to identify or accept as a causal factor as management mostly heads investigation processes and approves the findings from an investigation process and may not want to behold liable for a failure or a mishap within the mines. The mine was very objective and ready to identify vulnerabilities within the organisational processes or management system. Organisational factor was reference 83 as a causal factor from the incident analysis. Under this category, management decision (74.1%) was identified as mainly being responsible for the mishap, followed by operational process (55.5%) and corporate climate (24.1%). Detailed classification of the causal code under this tier is presented in Tables 11a, b and c.

The major causal factors associated with management decision were inadequate human capacity development (22.2%), followed by inadequate preventive maintenance (20.4%). Management pays attention to employees training and is even worse among contract workers. Management introduces new process and equipment within little/no training to employee and mostly rely on workers with high total mine experience. There is no planned or scheduled maintenance program within the mine, and equipment undergoes maintenance only when it breaks down or a fault is identified. Most of the standard operating procedures used within the mines did not fully capture all the processes and steps required to carry out a task efficiently and safely and was cited as the major causal nanocode associated with the organisational process. Procedure non-availability was also observed under organisational process, and employee relies mostly on experience in the task execution.

Table 10a Exemplars of Leadership Flaw

Leadership Flaw subcategory	Reference
Failure to ensure competency	13
Inadequate Supervision	9
Inadequate work planning/programming	9
Inadequate inspection	2
Failure to provide appropriate PPE	1
Incompetent Supervision	1
Violation of SOP	1
Total	**36**

Table 10b Exemplars of Communication -/Coordination

Communication/coordination subcategory	Reference
Inadequate vertical communication between workers and leaders	7
Unavailable/ineffective communication method	5
Inadequate communication between worker	3
Total	**15**

Table 10c Exemplars Technological Environment

Technological Environment subcategory	Reference
Defective equipment/tool	6
Inadequate equipment/tool maintenance	5
Electrical system failure/design flaw	3
Inadequate technical design	2
Dysfunction equipments/tools	1
No installed or missing safety devices	1
Total	**18**

Table 10d Exemplars of Physical Environment

Physical environment subcategory	Reference
Uneven/Slippery floor	9
inadequate road maintenance	5
inadequate road design	5
Inadequate signs/labels installations	4
weather condition	4
congested/restricted motion	3
steep road gradient	3
Inadequate lighting	2
Confined space	1
Loose/falling rocks	1
Poor House Keeping	1
Restricted Visibility	1
Total	**39**

Table 10e Exemplars of Physical/Mental Limitation

Physical/Mental Limitation subcategory	Reference
Lack of competency	5
limited experience/proficiency	5
Inexperience with job task	2
Emotional disturbance	1
Total	**13**

Table 10f Exemplars of Adverse Physiological-/Mental State

Adverse Physiological/Mental State subcategory	Reference
Complacency	5
Fatigue	5
Inattention	3
Stress	2
Fears or phobias	1
Medical Condition	1
Total	**17**

Table 11a Exemplars of Management Decision

Management decision subcategory	Reference
inadequate human capacity development	12
Inadequate Preventive maintenance	11
Inadequate tools and equipment	6
Road Design Flaw	5
Inadequate staffing	2
inadequate equipment design	2
Lack/Inadequate contract management system	2
Total	**40**

Table 11b Exemplars of Operation Process

Operational Process	Reference
Inadequate work standards	15
Procedure non-availability	9
Lack of job hazard analysis	5
SOP inconsistent with job practice	1
Total	**30**

Table 11c Exemplars of Corporate Climate

Corporate Climate	Reference
Inadequate enforcement of policies	3
No Structured Program	3
Poor safety culture	3
Inadequate organisational communication	2
Speak-up issues	2
Total	**13**

4 Conclusion

This study tested the usefulness and applicability of a proposed derivative of HFACS, HFACS-GMI, through a detailed analysis of incident data obtained from surface gold mines in Ghana. The outcome of the study is highlighted as follows. (1) workers within the younger age category (30-39) are most likely to be involved in a mine accident. Novices accounted for the majority of the cases recorded within the mines, and most of the incident occurred within the day shift. (2) Among the four tiers, workplace/operator's condition was most cited in the cases as a causal or contributory factor. (3) Regarding the causal codes, the physical environment was mainly associated with most cases, with uneven/slippery floor being the major contributor to the category. (4) Most cited causal nanocode were inadequate work standards and failure to ensure competency associated with the operational process and leadership flaw, respectively.

The HFACS-GMI is very useful and applicable for incident analysis within the mining industry and is recommended for the study of causal factors across the mines in Ghana to present topics such as causes of accidents, consequences and effects on the Ghana mines in the safety literature.

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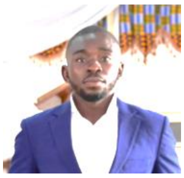
Authors



Theophilus Joe-Asare is a Teaching and Research Assistant and PhD candidate at the University of Mine and Technology (UMaT), Tarkwa, Ghana. He holds a BSc in Environmental and Safety Engineering from (UMaT), Tarkwa, Ghana. He is a member of Ghana Institute of Safety and Environmental Professionals, Red Cross Society and Society of Petroleum Engineers. His research interest is in the areas of Fire Risk Assessment, Occupational Hygiene, Accident Investigation and Control and Environmental Sampling and Monitoring.

Eric Stemn is a lecturer in the Environmental and Safety Engineering Department of the University of Mines and Technology (UMaT), Tarkwa, Ghana. Eric holds a PhD in Occupational Health and Safety from the University of Queensland (UQ), Brisbane, Australia, an MSc in Environmental Science from the Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana, and a BSc in Geomatic Engineering from the University of Mines and Technology (UMaT), Tarkwa, Ghana. Eric's research interests include Intelligent Risk Management, Occupational Health and Safety Management and using Remote Sensing and Geographic Information System for Environmental Management and Modelling.

Newton Amegbey is a Professor of Mining Engineering at University of Mines and Technology (UMaT), Tarkwa, Ghana. He holds a Dr-Ing from Technical University of Berlin, West Germany. He is a member of Mine Ventilation Society for South Africa, German Society of Mining and Metallurgy and Society for Mining, Metallurgy and Exploration, USA. His research areas are Mine Ventilation and Safety Engineering/Human Factors, Mining Regulations, and Environmental Management.