

## Original Research Article

# A Comprehensive Safety Strategy for Metalworking Industry: Integrating FRAM and PHA

Peter Onyango Ochieng , J.N. Keraita , Peter Nganga Muchiri\* 

Department of Mechanical Engineering, Dedan Kimathi University of Technology, Nyeri, Kenya



**Citation** P.O. Ochieng, J.N. Keraita, P.N. Muchiri. A Comprehensive Safety Strategy for the Metalworking Industry: Integrating FRAM and PHA. *J. Eng. Ind. Res.* 2024, 5 (4):188-203.

 <https://doi.org/10.48309/jeires.2024.491184.1137>

**Article info:**

**Submitted:** 2024-11-28

**Revised:** 2025-01-15

**Accepted:** 2025-01-30

**ID:** JEIRES-2411-1137

**Keywords:**

Comprehensive safety strategy;  
Frequency resonance accident model;  
Preliminary hazard analysis; Lagging  
indicators; leading indicators

**ABSTRACT**

This paper aims to develop a safety strategy for the metalwork industry to mitigate the effects of hazards, risks, and activities related to the metalwork industry. The study develops a safety strategy using quantitative and qualitative data on hazards, risks, and activities. Questionnaires, interviews, and workplace assessments were used to identify the activities, hazards, and risks in the company. The safety data were used to verify legal compliance and health. The researchers' safety assessment form, risks, hazards, and activities were analyzed using the preliminary hazard analysis (PHA). Functional resonance accident model (FRAM) was used by the researcher to develop the strategy based on the results from the questionnaires, workplace assessment, and the PHA categorizing them into the six variabilities of FRAM. The study found that the company gives a priority to production leading to poor maintenance planning difficulties which are a major obstacle to the safety of equipment and hence hazardous to the workers. The most common health hazards are dust, gases, and mechanical hazards including sharp objects. In addition, the company does not carry out pre-employment and periodic medical examinations which is helpful in the workers' placement. Safety performance was mainly driven by lagging indicators (injuries, illness, and fatalities) instead of employing safety-leading indicators. The developed safety strategy integrating PHA with FRAM will thus assist in improving safety in the metalwork industry.

**Introduction**

According to EVS metallic Precision solutions in 2023, global steel fabrication industry valued at over \$21 billion by 2024. There are around

10,000 workers that deal with metal and are members of an amalgamated union of Kenyan metal workers. However, there are many more people who are indirectly employed through scrap collection [1]. One of the main causes of declining worker health is accidents brought on

\*Corresponding Author: Peter Nganga Muchiri ([peter.muchiri@dkut.ac.ke](mailto:peter.muchiri@dkut.ac.ke))

by the machinery utilized and illnesses caused by pollutants. According to [1], workers who are exposed to high temperatures may experience dehydration, which can lead to an increase in accidents owing to worker tiredness. Occupational illnesses and accidents continue to be prevalent, especially in small and medium-sized businesses (SMEs). Due to a number of limitations, smaller enterprises are especially sensitive to occupational safety & health (OSH). Numerous studies emphasize the value of OSH training in order to alter this situation [2].

Because workplace health and safety are intrinsically related to employees' general well-being, they are seen as very important problems. The state of occupational health and safety in developing nations is problematic, though, workers must endure hazardous working conditions with little attention paid to safety concerns and little oversight from civil society or public organizations [3]. Locations where impoverished people are "employed" have inadequate safety and health records, which further worsen the problem. Because of its close relationship to severe poverty and workers' well-being, occupational health and safety is therefore crucial regardless of the kind of employment, size sector, or location of the workplace [4]. In addition, businesses do not fully comprehend the advantages of having a secure and healthy workplace [5]. It is considerably more difficult to rehabilitate those who have been exposed to hazardous job conditions in a culture that does not care about disabilities. Nevertheless, not much study has examined these interconnected concerns, despite their obvious connection to poverty, impairment/disability, and unfavorable working conditions. This lack of knowledge is also an important sign of less attention paid to this most important agenda which results in frequent reported and non-reported hazards at the workplace [6].

According to statistics, occupational diseases diagnosed in Kenya by DOSHS, 2010-2011, hazards related to the metalwork industry continue to be dangerous and there is a greater number of workers suffering from occupation-related diseases in comparison to other industrial sectors. This response is because of its complex interplay of technology and human

factors. Safety management is particularly challenging in the metalworking sector because of the high level of technology and manual labor involved in the manufacturing process. In the past, trailing indicators (fatalities, illnesses, and injuries) have largely determined and drove safety performance. Implementing safety-leading indicators (reporting near misses) to gauge worker safety performance can result in improvements and enhancements in safety performance [7].

To provide in-depth approach to the study of the metalwork industry, the company was selected for the study because it has an organizational structure in place with a defined population and clusters of various processes and activities carried out in a typical metalwork industry. The form of safety management utilized by industries is called the 'traditional safety management'. The characteristics include: communicating down, not engaging the employees, relying on punishment to gain safety behavior change, technical interventions that are short-term, focused, using safety tools after an accident and injury, the safety performance is lagged and the safety director is also responsible for safety program but does not have any power to change the program [8].

However, with the mentioned efforts among others to enhance the safety of employees, some of the biggest industrial catastrophes are still famous in different parts of the world. Challenges that are implied by scientific studies of these accidents by researchers included several major shortfall of the present safety management system. Some significant industrial disasters continue to occur often around the world in spite of these and other initiatives to improve worker safety. Researchers' scientific investigations of these incidents hinted at certain significant flaws in the current safety management system [9]. More than half of the accidents can be attributed to the lack of human and management aspects rather than to risks that people are unable to predict in terms of the technical aspect. These outcomes aroused more profound research to enhance the safety management systems. As a result of analyzing 217 organizations, [10] found that analyzed programs of quality and programs of safety have much in common. He wrapped up and said,

“Safety is a dimension of quality, after everything, the elimination of defects involves the eradication of unsafe work.” [11] conducted a mixed methods evaluation of health and safety hazards in a scrap metal recycling facility; [12] conducted a study on safety practices among metal workers in Bangladesh; and [13] conducted a study on occupational health in a steel rerolling mill in relation to high noise level and temperature. Just about all the earlier reviews estimate safety increases following the enforcement of chosen safety factors with many of the approaches being generalized and inclined towards causation safety, models of causation safety arrived at by Australian OHS Education Accreditation Board [14]. However, there is a shred of limited evidence in the literature regarding the development of safety strategies for the metalwork industry. The reliance on the evaluation of health and safety to assess safety in the metalwork industry has its advantages and drawbacks.

The contribution of this paper is to fill the literature gap by developing a safety strategy for the metalwork industry derived from integrating safety elements such as PHA and FRAM to develop a comprehensive a strategy that cannot only be used in the metalwork industry but also any other industry with related machinery and environment.

The research provides a holistic approach to safety, by identifying the safety-related strategy in the metalwork industry and looking at safety in the metalwork as a complex non-linear model and a three-way dimensional way of thinking about accidents and incidents in the metalwork industry as complicated and closely connected to technology and human factors at workplaces. Recognizing that factors (humans, technology, latent conditions, and obstacles) do not simply mix linearly to cause accidents and incidents in the metalworking business, safety must also be linked with organizational goals. Design constraints, technological flaws, and input/output combinations are a few examples of the variances. Furthermore, there is a pressing need for people to adapt to and effectively handle demands in the social systems in which they operate.

## Relevant literature review

### *Metalwork industry and common causes of injury and illnesses*

A wide range of activities, processes (pattern/tool making, mold preparation, metal preparation, metal melting, casting, removal of castings, fettling and finishing, heat treatment, plant maintenance, waste disposal, material handling and packaging, *etc.*), raw materials, products, and by-products are all part of the metalwork industry, according to the 4th edition of the ILO Encyclopedia (1998). A thorough awareness of what occurs in businesses gives one a strong sense of how to spot potential risks in the workplace. Understanding workplace events aids in anticipating potential mishaps, illnesses, and injuries that may affect employees. According to the ILO (2011), the data will then be used to inform planning and the implementation of particular control measures aimed at preventing work-related illnesses and injuries among people employed in this industry.

Among the common causes of injury and infection in the iron and metallic industry are falls, slips, and trips; falls from a height; unguarded equipment; falling devices; engulfment; working in restricted areas; exposure to managed and uncontrolled energy resources; asbestos publicity; exposure to mineral wools and fibers; inhalable retailers (gases, vapors, dirt, and fumes); contact with warm metallic; fireplace and explosion; immoderate temperatures; radiation (non-ionizing and ionizing); noise and vibration; and other factors [15]. Electrical malfunctions, pathologic biologic agents, ergonomic risks from uncomfortable postures to repeated actions, and manual handling of large objects and equipment are other causes [16]. Physical hazards, noise, vibrations, non-ionizing and optical radiations, chemical hazards, manual handling, heat, and molten metals are some examples of the environmental and activity-related risks that might arise in the workplace [17].

### *Developments of safety and health in Kenya*

When Kenya was a British colony, safety and health were implemented there in 1951, according to the ILO (2013). With limited knowledge on the part of the industrialists, law enforcement has been the driving factor behind the development of safety and health. The department in charge of protecting workers' health and safety has insufficient data on industrial accidents and occupational illnesses as a result of poor coordination on safety-related issues. Kenya has lacked political will from lawmakers who have limited knowledge of safety and health, in contrast to other nations where noticeable progress has been brought about by pressure from laws supporting these areas. This is indicated by the fact that significant instruments of the International Labor Organization, such the Occupational Safety and Health Convention No. 155, have not been ratified since 1981. Although Convention No. 155 has not been ratified, this does not imply that Kenya has not adopted its recommendations [1].

These rules was enacted by the government under the ministry of labor through the directorate of occupational safety and health services (DOSHS), these rules constitutes subordinate legislation that had their origin from section 65 (A) of the Factories and Other Places of Work Act (National Profile on Occupational Safety and Health – Kenya, 2013). The rules and guidelines are a subsidiary legislation made under the section 65(A) of the Factories and other places of work Act (National Profile on Occupational Safety and Health – Kenya, 2013) No. 31 of 2004. These rules are a subsidiary legislation established the section 65(A) of the Factories and Other Places of Work Act (National Profile on Occupational Safety and Health – Kenya, 2013). They have the regulation on the safety and health committee which provides advice concerning the operation of the safety and health committees. In accordance with sec. 2 Where ever from time to time there are twenty or more employees the safety and health committees are to be organized. In this subsidiary legislation, measures have been provided that training of the employer and the employee is essential counter measure to assure

the realization of the risks, which exist and that the employer and the employee shall take measures to protect their safety and health in the workplace [18].

The OSH 2007, which replaced the previous one, contains measures for ensuring people's welfare, health, and safety at work. It offers restricted protection against hazardous exposure for the health, safety, and welfare of employees and other people who are legally present at work. According to [18], employers are required by law to ensure everyone's safety, health, and welfare at work. Employers impose duties on the workers by law to make sure they cooperate fully with them on health and safety of employees during working.

They are to protect themselves and other people from the workplace risks, where they are able to eliminate them, or inform their employer of the hazards existing at the workplace, where they are unable to eliminate them. Where the employer provides personal protective appliances the worker is supposed to use those as in [18]. The statistics of occupational diseases that were diagnosed in Kenya during the 2010/2011 are provided in Table 1.

### *PHA*

The PHA is used to identify safety-critical areas in the system to roughly evaluate hazards and begin to consider safety design criteria. It is more of an analysis of hazard discovery. This is a list of possible hazards inherent to the system of the type. Preliminary hazard list (PHL) will usually be analyzed by PHA [19]. The PHA comprises the following activities at the least:

- 1) Review of historical safety experiences in similar systems.
- 2) Examination of primary energy sources and provisions that will control the energy sources. The sources should include chemicals and hazardous chemicals.
- 3) Identification of the safety requirements and regulations concerning personnel safety, environmental hazards, and toxic substances to which the system must adhere.
- 4) Examination of environmental hazards, e.g., shock, vibration, extreme temperatures, examination of operation tests, maintenance, and emergency procedures.

5) Examine safety-related equipment for adequacy. These will include redundancy, interlocks, fail-safe designs in hardware and software, fire suppression systems, personal protective equipment, noise, ventilation, and radiation barriers.

6) Examination of operating, test, maintenance, and hazards that may arise in these activities. These would include human failures in the operator's function, effects of factors such as

equipment layout, lighting, exposures to toxic materials, effects of noise, vibration, or temperature on human performance, life support requirements in manned systems, and egress of manned systems during accidents as well as rescue and survival of human operators.

The results of the PHA are usually reported by using a PHA worksheet (or, a computer program). A typical PHA worksheet example is summarized in Table 2 [20,21].

**Table 1:** Statistics for occupational diseases diagnosed in Kenya by DOSHS 2010-2011

Type of hazard	No. of workers examined	No. of workers with occupational diseases
Adverse temperatures	241	2
Asbestos fibers	5	1
Cotton dust	446	11
Organic dust	808	16
Fossil fuels	90	29
Noise	3229	118
Organophosphate and other pesticides	1243	39
Repetitive manual work	13	1
Respiratory: Solvents	29	1
Silica dust	52	3
Welding alloys	67	1
Total	6223	222

**Table 2:** PHA example

System	Operating mode	Analyst
Hazard	Probable causes	Date
Accidental event (what, where, and when)	Contingencies/preventive actions	Prob. Sev. Comments

### *Functional resonance analysis method (FRAM)*

Because socio-technical systems are often controlled with human, technological, and organizational elements, it is challenging to predict their behavior using conventional methods like why-because analysis.

FRAM is effective in evaluating the safety of these systems. Each component of a socio-technical system may operate with certain variables, and the interactions of those variables determine the global behavior of the system. FRAM was offered as a solution to the problem from a systemic perspective [19,22].

As seen in Table 3, FRAM begins with the definitions of the six aspects' functions. Each

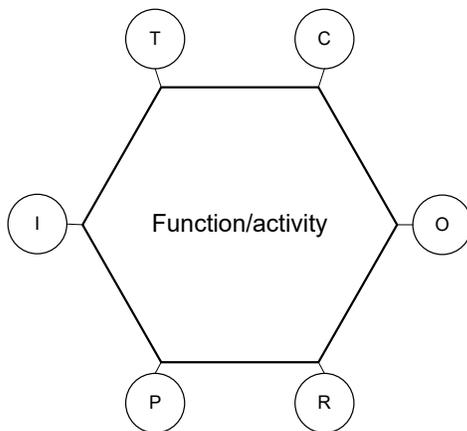
item listed in manuals or checklists is a typical example of a function in FRAM, which is defined as "what has to be done to achieve a specific goal." According to [19,23], an instance is a

network of FRAM functions that connects them and represents a target system.

Figure 1 shows a hexagon representation of the six aspects of the FRAM.

**Table 3:** Six aspects of FRAM function [24]

Aspect	Description
Input	Input/Trigger of a FRAM function
Output	What results from a FRAM function
Precondition	Conditions that must be satisfied before a FRAM function is carried out
Resource	What is consumed by a FRAM function (e.g. fuel, energy, labor force)
Control	What supervises or restricts a FRAM function
Time	Time constraints for a FRAM function



**Figure 1:** A hexagon representing a function with the six aspects FRAM

Variability of FRAM functions is usually initiated by existing variability in a working environment. The socio-technical systems are best run in precisely following set operational protocols. However, it is recognized that there can be variations of the working environment in the real world at a particular time due to temporal factors like available time for implementation of the expected operations. They force the operators to perform their tasks in a more efficient way to cope with the situation (e.g., deviations from SOPs: SOP's and they are supposed to do it while at the same they are always expected to deliver the SOP's right. This kind of problem is called ETTO: The Efficiency and Thoroughness Trade-Off [25] and ETTO normally leads to task Performance Deviation from work as Imagined and causes variability in FRAM functions by [26]. To mitigate the effects of hazards, risks, and activities related to the

metalwork industry, we have been developing a simulator and building a model of FRAM by introducing numerous papers. However, FRAM is a method rather than a model, suggesting that there is no systematic procedure for FRAM and that it must be implemented for its practical use [27]. The study develops a safety strategy that utilizes hazards, risks, and activities' quantitative and qualitative data. Questionnaires, interviews, and workplace assessments were used to identify the activities, hazards, and risks in the company. Health and legal compliance were determined through the safety records. The researchers' safety assessment form, risks, hazards, and activities were analyzed using the PHA. FRAM was used to develop the strategy based on the results from the questionnaires, workplace assessment, and the PHA categorizing them into six varieties of FRAM. The study found that the company gives a priority to production leading to poor maintenance planning difficulties, which are a major obstacle to the safety of equipment and hence hazardous to the workers. Likewise, it was found that the most common health hazards are dust, gases, and mechanical hazards including sharp objects. In addition, the company does not carry out pre-employment and periodic medical examinations, which is of significant help in the workers' placement. It was also established that safety performance was mainly driven by lagging indicators (injuries, illness, and fatalities) instead of employing safety-leading indicators. The developed safety strategy integrating PHA with FRAM assists in improving safety in the metalwork industry. Typical

definition of FRAM entities (*e.g.*, varieties of working environment or FRAM functions) [28].

## Research methodology and data analysis

### Overview of research methodology

The methodology employed in this article consists of several steps including data collection, risk and hazard identification, analysis, and mitigation. This section describes the mentioned steps. Figure 1 displays the summation conceived by researchers showing steps adopted in this research method.

### Data collection

This entailed the collection of data by reviewing the safety and health records, data collected from the questionnaires, and direct

interviews with maintenance engineers and Safety and health committee members who are directly involved in the Safety and health-related aspects.

### Sample selection criteria

All of the company's employees were included in the research population Figure 2. The chosen staff members were enrolled in the research. The data collecting flow diagram is depicted in Figure 3. The study covered all of the enterprise's employees who were willing to participate and had been employed there for at least one month at the time of the study. Employees who refused to complete the survey or opposed to taking part, as well as those who provide services like cleaning and security that are outsourced, were not included in the proposed study.

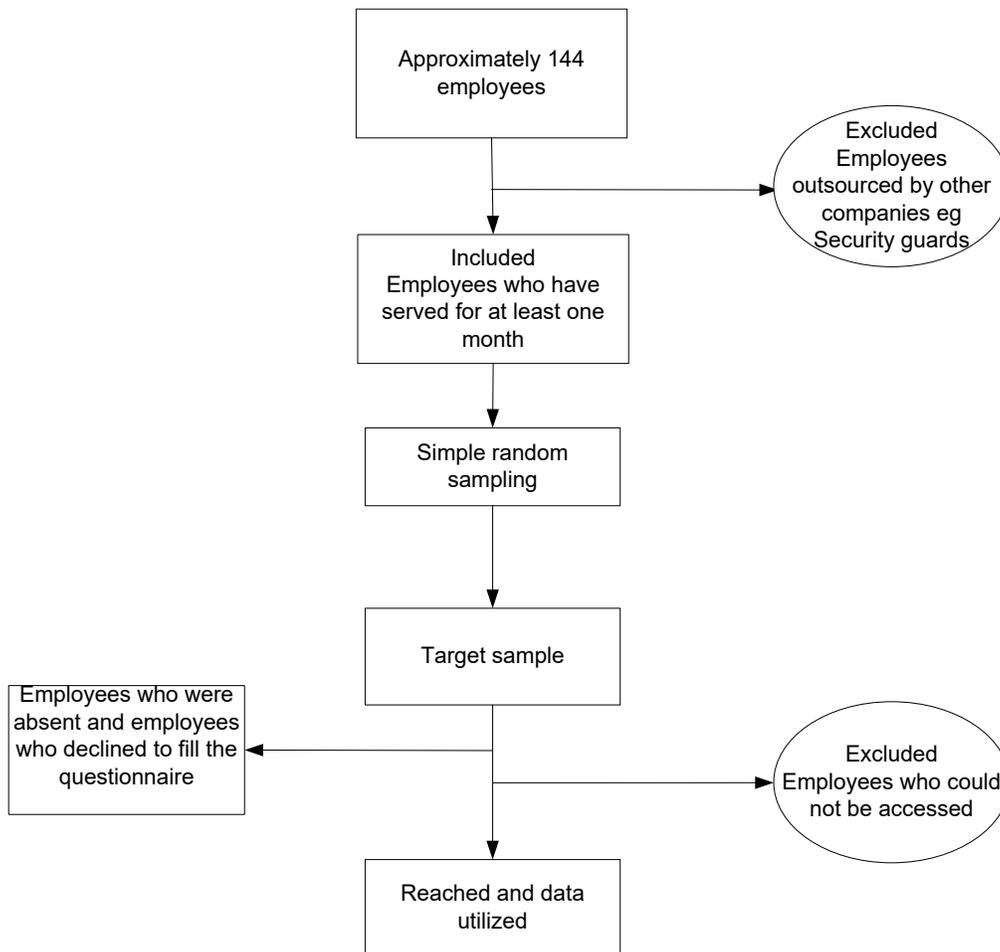


Figure 2: Flow diagram of sample selection procedure

*Sampling procedure*

The sample size was calculated by the formula as shown by Equation (1):

$$n = \frac{N \times p \times q \times (Z_{\alpha/2})^2}{(N-1) \times E^2 + p \times q \times (Z_{\alpha/2})^2} \times (1 + NRR) \quad (1)$$

Where,

n: sample size

N= Population size (Total employees = 144)

$Z_{\alpha/2}$ : Critical value for desired confidence degree (1.96 for 95%)

p: Proportion of estimated results (assumed 50%)

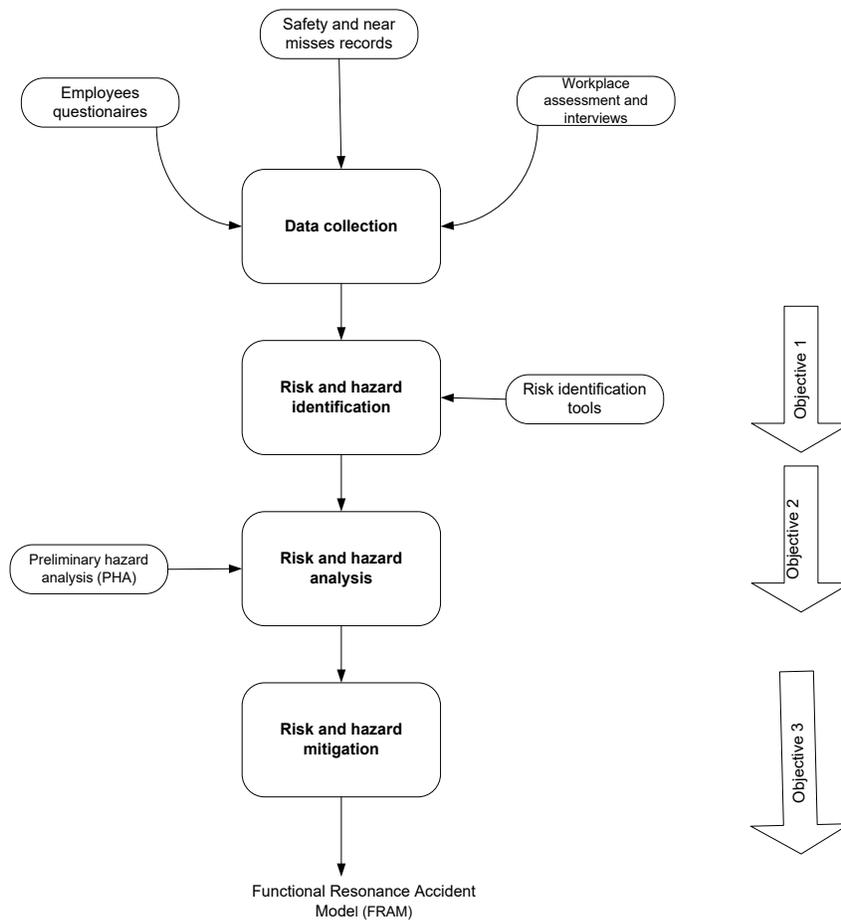
$$q: 1-p \quad (2)$$

NRR= Non-response rate (assumed 20%)

E= Desired error rate (assumed 5%)

$$n=105 \times 1.2=126 \quad (3)$$

A random sampling method was used. Target workers were picked randomly by choosing a worker from the register which contains 144 workers with the help of safety experts from the company to distribute questionnaires to the selected workers.



**Figure 3:** Summary of research methodology

*Hazard and risk identification*

To achieve this, it was necessary to identify the most frequent causes of disease and injury that

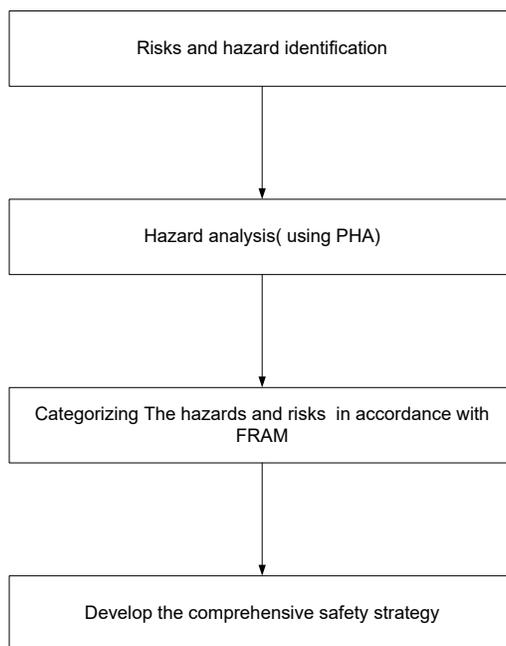
are associated with the steel, iron, and metalworking industries. These included environmental risks, radiation dangers, spill hazards, mechanical hazards, electrical hazards,

fire hazards, and hazardous chemicals. This was carried out by the use of one-on-one interviewing, audit reports on accidents and incidents as well as questionnaires where risk-related questions were asked.

### *Hazard and risk mitigation using FRAM*

The results obtained from the brief walk-through survey and questionnaire to establish the employees' findings in the company by the researchers' i.e. the workplace assessment and questionnaire were analyzed by PHA and further categorized using FRAM. The major risks, hazards, and activities (Mechanical hazard metal processing, and fabrication) were analyzed by PHA and afterward using the FRAM aspects, the stepwise activities that are associated with hazards and activities were analyzed and determined to develop a comprehensive strategy that can be used to improve safety in the metalwork industry. The activities were found

to revolve around metal processing and fabrication. The FRAM six aspects—Input (I), Output (O), Preconditions (P), Resources (R), Time (T), and Control (C)—as well as the safety procedures for completing these crucial tasks were created. The elements came from PHA's active and passive mitigation approach. The tasks included lifting and transporting materials connected to metal production and processing, as well as soldering, welding, folding, rolling, painting, cutting, and grinding. The six aspects as per the FRAM were determined for the steps for the activities by finding a way of safely carrying out the steps to enhance safety and thus the comprehensive Safety strategy to be used to improve safety in the metalwork was developed. The inputs were derived from the PHA hazard mitigation measures. Figure 4 shows the chart used to develop the comprehensive safety strategy. Figure 4 illustrates the chart employed in the development of the comprehensive safety strategy.



**Figure 2:** Chart employed in the development of the comprehensive safety strategy.

## Results and Discussion

### *Workplace assessment*

The researcher did a quick walkthrough survey to collect data on company safety. Soldering and

welding, folding and rolling metals, painting, cutting and grinding, lifting, and moving manufacturers were a few of the tasks that were performed during the company's existence. Additional processes include pickling, aluminum plating, metal heat treatment, cement-clay

mixing, riveting, molding, and maintenance services, as well as surface cleaning of the finished goods. The human hazards identified included Heat (Medium risk/low frequency), Cold (low risk, no exposure), Noise (Low risk/very low exposure), Light (Low risk/low exposure), Vibration (present at very low exposure), Electric Shock (High risk/moderate exposure), and objects and parts with possible contact hazards (High risk/High exposure). Of the chemical hazards that were identified in the workplaces, some common classifications included the following risks; Metals (Both Very High risk and High Exposure), solvents (Moderate risk but Low Exposure), dust (High Risk, but moderate exposure, and gases (Moderate risk, but No exposure). Ergonomic injuries in the form of manual lifting and/or carrying were noted to be present; everyone was observed to lift their hands above shoulder levels and have awkward body postures as well as engage in repetitive movements. Bodily agents of disease were considered to be potentially possibly found at some places at work. These noted hazards were subjectively described into "magnitudes" as per the probable severity of the hazard in terms of or ill health impact injury /severity of the injury. Those of high magnitude had the inherent potential to produce serious tissue damage during short-time slopes. High magnitude ones having the natural capacity to inflict serious harm after brief exposure. Noise, heat, metals, physical labor, and sharp and mechanical metal components were all deemed to be of high intensity. On a scale of 0 to 5, the exposure to the dangers was graded among the businesses that have hazardous agents (0= Not exposed). 1 denotes very low, 2 low, 3 moderate, 4 high, and 5 extremely high.

#### *Employee questionnaire findings*

Out of 126 employees, 93 provided data, representing a 73.8% response rate. Some of the issues, nevertheless, were not fully addressed, and the variations in the sum totals in the analysis of different variables will reflect this. The workers performed cutting (37.2%), grinding (30.6%), and soldering and/or welding

(18.6%). [Table 3](#) lists the specific types of labor that employees perform.

On the other hand, [Table 4](#) indicates that the majority of the dangers have high exposure ratings. They were always or nearly constantly in contact with heat (25%), as well as sharp and mechanical objects (66.7%). In addition, some were exposed to adverse weather conditions (10%), cold (27.3%), noise (68.4%), lighting risks (69.2%), unpleasant postures (60%), repetitive actions (50%), and biological dangers (30%) for about half of their working hours. Radiation (41.7%), vibration (26.7%), dust (5.5%), and gases (77.8%) all had the modest exposure levels.

The majority (87.5%, or 72 employees) did not have any involvement in an accident at work. According to [Table 5](#), they also experienced repeat accidents up to five times: 5.95% once, 3.57% twice, 2.38% three times, 1.19% four times, and 1.19% five times.

#### *PHA*

An overview of the possible environmental risks at the company is provided in [Table 6](#). The safety committee was consulted, and general possible danger groups were used to compile this list. The purpose is to offer a checklist for recognizing any risks that might arise in the workplace. The list is not meant to replace a comprehensive on-site assessment. It functions as a checklist of notifications and vigilant encounters instead. The risks were majorly mechanical hazards and included: micro-climate, noise and vibrations, non-ionizing and optical radiations, chemical hazards, manual handling, heat and molten metal, working in uncomfortable postures, biologic agents, and mechanical and sharp objects [Table 7](#).

#### *Developed safety strategy*

The results of the work placement assessment, employee findings, and the results of the PHA were then organized as per six aspects of the FRAM.

The safety Strategy was developed by considering the main hazard and activity in the

metalwork industry. The main activity that involves metal processing and fabrication involves various steps to achieve. The various steps are:

*Assembly of tools, materials, and equipment:* This requires certain aspects of FRAM as Job Safety analysis, Preparation of the working area, and running the safety check which is also further analyzed using the six aspects of FRAM.

*Conducting safety training:* It has preconditions such as safety training awareness that require resources like instructors and preconditions like collaboration with the government agencies and controls such as safety examinations.

*Running safety, check:* This has to be done after the safety briefing.

**Table 4:** Specific type of work done by employees

Current type of Work	N	n	%
Soldering and welding	86	16	18.6
Folding and rolling metals	86	12	14.0
Painting	86	12	14.0
Cutting and grinding	86	32	37.2
Lifting and carrying materials	86	20	23.3

**Table 5:** Workplace hazards and exposure rating

Hazard	N	Never or almost never exposed	Exposed around half of the time	Almost always or always present
		n %	n %	n %
Heat	4	18 40.9	15 34.1	11 25
Cold	4			
	3	9 27.3	15 45.6	9 27.3
Extreme weather conditions	3	18 60	9 30	3 10
	0			
Noise	5	3 5.3	15 26.3	39 68.4
	7			
Optical radiation	3	15 41.7	9 25	12 33.3
	6			
Vibration	4	12 26.7	6 13.3	27 60
	5			
High Voltage application	3	6 15.4	6 15.4	27 69.2
	9			
Solvents	3	9 25	18 50	9 25
	6			
Dusts	5	3 5.5	9 16.7	42 77.8
	4			
Gases	5	0 0	12 22.2	42 77.8
	4			

Lifting and carrying materials	5	9 16.7	12 22.2	33 61.1
	4			
Working in uncomfortable postures	4	12 26.7	6 13.3	27 60
	5			
Repetitive movements	4	6 14.3	15 35.7	21 50
	2			
Biological agents insects, fungi, bacteria	3	12 40	9 30	9 30
	0			
Mechanical and Sharp objects	5	12 22.2	6 11.1	36 66.7
	4			

**Table 6:** Frequency of workplace accidents

Number of times involved in workplace accident	N	%
0	72	85.71
1	5	5.95
2	3	3.57
3	2	2.38
4	1	1.19
5	1	1.19
Total	84	

**Table 7:** Synopsis of potential hazards

Hazard type	Consequence	Initiating event	Severity/ probability	Comments and hazard mitigation measures
Mechanical hazards	Personnel injury	Unsafe practices	High	<p>Comments: Operation of hand-held power tools, manual tools, rotating machinery operations and pressurized systems. Also possible injury to personnel if proper procedures are not adhered to when lifting and moving heavy objects.</p> <p>Passive Mitigation: Equipment safety guards.</p> <p>Active mitigation: All personnel need proper training and a diurnal review of the hazards (JSA).</p>

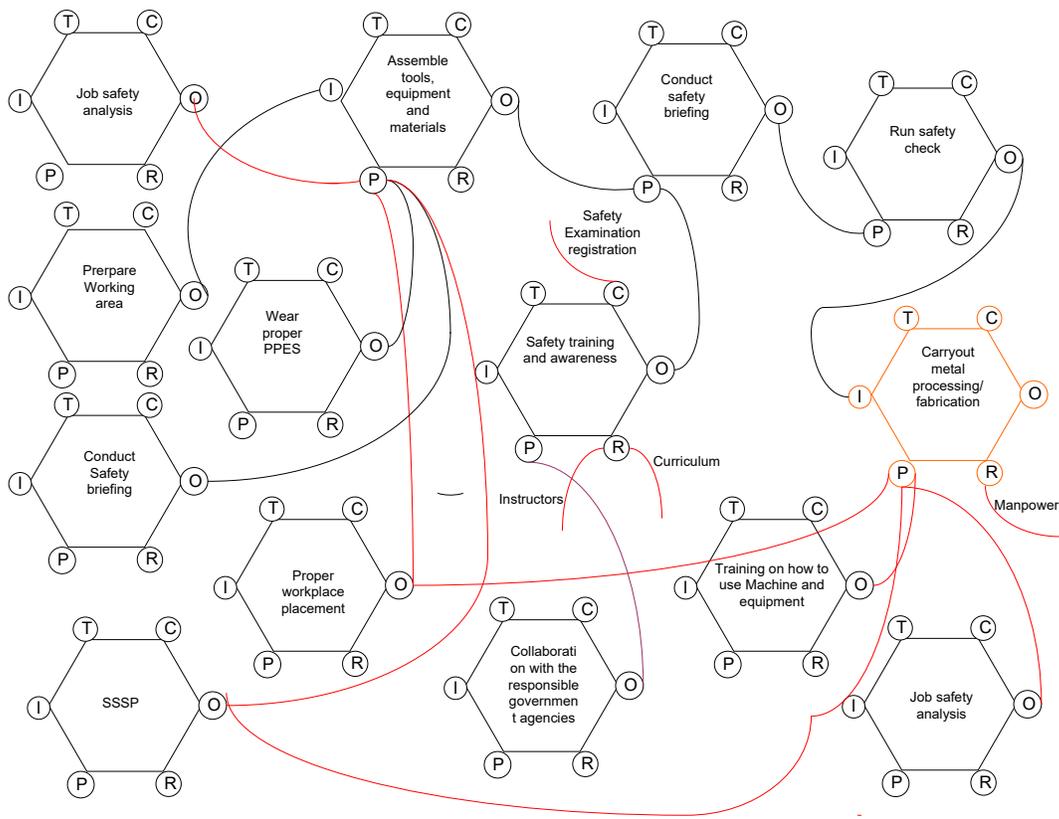
*Key findings*

- 1) Pre-employment and periodic medical examinations have not been done for most of the employees.
- 2) Use of lagging indicators (injuries, illnesses, and fatalities) as the driver and measure of safety performance,
- 3) The employees work at places where they are exposed to numerous Health and safety hazards with most of them having risks affecting their health hence putting their Health and Safety at risk.

- 4) The common health hazards in the Company are Dust and gases as well as Mechanical and Sharp objects and there is a lot of manual handling.
- 5) First aid and Fire control equipment are present though inadequate.
- 6) Priorities to production and planning, difficulties, as well as the lack of support and audience from the Government are the major obstacles to Health and Safety Equipment.
- 7) The appropriate work placement procedure is not established.
- 8) Safety Training is carried out for the employees but is inadequate.
- 9) No, Safety department in the company thus poor coordination of Safety activities.

Improved training for employees to guarantee they understand who is in charge of safety and health is one of the recommendations derived from the main results. Likewise, a safety department can be formed for easier coordination of safety-related activities. According to the developed strategy, this improves human performance variability, which is one of the major causes of accidents and incidents. For proper placement, the management should introduce pre-employment and periodic medical examinations to the employees. The employees ought to be qualified for the particular duties given to them. Also, administrative agents should control targets through work schedules (rotation) to minimize exposure to hazards. These are very latent conditions but will improve immensely the safety culture as per the model developed. Processes that are highly dangerous, including

handling molten metal in furnace regions, should be automated by the company. By reducing manual handling, this concept would improve human performance variability, which the model indicates is a significant variability in the components that cause accidents and incidents. The management must also spend money on PPE that can withstand high temperatures in hot environments. According to the modified FRAM model created, human contact, if required, will need the use of suitable PPEs in order to enhance human performance variability. The respondents' comments about production priority and other barriers to occupational health and safety should be investigated and used as initial advice for the intervention aimed at improving the health and safety of persons employed in the industry. In accordance with the development plan, establish a reliable method for reporting accidents, incidents, and near-misses so that the leading indicators may be used to stop incidents and accidents from occurring at the causative stage and under latent conditions. Provide a workplace health service for basic curative services and first aid care to the employees in the case of accidents or incidents. Ensure quality equipment and Maintenance other than giving production preference to maintenance. This idea will reduce impaired or missing barriers such as limited maintenance and reduce the problems related to equipment design which is a part of the four types of variability that are responsible for causing incidents and accidents. Improve the factory's layout design to ensure workers' and material flow during production. [Figure 5](#) shows the FRAMnet developed for metalwork safety strategy.



**Figure 5:** A FRAM net strategy for metalwork safety strategy

## Conclusion

The main aim of the present study was to develop a safety strategy for the metalwork industry integrating FRAM and PHA to mitigate the effects of the hazards and activities in the metalwork industries. The first aim was to identify safety, hazards, and activities related to the metalwork industry. The second aim was to analyze risks, hazards, and activities using PHA. The PHA output was categorized using FRAM, analyzing the major activities and hazards using the six FRAM aspects. The various steps would be used with the six FRAM aspects to develop a comprehensive safety strategy for the metalwork industry. Safety is viewed as a three-dimensional convergence system, combining both linear (sequential) and lateral (random) factors that can lead to accidents or incidents. The steps for major activities and hazards (both active and passive) are analyzed further according to the six FRAM aspects to identify and eliminate potential risks. The investigation of the hazards,

safety, and activities in the metalwork industry deduced that pre-employment and periodic medical examinations were not common practices, the company made use of lagging indicators (injuries, illnesses, and fatalities) as driver and measure of safety performance. The employees work at places where they are exposed to numerous health and safety hazards with most of them having risks effecting their health hence putting their health and safety at risk, the common health hazards found are Dust and gases as well as Mechanical and Sharp objects and there is a lot of manual handling. First aid and fire control equipment are present though inadequate priority to production and planning difficulties as well as lack of support and audience from the government are the major obstacles to health and safety equipment. The appropriate work placement procedure is not established. Safety training is carried out for the employees but is inadequate. Also, there was a safety department in the company and thus poor coordination of Safety activities. The

developed strategy will attempt to eliminate the hazards and will ultimately improve safety immensely in the metalwork industry. Future studies should be performed to eliminate the following limitations of this work. The results may not be applicable to the whole metalworking industry due to the tiny sample size. To overcome this constraint, the author suggests conducting more research with a few associated companies. Some workers refused to readily divulge all of the necessary data. Since many employees were unaware of the diseases, their consequences, and how to avoid them from impacting them, occupational risks and diseases, awareness, and management would be important areas to improve this research. Regarding these illnesses and ailments, the majority of the staff members were ignorant of their presence and health status.

### ORCID

Peter Onyango Ochieng

<https://orcid.org/0009-0005-6350-6097>

J.N. Keraita

<https://orcid.org/0000-0003-0009-5006>

Peter Nganga Muchiri

<https://orcid.org/0000-0001-6176-5240>

### Reference

[1]. J.M. Waweru, An evaluation of occupational safety and health hazard awareness in Steel rolling Mills in Nairobi Metropolis, *Thesis*. **2013**. [Google Scholar], [Publisher]

[2]. B.L. Barrosa, A.R. Dores, M. Rodrigues, Effects of safety and health training in metalworking small-sized enterprises, *International Journal of Occupational and Environmental Safety*, **2020**, 4, 48-61. [Crossref], [Google Scholar], [Publisher]

[3]. D.R.V. Chetty, R. Boojhawon, S. Bhagwant, L. Levy, Factors affecting the occupational safety and health of small and medium enterprises in the Construction Sector of Mauritius, *Social Sciences & Humanities Open*, **2024**, 10, 100964. [Crossref], [Google Scholar], [Publisher]

[4]. F.J. Afolabi, P. de Beer, J.A. Haafkens, Can occupational safety and health problems be prevented or not? Exploring the perception of informal automobile artisans in Nigeria, *Safety*

*Science*, **2021**, 135, 105097. [Crossref], [Google Scholar], [Publisher]

[5]. O. Akram, Occupational health and safety in urban and peri-urban Bangladesh: An important cause and consequence of extreme poverty, *Governemnt of the People's Republic Bangladesh, UKaid, Swiss Agency for Development and Cooperation SDC, Eprg, Centre for Development Studies, ADD International*, **2014**. [Google Scholar]

[6]. M. Iqbal, B. Sarker, N. Paul, M.S. Rahman, occupational health and safety assessment of a metal fabrication industry in sylhet, bangladesh. *International Conference on Mechanical Engineering and Renewable Energy*, **2017**. [Google Scholar], [Publisher]

[7]. B. Fabianoa, M. Pettinatoa, A.P. Reverberib, F. Curròa, Human factors and safety management: A field study on safety performance in the process industry, *Chemical Engineering*, **2019**, 77. [Crossref], [Google Scholar], [Publisher]

[8]. B. Vaiagae, Workplace Safety Strategies Used by Managers to Reduce Workplace Accidents (Doctoral dissertation, Walden University). **2020**. [Google Scholar], [Publisher]

[9]. S. Kim, J. Lee, C. Kang, Analysis of industrial accidents causing through jamming or crushing accidental deaths in the manufacturing industry in South Korea: Focus on non-routine work on machinery, *Safety Science*, **2021**, 133, 104998. [Crossref], [Google Scholar], [Publisher]

[10]. S. Tappura, A. Jääskeläinen, J. Pirhonen, Creation of satisfactory safety culture by developing its key dimensions, *Safety Science*, **2022**, 154, 105849. [Crossref], [Google Scholar], [Publisher]

[11]. R.L. Neitzel, A. Crollard, C. Dominguez, B. Stover, N.S. Seixas, A mixed-methods evaluation of health and safety hazards at a scrap metal recycling facility, *Safety Science*, **2013**, 51, 432-440. [Crossref], [Google Scholar], [Publisher]

[12]. F. Islam, M. Alam, S.A.A. Mamun, M.S. Hossain, Occupational safety practice among metal workers in Bangladesh: a community-level study, *Journal of Occupational Medicine and Toxicology*, **2022**, 17, 23. [Crossref], [Google Scholar], [Publisher]

[13]. M. Nafees, B. Khan, R. Naz, Study of occupational health safety in steel re-rolling mill with reference to high noise level and

temperature, *Journal of Engineering and Applied Science*, **2013**, 32. [[Google Scholar](#)]

[14]. Y. Toft, G. Dell, K. Klockner, A. Hutton, Models of causation: Safety, *Engineering*, **2012**. [[Google Scholar](#)], [[Publisher](#)]

[15]. P. Dehury, K.A. Kumar, Identification of hazardous substances and occupational morbidity associated with steel and power industry workers in Odisha, India, *Clinical Epidemiology and Global Health*, **2023**, 22, 101312. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[16]. N.S.B. Lop, N.M. Salleh, F.M.Y. Zain, M.T. Saidin, Ergonomic risk factors (ERF) and their association with musculoskeletal disorders (MSDs) among Malaysian construction trade workers: Concreters, *International Journal of Academic Research in Business and Social Sciences*, **2019**, 9, 1269-1282. [[Google Scholar](#)]

[17]. E. Hollnagel, FRAM: the functional resonance analysis method: modelling complex socio-technical systems, *CRC Press*, **2017**. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[18]. D.A. Crawl, Hazard analysis and risk assessment, *Kirk-Othmer Encyclopedia of Chemical Technology*, **2000**, 1-21. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[19]. W. Tian, C. Caponecchia, Using the functional resonance analysis method (FRAM) in aviation safety: a systematic review, *Journal of Advanced Transportation*, **2020**, 2020, 8898903. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[20]. T. Sawaragi, Design of resilient socio-technical systems by human-system co-creation, *Artificial Life and Robotics*, **2020**, 25, 219-232. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[21]. E. Hollnagel, Barriers and accident prevention, *Routledge*, **2016**. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[22]. D. Slater, R. Hill, M. Kumar, B. Ale, Optimising the performance of complex sociotechnical systems in high-stress, high-speed environments: The formula 1 pit stop test case, *Applied Sciences*, **2021**, 11, 11873. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[23]. T.A. Saurin, The FRAM as a tool for modelling variability propagation in lean construction, 24th Annual Conference of the International Group for Lean Construction Proceedings on Proceedings, *Sect*, **2016**, 3-12. [[Google Scholar](#)]

[24]. T. Hirose, N. Hideki, E. Hollnagel, R. Hill, T. Sawaragi, D. Slater, Treating variability formally in FRAM, *Preprint*, **2020**, 10. [[Google Scholar](#)]

[25]. M.E. Amouzad, Microgrid control to ensure stability and increase flexibility in storage applications, **2022**. [[Google Scholar](#)], [[Publisher](#)]

[26]. V. Emelu, C. Emelu, B. Babatunde, E. Wali, O. Afolabi, Corrosion control (cathodic protection) on pipelines in port harcourt, nigeria: A quantitative approach, *Journal of Engineering in Industrial Research*, **2023**, 4, 22-30. [[Crossref](#)], [[Google Scholar](#)], [[Publisher](#)]

[27]. H.V. Nasab, Structures in urban and rural areas against the occurrence of earthquakes, *Moment*, **2022**, 3. [[Google Scholar](#)]

[28]. H.S. Samuel, U. Nweke-Maraizu, E.E. Etim, Formation and Applications. *Journal of Engineering in Industrial Research*, **2023**, 4, 176-188. [[Google Scholar](#)]