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An accident prevention model: case application in a small-scale wood workshop of a developing country

Ozichukwu OSAKWE[1], Ukemeobong Etokowo OWOH[1], Sunday Ayoola OKE[1]

[1] Department of Mechanical Engineering, Faculty of Engineering, University of Lagos, Nigeria
*Corresponding author:

Abstract

Majority of processing activities in small-scale wood workshops are huge, including lifting, stacking and cutting of wood materials. These generate substantial hazards, which trigger accidents, injuries and possibly death. To prevent these calamities, a new accident prevention model is proposed based on barriers (human shields) that safeguard the human body from attacks and damages. The effectiveness of creating and optimizing these barriers, using principal barriers for skin, organs (internal and external), bone and fatigue is presented. The predicted rate of accident occurrence ranged from 0 (best) to 0.4587 (worst) accident per period. The percentage rate of occurrence varied from 0 (best) to 26.85 (worst) accident percentages per period. The bone injury prevention barrier involving factors of trips, slips, contact with moving machine parts, and contacts with rollers yielded a range of values from 0.2635 to 0.4255. Results showed that a high percentage (almost 50%) of the probable accidents would be classified under external organ injury prevention barrier. Results further showed that EOIPB is a first degree accident. This implies that the wood workshop has a high degree of uncertainty in terms of predicting when and what type of accident is likely to occur. The main novelty of this contribution is the unique integration of barrier factors with the fault tree analysis and being able to optimise than using Lagrange's multiplier. The presented methodology serves as an effective tool in the identification of influential accident causative factors, on a preventive basis, before any accident occurs. It can be appropriately applied in other processes, such as manufacturing with some practical utility to the safety coordinator.

Keywords: Accident, prevention, barriers, tree analysis, Lagrange's multiplier.

1. Introduction

Wood is one of the commonly used materials for processing a huge number of furniture, construction and structures both for households, offices and industrial settings. Specific uses of wood include furniture design, interior design, pre-fabricated roof trusses, roof frames and many other purposes. The small wood workshop provides significant income for the economy. It promotes industrial growth as many small-scale industrial still depends on the outputs of small-scale wood workshops for survival. It also provides enormous employment for the large population of urban dwellers. However, the frequent accident occurrences, which result into significant losses in injuries, deaths and compensation costs weakens the workshop sustainability. It also threatens the continued existence of small-scale wood workshops in developing countries. However, compared with the corrective accident control approach, the accident prevention task is attracting a heightening interest of stakeholders in safety [1-2]. These could be researchers, safety regulators and governments. Also accident prevention leads to tremendous savings in liability cost, injuries and lives of personnel involved in wood processing.

Huge national currencies could be saved if employees are well-guided in the identification of hazards, how to eliminate them and they willingly comply with accident prevention proper scientific guidance in models need to be provided [3]. In this sense, the development of barriers in combination with fault tree analysis and Lagrange's multiplier may serve as an important tool for accident prevention [4-6]. Barriers in safety are widely recognised as a prime accident avoidance tool and has been extensively utilised due to its effectiveness, robust nature and its flexible attribute of being applicable in different industrial settings [4]. Barriers have the capability of checking to stem accident evolution and propagation through starring of the causative factors. Thus, the logical causes and effects of barrier removal and role on accident propagation could be determined. On the other hand, fault tree analysis is widely accepted for its ability to identify the causes of certain event analysis on the fault tree. Lagrange's multiplier has the capability of optimising variables that are captured through it.

Now, considering the advantages of these three tools (i.e. barriers, fault trees and Lagrange's multiplier) and the complexity of the accident prevention tasks in the small wood workshop, it is expected that a useful, important and scientifically valid avenue for the accident prevention tasks will be created if an integrated barrier-fault tree-Lagrange's multiplier framework is pursued [7]. Thus, the current investigation aims to evolve a novel approach that quantitatively analyse the state of the accident proneness of the small-scale wood workshop. A developing country example is given.

The worldwide attempt to eliminate accidents through zero-level accident policy has motivated companies to rewrite their laws and reformulate policies. Generally, the safety acts governing practices in the wood workshop in developing countries specifies preventing accidents but no concrete quantitative measures exist on this. So, proactive development of new safety practices, investigations and measurements of existing safety levels in the wood workshop are needed. The evolution of accident prevention models are needed in order to reduce accidents, fatalities and injuries. In this way, accident prevention remains a major concern in the daily processing activities of the small-scale wood workshops. Presently, there are various models that have been contributed in literature to address accident prevention and prediction but most of these models are highly theoretical in nature and provide very little utility to the practicing safety manager or workshop coordinator responsible for implementing safety policies in the wood workshop. In addition, none of these models appears to have been applied to the wood workshop of small-scale nature.

Furthermore, there are no literature reports on the application of these models to developing countries' unique operational environment. Further still, there is no single case application of such models treated in literature that concerns the Nigeria wood workshop practices. Consequently, attractive and easily implementable accident prevention models ought to be developed/adopted and implemented in totality in developing countries. Wood workshops must avail this opportunity to enhance their standard to world-class status. Consequently, the wood workshop should be safe for working, thereby imposing less financial liability on the workshop in terms of accident compensation avoidance. In this work, the accident quantifying aspects of the modified SHIPP model alongside the probability theory is employed. The system hazard identification, prediction and prevention is the full meaning of the SHIPP methodology. The process accident model has a core function in analysisng safety barriers as well as predicting their performance. The credit of advancement of the scientific tool is due to Rathnayaka, Kahn and Amyotte [8-9]. It was used in obtaining the probability values of accident occurrence generated form data collated from fault tree analysis [10]. Lagrange equations were then used in obtaining the accident rate of occurrence and hence, incorporated into an objective function for optimisation. In the optimisation of mathematical function, the approach of Lagrange multipliers has reputation for strategically optimising multiple variables such that local maxima and minima are obtained when the function is subjected to constraints of equality. Based on the success stories in literature, Lagrange multipliers are applied in the current paper. Data was collected from a small-scale workshop domicile in the Faculty of Engineering, University of Lagos, Nigeria, which serves the wooden structural needs of the university community. These data provides a basis to the verification of the model.

By drawing motivation from the above-stated facts, this paper presents a new accident prevention model for implementation in small-scale wood workshop. The model, involving injury prevention barrier for bone, skin, internal and external organs as well as fatigue was developed. The fault tree analysis was applied to evaluate the possible fault categories for each group of injury barrier prevention framework mentioned. Then Lagrange's multiplier was adopted in the optimisation of the injury preventive barrier-fault tree analytical framework. This was formed at this phase of the evaluation transformation framework. Faulty tree analysis has the ability of specifying the probability of occurrence of events. For the workshop activities, a clear quantitative description of the injury barrier preventive tasks in the workshop was made. Thus, discrete values were obtained to identify the level of influence of the alternative outcomes of the injury barrier prevention framework.

The model would potentially serve as a useful practical tool that the safety coordinator or the workshop head in the small workshop could use in having snapshop assessment of the accident prevention status and a detailed analysis for justifying a safety investment. The principal contributions of the work are spelt out as follows:

- Development of a unique integrated approach that considers two main perspectives of injury prevention barriers, namely, by organs and major parts of the body, and by fatigue. These are physical and non-physical factors. Such a report is given for the first time in literature.
- A first time documentation of an integrated model, combining the powerful features of injury prevention barrier-fault tree analysis-Lagrange's multiplier has been made.

Specifically, the study presents a modified SHIPP (system hazard identification, prediction and prevention) model, which is an improvement over Owoh's [11] research effort. Owoh's initiative sprang up from an original attempt by Rathnayaka et al. [8-9]. The current proposal is a deviation from the originalSHIPP model in that it was adopted to the wood industry, particularly the woodworkshop SMS, through a slightly different perspective. The shortcomings in the modified SHIPP model Owoh's [11] was the human perspective approach where the assignment of prior probability values are dependent on personal experience of the investigator and its limitation to the process industry. The current proposed model eliminates the uncertainties and errors arising from the human perspective approach adopted for the improved-SHIPP method of analysis by Owoh [11]. It also accounts for other accident scenarios which have not been studied yet. The current work calculates the efficient probability values for accident occurrence and ranked each type of accident according to its severity by using its rate of occurrence values computed. Unlike the modified SHIPP method advanced by Owoh [11], basic mathematical skills alongside a comprehensive facility layout plan is sufficient in applying this model to an a wood-working system, which may represent a situation of data sampling such that the model of this research could be applicable for the workshop at university that has the same layout. The specific objectives of the research are two-folds. First, the paper attempts to develop a model that aids assignment of prior probability values for accident causatives. Second, the work computed the rate of accident occurrence in order to predict and minimise accident occurrence in the wood-working industry with a case drawn from a small scale workshop in a Faculty of Engineering of the University of Lagos, Lagos, Nigeria.

In the remaining parts of the article, the following sub-sections will be implemented. First, a literature review that reveals the gaps in the small-scale wood workshop is presented in section two. In section three, the methodology, containing the procedure for the model analysis and integration is presented. Scientific discussion concerning the outcome of the results is given in section four. Section five presents the concluding remarks from the study and future research suggestions.

2. Literature review

Many of the accidents in small-scale wood workshops, such as those due to revolving and reciprocating cutting tools, in-running nips in-between rotating parts in pairs and revolving parts having projections, are partly due to poor accident preventive strategies and weak controls. The outcomes of these accidents may be severe workshop injuries, including crushed fingers, damaged hands, hand and leg amputations, blindness and even death.

For advanced countries such as the United Kingdom and the United States of America, where the controls on safety in wood-workshops are strong and effective, the severities and rate of accidents are minimal; although requiring improvements. However, for developing countries such as Nigeria, workshop accident rates and severities are high and frequent, with the magnitude of accidents very disturbing, leading to devastated conditions of both workers and the workshop at large after accident occurrences. The situation is that huge investments may be lost in workshop accidents, survival of lives may be threatened, customers may be scared in taking custom in the services of the workshop, and the workshop activities may eventually close down. Since accident frequencies and severities are not satisfactory in developing countries, significant improvements are needed. Over the years, several accident preventive models have been developed to address these challenges.

Much of the extant accident preventive modelling reports have been limited from two perspectives. First, the central focus has generally been on systems outside the small-scale workshop environment while wood workshops, metal workshops and foundries are often downplayed or ignored. However, since many small-scale engineering wood workshops of universities participate actively in the economic enhancement of developing countries through training of students and provision of services to stakeholders, their existence is threatened with accident occurrences and severities, while new theoretical and practical research are needed. These studies may include a clear definition of models, using barrier analysis, distinctly classified according two main aspects – the physical human body parts susceptible to accidents such as skin, internal organs, external organs and the bone. The other aspect is physiological, involving fatigue quantification in modelling.

Second, the existing reports have been tailored to single modelling and theoretical frameworks, while examinations of hybrid models, with respect to the small-scale wood workshops have been omitted. For instance, the head injury barrier prevention model could be integrated with decision tools such as decision trees and fault tree analysis, which possess tremendous benefit of clear distinct quantitative specifications of probability of occurrence of accidents. However, ideas about these are missing in literature. Although such frameworks treatment of single models assists in laying the foundational research for the first wave of accident prevention research, the more advanced and expanded wave of research, which is the next and promising one, with the hope of radically transforming research and practice on small-scale workshop accident prevention tasks is yet to come. This is the time to initiate this new research agenda –the second phase and give hope of survival to threatened small-scale university wood workshops in developing countries.

Third, previous studies have historically omitted optimisation of preventive activities but new theories and practical steps are required to understand how optimisation enhances the performance of small-scale wood workshop. Of particular interest will be the outcomes of the optimisation attempt on the integration of the injury barrier prevention factors and fault tree analysis, which is an example of a decision model. Scholars rarely considered this and it becomes the novelty of this study. An attempt is made to present a formulated study and practical example from the small-scale wood workshop of engineering faculty of a university in a developing country.

A brief review of the relevant literature follows. Chi and Han [12] applied systems theory to exploit the accident prevention task through the use of Heinrich's domain theory. Akynz and Celik [13] utilized cognitive map to the diverse marine accidents in an attempt to analyse the influence of human factors during the course of events. Fonsea et al. [14] applied the concept of construction hazards prevention through design to show the integration between production and safety. Jorgensen [15] determined the extent to which the same type of prevention or safety methodologies as well as algorithms affirmed for significant accidents are applicable to simple accidents. Chinniah [16] considered serious injuries and fatalities associated with moving parts of machinery and proposed preventive schemes. The variables proposed have relationship tom moving parts of machineries; however, this is also incorporated in the current proposed method and also incorporates other work areas and aspects of the woodwork shop. Bakish et al. [17] improved the system hazard identification, prediction and prevention (SHIPP) accident modelling approach by mitigating the restrictive sequential progression assumption of the SHIPP methodology through the allowance of non-sequential failure of safety barriers to promote adverse events in any order.

Van Nunen et al. [18] studied the pattern of decision making in people when considering the necessity to choose between preventive and production investments. In this situation, the decision making is characterized by risks and uncertainties which could trigger negative outcomes. Cowlagi and Saleh [19] applied systems theory in the investigation of accident prevention and causation with the futter development of system analysis techniques-based principles. Kongsvik et al. [20] used quantitative risk analysis as decision inputs based on interviews and observations; suggestions on decision support improvement was given based on a number of principles. On preventive accident management, Albrechtsen [21] elaborated on the protection, safety and security of information resources as well as guaranteeing reliable and safe flow of information with case drawn from a technology-based work system. It should be noted that process systems differ from work-working systems in diverse respects, including size, capacity and resource requirements, which affect safety.

Barrier usage in accident prevention is proving its potentiality as an appropriate accident intervention strategy for many years more. Sevenson [4] was an earlier worker in this respect with a proposed accident evolution barrier model which was designed specifically for the process industry. In 2006, the concept of barrier and operational risk analysis was introduced and applied to the issue of hydrocarbon release.

The focus on accident preventive activities has dramatically impacted on the perception of workers toward accidents and increased the understanding of workers on accident triggering mechanisms for several years now. Carter et al.'s [7] work aimed at improving the accident prevention tasks as well as accident statistics by combining the routines of two groups as well as the effective monitoring of an accident-probing group. Some conceptual framework in 2010, placing priority on accident prevention in the process industry specification in offshore environment.

Kjellen's [2] approach was to prevent accidents through an experience feedback mechanism. In 2007, after reviewing previous research works on accident modelling techniques, the idea of predicting accident occurrence was proposed. Yet in 2012 research based on recursive modelling to investigate accidents was produced. The authors combined a cybernetic model of organisational factors and process to obtain a preventive value.

Development in risk mitigation requires proactive investigations for value added research on safety. In this respect, the fault tree analysis, which for many years have been proved useful. In accident analysis is adopted in the current study. This tool, is integrated with barrier analysis as well as certain injuries that could be avoided is utilised in this work.

Previous reports on barrier are comprehensive but focused on process industries. In addition, several other studies have applied barriers to road transportation. To the best of the current authors' knowledge, cases of barrier as they concern (1) small-scale industries; (2) wood workshop; and (3) developing countries such as Nigeria have not been reported in literature. In addition, no probabilistic concepts have fully exploited on this issue, in the past. Thus, the association of barrier as an intervention strategy with accident prevention model on one hand, and the specific injury inflicted on the worker according to the parts of the body on the other hand, has not been documented in literature.

The barrier framework used as the basis for avoiding damage to the human body has been studied by a number of authors that emphasise not exclusively manufacturing industries but accidents in general. Majority of these studies are based on road accidents. However, the possibility of improving on the conceptualisation of barrier from the single, disjointed view of barriers for the brain protection and leg protection against injury, for instance, to the holistic form in which these barriers are integrated in conceptualisation to include all parts of the body is now pursued in this work. The argument made have is that models that focus on only parts of the body in barrier framing against injury are limited. What happens to the other parts of the body? Are they not exposed to accidents if not protected? This obviously give us a clue as to focus on the skin, internal and external organs, bone as well as fatigue issues, which relates to the body in general. The superior attributes of the integrated barrier, fault tree and Lagrange's multiplier approach to accident preventive models used in literature lies in the following points: (1) In defining barriers, the specification parts of the human body are mentioned. This brings consciousness to the worker that accidents could happen to any parts of the body. This knowledge of the danger places the worker on a platform of carefulness in al the company activities, to be safety conscious and avoid accidents. (2) The fault tree analysis promotes knowledge of the possible alternatives to the analysis of tasks and hence, the understanding of the worker is widened. (3) Optimal decision could be embarked upon with respect to the analysis and implementation of safety investment as against sub-optimal values used if the model was not designed to optimise.

3. Methodology

The conceptual representation of the accident prevention model is shown in Figure 1.

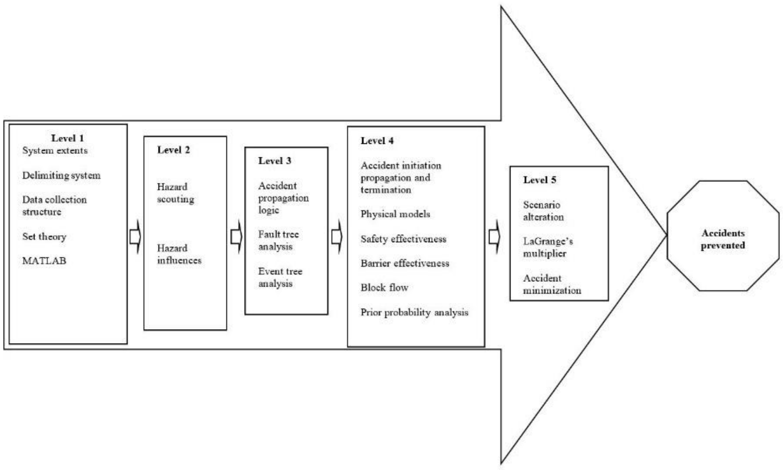


Figure 1 Conceptual framework for the accident prevention model

Since the whole floor is being considered, every possible location within the layout is treated as a high risk area (Figure 2). This is because the space is small and any hazard may affect those in the office.

Layer 1 development

Table 1 Various machines and their dimensions

Label	Name	Dimension (cm x cm)
A	Workbench 1	178 x 82
B	Band saw	136 x 76
C	Circular saw	151 x 111
D	Spindle	212 x 150
E	Thickness planer	110 x 103
F	Surface planer	66 x 200
G	Mortiser	56 x 70
H	Drilling Machine	41 x 31
I	Grinding Machine	31 x 45
J	Wood Lathe	284 x 58
K	Workbench 2	144 x 202
L	Combination Machine	175 x 84
M	Workbench 3	196 x 104
N	Workbench 4	180 x 102
O	Tools Storage Cupboard	89 x 46

The details of labels A to O show the various layout items in Figure 2. It consists of basically workstations of benches and machines for the wood-work.

System extents and delimitation

Here, the machines present in the wood workshop are labelled alphabetically. Their distances apart and exact positions are also represented in the layout in Figure 2. The dimension of the wood workshop is 765 cm x 1595 cm.

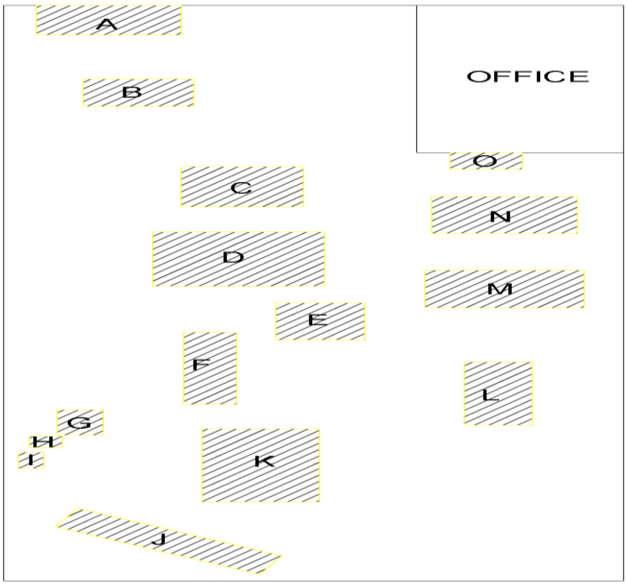


Figure 2 Layout of wood workshop

Layer 2 development

System hazard scouting and classification

This area involves pinpointing zones in which accident occurrence are more likely to be. The various hazards from each machine present in the wood workshop is listed alongside the machine. Table 2 summarizes this layer.

Table 2 Hazards from each machine (accident occurrence zones)

S/N	Task	Hazard
1-7	Working on band saw	Blade, Chips, Electricity, Dust, Slip, Trip, Noise, respectively
8-14	Working on circular saw	Blade, Chips, Electricity, Dust, Slip, Trip, Noise, respectively
15-21	Working on spindle	Cutter, Electricity, Chips, Dust, Slip, Trip, Noise, respectively
22-28	Working on thickness planer	Cutter, Rollers, Dust, Electricity, Slip, Trip, Noise, respectively
29-35	Working on surface planer	Cutter, Rollers, Dust, Electricity, Slip, Trip, Noise, respectively
36-42	Working on mortiser	Drill bit, Chips, Dust, Electricity, Slip, Trip, Noise, respectively
43-49	Working on drilling machine	Drill bit, Chips, Dust, Electricity, Slip, Trip, Noise, respectively
50-56	Working on grinding machine	Grinding wheel, Chips, Dust, Electricity, Slip, Trip, Noise, respectively
57-65	Working on wood lathe	Spindle, Lead screw, Chips, Chemicals, Electricity, Dust, Slip, Trip, Noise, respectively
66-73	Working on combination machine	Cutter, Drill bit, Chips, Dust, Electricity, Slip, Trip, Noise, respectively
74-81	Workbench	Sharp edges, Chips, Slip, Trip, Dust, Chemicals, Noise, Paint, respectively
82-84	Tools storage cupboard	Sharp edges, Slip, Trip, respectively

Hazard influences

The hazard influences are the instigators that must be present for the accident to occur. It is necessary and a key component for successfully applying this model. The hazards, alongside the means and the accident description are summarized in Table 3.

Table 3 Hazard influences

S/N	Hazard	Initiating function	Propagating function	Probable accident
1	Blade	Finger in blade locus area	Non-use of PPE Machine guard failure	Bone breakage and cut on finger
2	Cutter	Finger in cutter locus area	Non-use of PPE Machine guard failure	Bone breakage and cut on finger
3	Chips	External organ contact	Non-use of PPE	Partial blindness
4	Electricity	Direct contact Indirect contact	Prolonged exposure	Electrocution
5	Dust	Inhalation	Prolonged exposure	Temporary illness
6	Trip	Body contact with trip hazard	Walking at high speed	Bone breakage
7	Noise	High noise level	Prolonged exposure	Partial deafness
8	Slip	Body contact with slip hazard	Slippery floor Non-use of PPE	Bone breakage
9	Rollers	Body contact Cloth contact	Non-use of PPE	Bone breakage
10	Drill bit	Finger in drill locus area	Non-use of PPE Machine guard failure	Bone breakage and cut on finger
11	Grinding wheel	Finger in wheel locus area	Non-use of PPE Machine guard failure	Bruise on finger
12	Spindle	Body contact with spindle	Non-use of PPE Machine guard failure	Bone breakage
13	Chemicals	Inhalation Skin contact	Prolonged exposure	Illness Skin burn
14	Sharp edges	Skin contact	Contact at high velocity	Cuts and concussion

Layer 3 development

The occupational barriers are the same as that adopted for the personal products company. These are;

1. Bone injury prevention barrier (BIPB)
2. Skin injury prevention barrier (SIPB)
3. External organ injury prevention barrier (EOIPB)
4. Internal organ injury prevention barrier (IOIPB)
5. Fatigue injury prevention barrier (FIPB)

Layers 4 and 5 development

The objective of this paper is the minimization of accident occurrence through the minimization of the probability of a safety barrier being violated by using a non-linear programming method, employing Lagrange's multiplier. However, in order to bring the modeling into the right perspective, a mathematical representation for the minimization of accidents is therefore achieved as follows:

Allow the probability of occurrence of the primary events to be represented by a_i, where $a = f(a_1, a_2, \ldots, a_n)$ such that i is the primary event reflected on ($i > 0$) as well as an individual value function be signified as x_i, which is exceptional to a primary event.

$$X_i = f(x_1, x_2, \ldots, x_n) \quad (1)$$

The broad expression thus obtained is therefore:

$$\text{Minimise } Z = \sum_{i=1}^{n} \sum_{j=1}^{m} a_i x_j^{mi} \quad (2)$$

where *m* is the number of events leading to the occurrence of the primary instigator i.e.

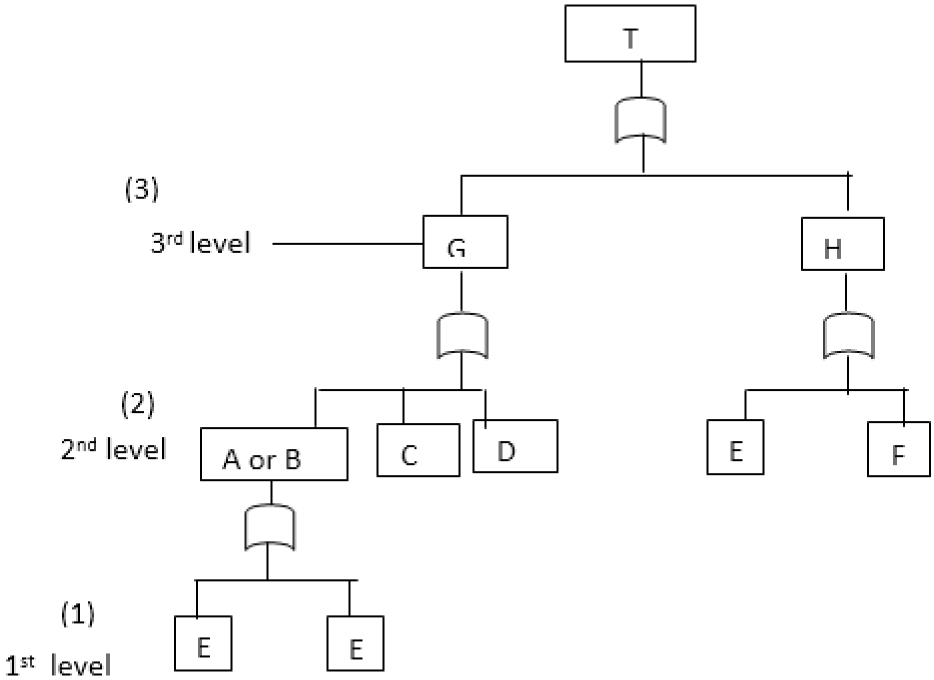


Figure 3 Obtaining the value of *m* for the generalised equation

In Figure 3, G and H are the primary events leading to the top events *T* being breached. *A*, *B*, *C*, *D*, *E* and *F* are all basic events. The individual value function is raised to the power of the number of levels present for the possible events that result in it occurring which is 2 for *G*, its representation in the generalized equation is written as $P(G).X_G^2$ where $P(G)$ is the probability of *G* occurring and X_G is the individual value function of *G*. X_i is the individual value function of the primary event while a_i is the probability of occurrence of the primary event. On introducing the AOPCF factor the general equation is re-written as:

$$\text{Minimise } Z = \sum_{i=1}^{n} \sum_{j=1}^{m} (a_i \text{x AOPCF}) \mathrm{X}_j^{mi} \qquad (3)$$

Where z is the safety barrier being considered and a_i is the probability of occurrence of the i^{th} event.
AOPCF is the accident occurrence prevention correction factor
X_i is the individual value function of the i^{th} primary event
M is the number of levels in the path resulting the i^{th} primary event.
Equation (3) can thus be re-written for the purpose of simplicity as

$$\text{Minimise } Z = \text{AOPCF} \sum_{i=1}^{n} \sum_{j=1}^{m} (a_i) \mathrm{X}_j^{mi} \qquad (4)$$

Equation (4) is so because the AOPCF is a constant. The constraint attached to the generalized model is

$$\sum_{i=1}^{n} X_i = 1 \qquad (5)$$

The reason for equation (5) is to define each primary event by its individual value function which can also be called a ranking factor and thus reveal a clear understanding of the level of importance of each of these primary events with respect to each other. Prioritizing the primary events results in a clearer understating of the areas needed to be addressed i.e. areas that accidents occur mostly. Also, the summation of the product of the AOPCF and the probability of occurrence of a primary event yields the probability of a safety barrier being breached also known as the prior probability.

The solution to Equations (4) and (5) is thus obtained using the Lagrange's multiplier as follows:

$$L = [\sum_{i=1}^{n} \sum_{i=1}^{m} (a_i.\text{AOPCF})\, X_i^{mi}] – \lambda[(\sum_{i=1}^{n} X_i)-1] \quad (6)$$

$$L = [(\text{AOPCF})(\sum_{i=1}^{n} \sum_{i=1}^{m} a_i.X_i^{mi})] – \lambda[(\sum_{i=1}^{n} X_i)-1] \quad (7)$$

Thus, in order to find the maximum value, finding the differential of L with respect to X and then equating to 0 yields:

$$\frac{\partial L}{\partial X} = [\ (\text{AOPCF}).m_i.a_i.x_i^{mi-1}] – \lambda = 0 \quad (8)$$

Hence for i = 1, 2, 3,…n we obtain:

$$\frac{\partial L}{\partial X_1} = [(\text{AOPCF}).m_1.a_1.x_1^{m1-1}] – \lambda = 0 \quad (9)$$

$$\frac{\partial L}{\partial X_2} = [(\text{AOPCF}).m_2.a_2.x_2^{m2-1}] – \lambda = 0 \quad (10)$$

$$\frac{\partial L}{\partial X_3} = [\ (\text{AOPCF}).m_3.a_3.x_3^{m3-1}] – \lambda = 0 \quad (11)$$

$$\frac{\partial L}{\partial X_n} = [\ (\text{AOPCF}).m_n.a_n.x_n^{mn-1}] – \lambda = 0 \quad (12)$$

Likewise, it could be stated that

$$\frac{\partial L}{\partial \lambda} = -\lambda^{1-1}[(\sum_{i=1}^{n} X_i - 1)] \quad (13)$$

$$\frac{\partial L}{\partial \lambda} = -\lambda^{0}[\ (\sum_{i=1}^{n} X_i - 1)] \quad (14)$$

$$\frac{\partial L}{\partial \lambda} = -1\ [\ (\sum_{i=1}^{n} X_i - 1)]$$

(15)

$$\frac{\partial L}{\partial \lambda} = -(\sum_{i=1}^{n} X_i) + 1 \quad (16)$$

$$\frac{\partial L}{\partial \lambda} = 1 - (\sum_{i=1}^{n} X_i) \quad (17)$$

Also, equating Equation (17) to zero yields:

$$\frac{\partial L}{\partial \lambda} = 1 - \left(\sum_{i=1}^{n} X_i\right) = 0 \quad (18)$$

Hence, for $i = 1, 2, 3, \ldots, n$ we obtain:

$$\frac{\partial L}{\partial \lambda} = 1 - (X_1 + X_2 + X_3 + \ldots + X_n) = 0 \quad (19)$$

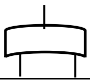
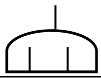
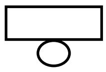
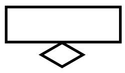
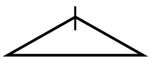
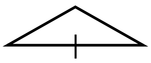
The values of X_i are thus obtained by solving Equations (9) to (12) and (19) simultaneously. Note that Equation (18) will yield n number of equations with n unknowns.

4. Results and Discussion

Fault tree development and analysis

In the current investigation, fault trees were employed in the determination of prior failure probability of each occupational safety barrier (i.e. skin, bone, external organ, fatigue and internal organ prevention barriers) for the wood workshop. The employment of OR Gate as well as Gate is made, primarily consisting of three main symbols of two variants each, namely, logic gates, input events and states as we as transfer symbols. The logic gates exhibits two logics-OR Gate as well as AND Gate. The input events and states have two variants- Basic events as well as undeveloped events. Finally, the transfer symbols have two variations- Transfer out and transfer in. The summary of their descriptions is shown in Table 4. The results of the fault tree development and analysis are shown in Figure 4 to 11.

Table 4 Applied fault tree symbols and meanings

Item	Symbol	Description
Logic Gates		**OR Gate:** Specifies that the output event takes place if any of the input events crop up
		**AND Gate:** Specifies that the output event takes place only if all of the input events crop up at equal period
Input Events and States		**Basic Event:** This stands for a basic situation or an act that cannot be further streamlined
		**Undeveloped Event:** It stands for an event or situation that is not developed further because of inadequate causal information
Transfer Symbols		**Transfer Out:** This explains that the fault tree branch is further developed at the occurrence of a corresponding transfer in symbol
		**Transfer In:** This explains the development of a fault tree from a point where the corresponding transfer out symbol occurs

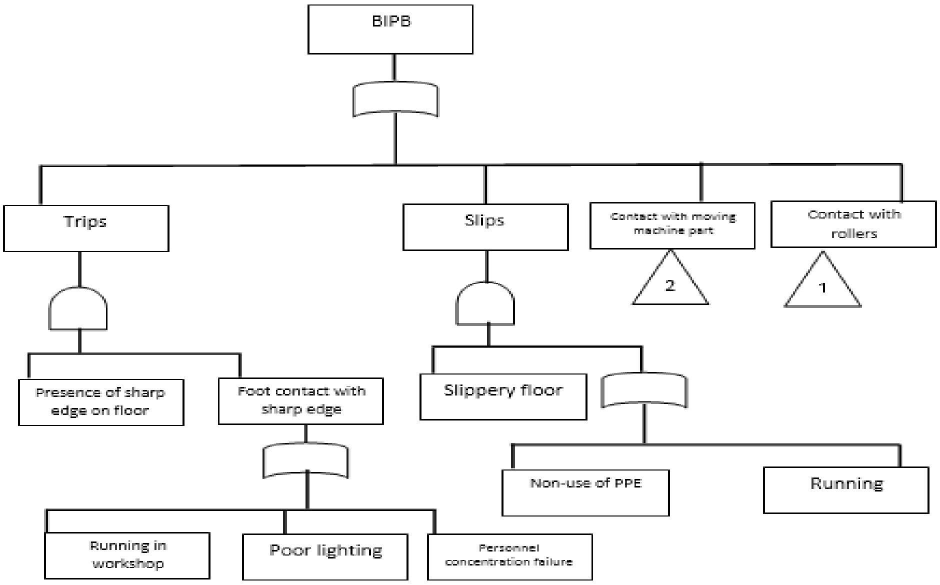


Figure 4 Bone injury prevention barrier

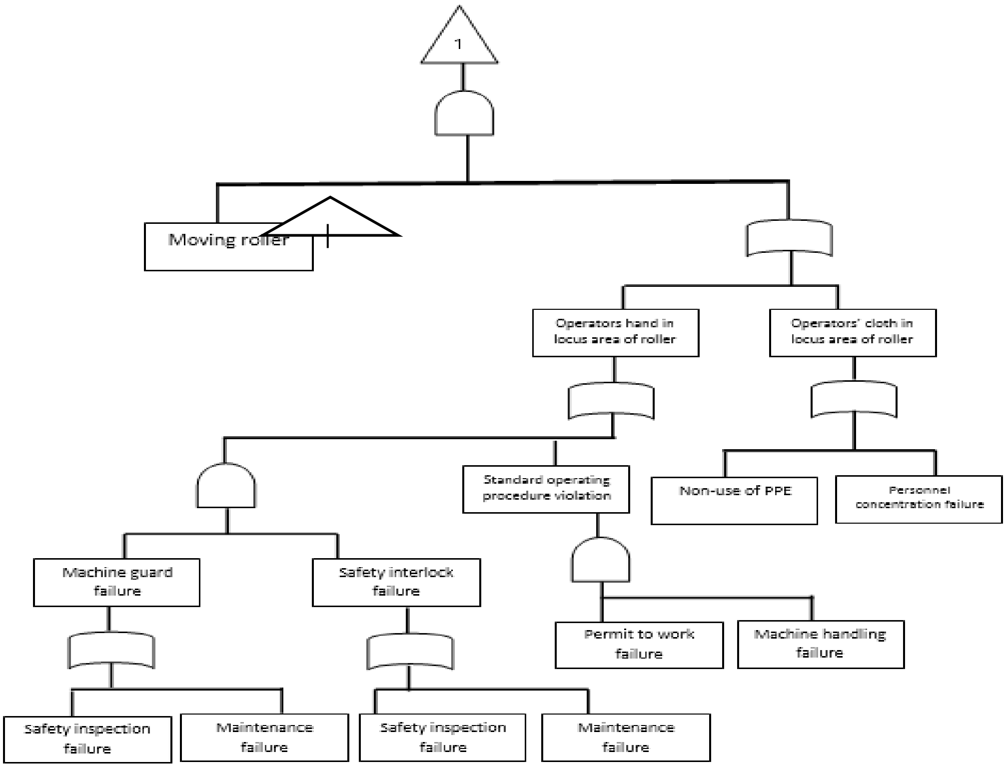


Figure 5 Bone Injury prevention barrier (triangle 1)

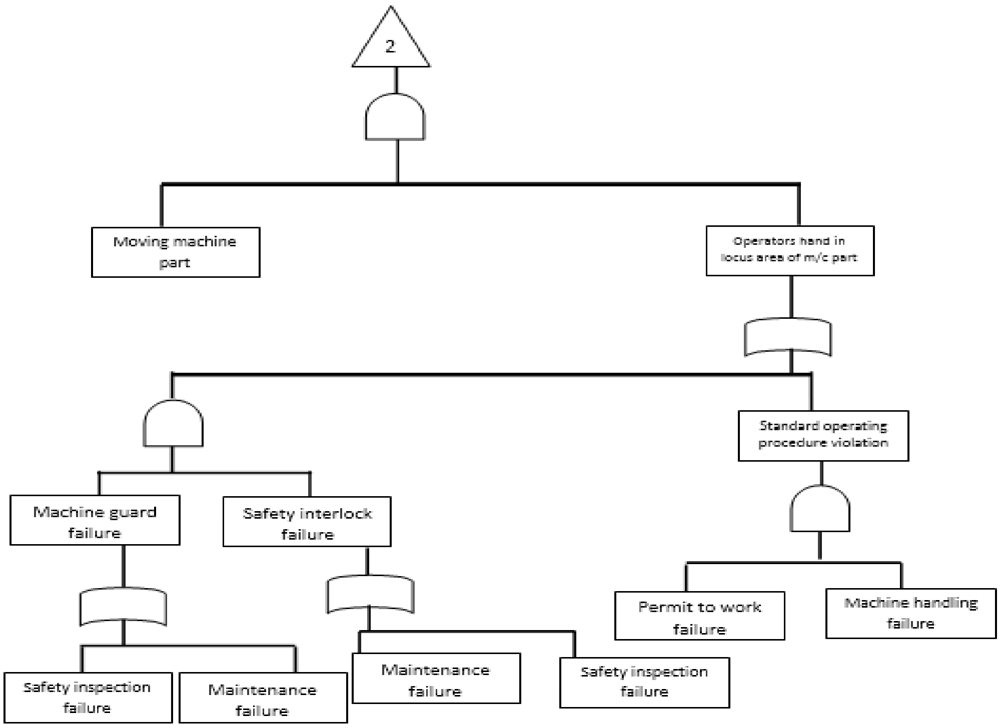


Figure 6 Bone Injury Prevention Barrier (triangle 2)

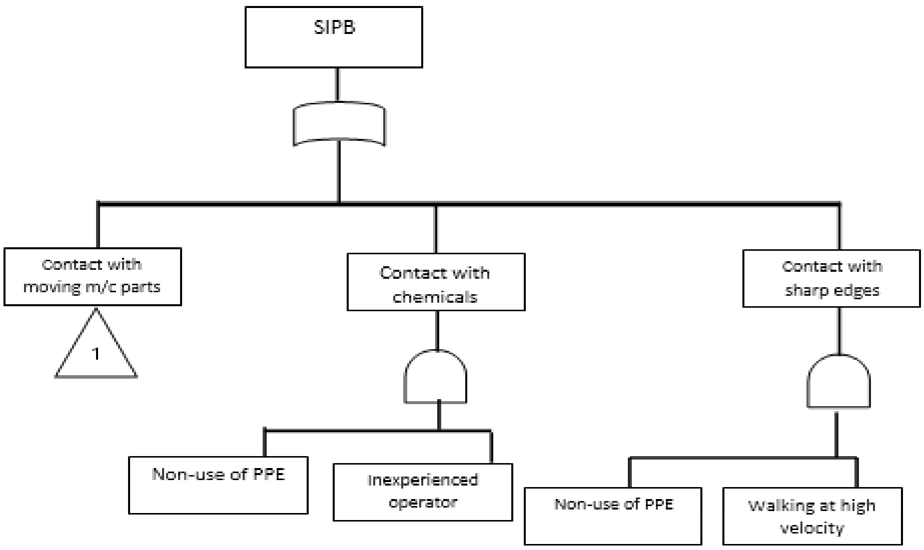


Figure 7 Skin injury prevention barrier

In Figures 4-11, the fault tree analysis of the accident was illustrated.To develop the fault tree diagrams the diverse combinations of human activities that could result in the unintended events for the manufacturing system are determined. These unintended events are called the top events. A top-down approach is employed in developing the fault tree diagram in which deductions start at the conclusion and later makes efforts in defining the particular cause of the conclusion. This is approached using a logic diagram, term fault tree which depends on Boolean algebra. A main advantage of the fault tree is to help in pin-pointing the possible cause of accidents prior to the accident events. A useful part of the fault tree analysis also involves the possible assessment of the probability of the top event with the use of analytical as well as statistical methods. With the completion of the fault tree analysis, efforts at enhancing the system safety could be pursued. Specifically, the following steps could assist in the application of the fault tree analysis to the accidents scenario of interest to in this work [22].

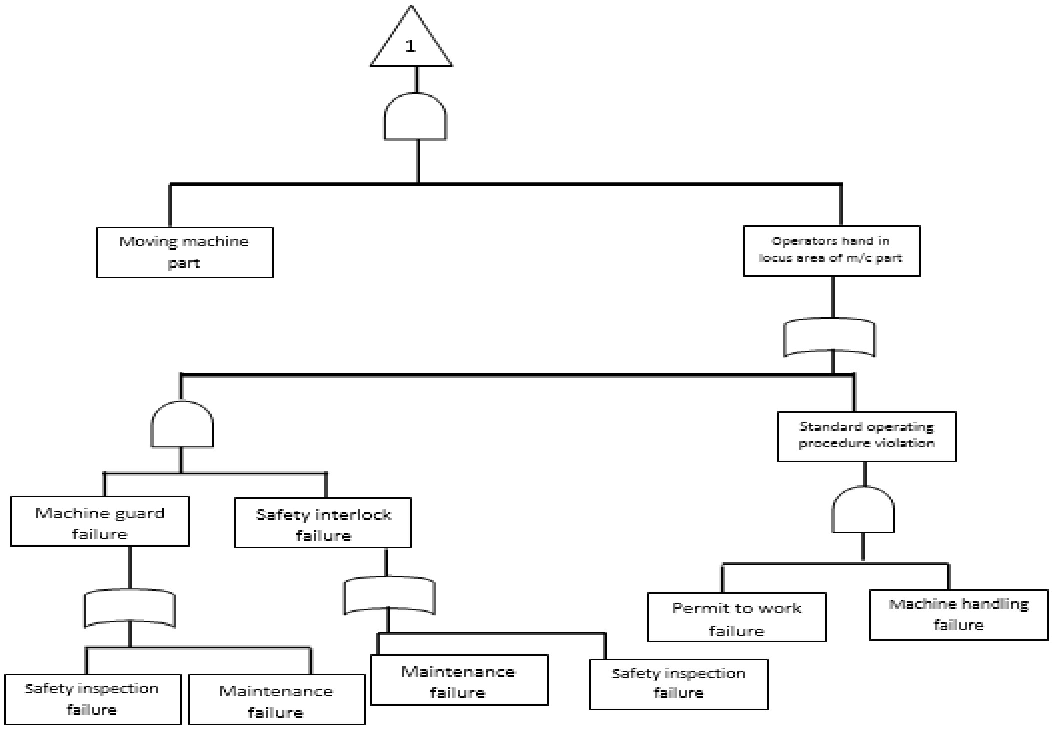


Figure 8 Skin Injury Prevention Barrier (triangle 1)

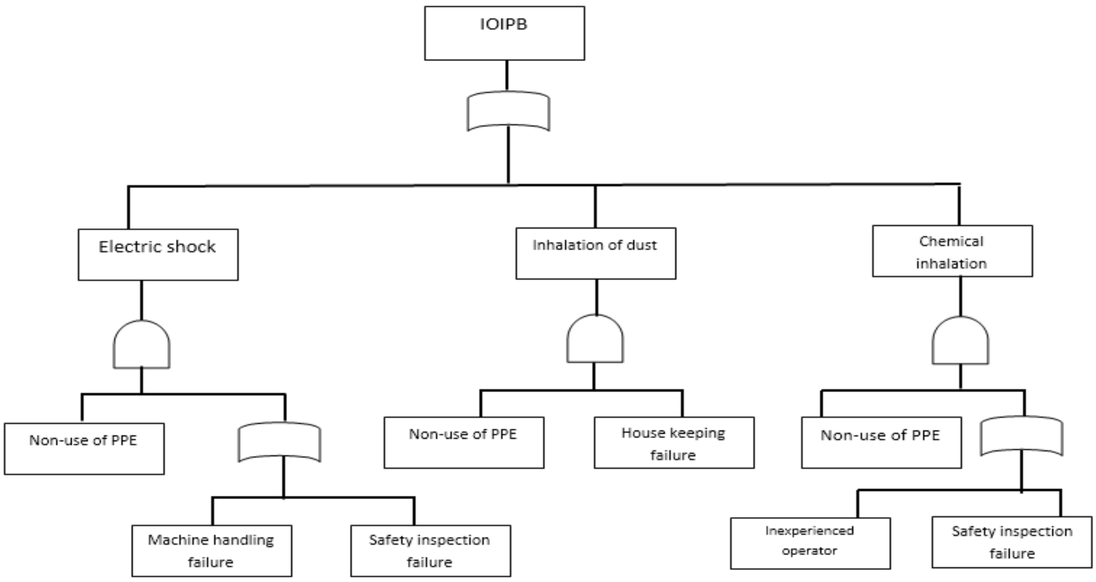


Figure 9 Internal organ injury prevention barrier

First, the accident condition is defined by putting down the accident occurring at the top level.Next is to exert professional judgement as well as the employment of information (technical) to know the likely associated reasons that promoted the accident. The level of the elements at this stage is the second as they occur merely below the accidents at the top level of the fault tree.A third step involves progressive breakdown of each element by employing more gates until lower levels are reached. As pilot noted [22], the interaction among the elements aid in decision concerning the usage of “and” or an “or” logic gate. As noted by pilot, [22], the fourth step involves finalizing and reviewing the whole diagram. The last step involves the possible assessment of the probability of occurrence for every lower level element.It also involves a computation of statistical probabilities arising from the bottom and proceeding up.

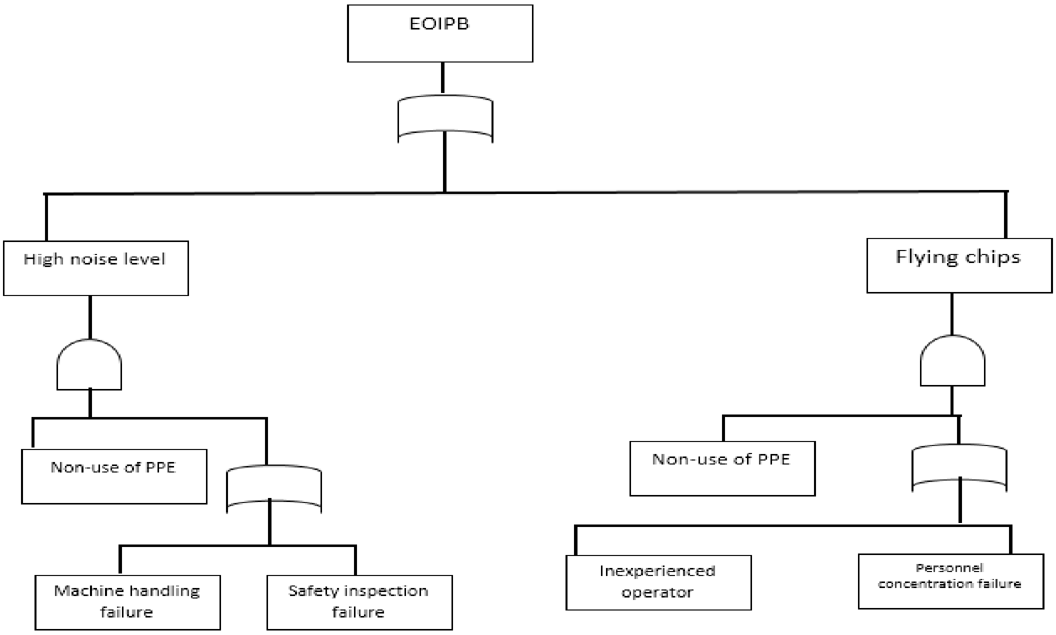


Figure 10 External organ injury prevention barrier

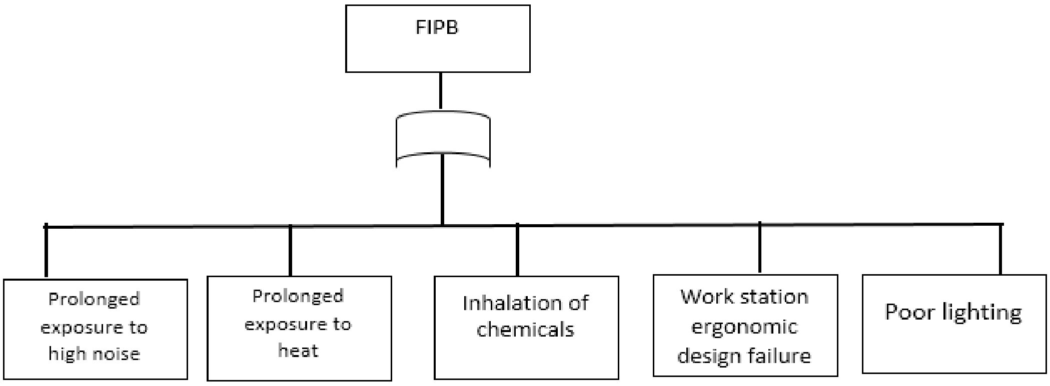


Figure 11 Fatigue injury prevention barrier

BIPB (Bone Injury Prevention Barrier)

TRIPS: The probability of "presence of sharp edges on floor" is assigned as 1 because without it there can be no trip. The probability of "foot contact with sharp edge" is thus obtained as below

P(foot contact with sharp edge) = P(running in the factory) OR P(poor shop floor lighting) OR P(personnel concentration failure).
For easy calculation, let
A - Running in the factory
B - Poor shop floor lighting
C - Personnel concentration failure
Therefore,

P(Foot contact with sharp edge) = P(A) OR P(B) OR P(C)

= {[P(A) P^I(B) P^I(C)] + [P^I(A) P(B) P^I(C)] + [P^I(A) P^I(B) P(C)] + [P(A) P(B) P^I(C)] + [P(A) P^I(B) P(C)] + [P^I(A) P(B) P(C)] + [P(A) P(B) P(C)]}

where $P^{I}(A)$ is the probability that A does not occur and P(A) is the probability that A occurs. Since there are only three possible causatives, we assign equal probability values to each of them since an occurrence of any of them results in the occurrence of the succeeding event. From summation rule in probability, P(A) + P(B) + P(C) = 1. Hence, each of these preceding events assume a value of 1/3 and their probabilities of failure will be 2/3.
Hence,

P(foot contact with sharp edge) = (1/3 x 2/3 x 2/3) + (2/3 x 1/3 x 2/3) + (2/3 x 2/3 x 1/3) + (1/3 x 1/3 x 2/3) + (1/3 x 2/3 x 1/3) + (1/3 x 1/3 x 1/3) + (2/3 x 1/3 x 1/3) = 19/27

Therefore,
P(trips) = P(presence of sharp edge on floor) AND P(foot contact with sharp edge) = 1 x 19/27 = 19/27

SLIPS:

P(slips) = P(slippery floor) AND { P(non-use of PPE) OR P(running)}
P(slippery floor) = 1
P{P(running on stairs) OR P(non-use of railings) OR P(slippery stair case)} = 19/27
P(non-use of PPE) = ½
P(running) = ½
P(non-use of PPE) OR P(running) = {(½ x ½) + (½ x ½) + (½ x ½) } = ¾
P(SLIPS) = 1 x ¾ = ¾

CONTACT WITH MOVING MACHINE PARTS:

P(contact with moving machine parts) = P(moving machine parts) AND P(operators hand in locus area of moving machine part)
P(moving machine parts) = 1
P(operators hand in locus area of moving machine part) = P{P(machine guard failure) OR P(safety interlock failure)} OR P(standard operation procedure violation)
P(machine guard failure) = P(safety inspection failure)
OR P(maintenance failure) = {(½ x ½) + (½ x ½) + (½ x ½)}
= ¾
P(safety interlock failure) = ¾
P(standard operation procedure violation) = P(permit to work failure) AND P(machine handling failure)
P(permit to work failure) = 1,
P(machine handling failure) = ½
P(standard operation procedure violation) = 1 x ½ = ½
P(operators hand in locus area of moving machine part) = {(¾ x ¼) + (¼ x ¾) + (¾ x ¾)}
= 15/16
P(contact with moving machine parts) = P(½)
OR P(15/16) = (½ x 1/16)+(½ x 15/16)+(½ x 15/16)
= 31/32

CONTACT WITH ROLLERS:

P(Machine guard failure) = ¾
P(Safety interlock failure) = ¾
P(Standard operating procedure failure) = ¾
P(operators hand in locus area of roller) = {P(machine guard failure) AND P(safety interlock failure)} OR P(standard operation procedure violation)
P(operators hand in locus area of roller) = P(¾ x ¾) OR P(¾)
P(operators hand in locus area of roller) = (¾ x 7/16) + (¼ x 9/16) + (¾ x 9/16) = 57/64
Also, P(operators cloth in locus area of roller) = ¾
Hence, P(contact with rollers) = P(moving rollers) AND {P(operators hand in locus area of rollers) or P(operators cloth in locus area of roller)}
P(contact with rollers) = 1 x {P(57/64) OR P(¾)}
P(contact with rollers) = 249/256
The equation obtained is thus of the form;
$(19/27)\, X_1^2 + (\tfrac{3}{4})\, X_2^2 + (31/32)\, X_3^4 + (249/256)\, X_4^5 = BIPB$
Subject to;
$X_1 + X_2 + X_3 + X_4 = 1$

The values of X_i are obtained by solving the equation above and applying the objective function
$\lambda = 0.4587$; $X_1 = 0.3259$, $\mu(X_1) = 0.2781$; $X_2 = 0.3058$, $\mu(X_2) = 0.2635$
$X_3 = 0.4910$, $\mu(X_3) = 0.3880$; $X_4 = 0.5542$, $\mu(X_4) = 0.4255$

A similar procedure is carried out on the Skin Injury Prevention Barrier, Internal Organ Injury Prevention Barrier, External Organ Injury Prevention Barrier and the Fatigue Injury Prevention barrier, Table 5 shows their rate of occurrence alongside the percentage rate of accident occurrence. Table 5 shows that for the accident situation, FIPB has no contribution while the greatest contribution goes to BIPB.

Table 5 Barrier rate of occurrence for wood workshop

Safety barrier	Rate of occurrence (λ)	% rate of occurrence (% λ_{total})
BIPB	0.4587	26.85
SIPB	0.25	14.63
IOIPB	0.25	14.63
EOIPB	0.75	43.89
FIPB	0	0

The sole objective of this section is to depict a comprehensive assessment of the results obtained from the application of this mathematical model methodology to the wood workshop. In the application of the mathematical model, prior probabilities were initially obtained from the fault tree, then combined to form a unique equation linking all basic events that occur for each safety barrier as carried out in the previous analysis of the personal products factory. A rate of occurrence was then obtained. From the results obtained, a graph was plotted to better depict the trend predominant in this location.

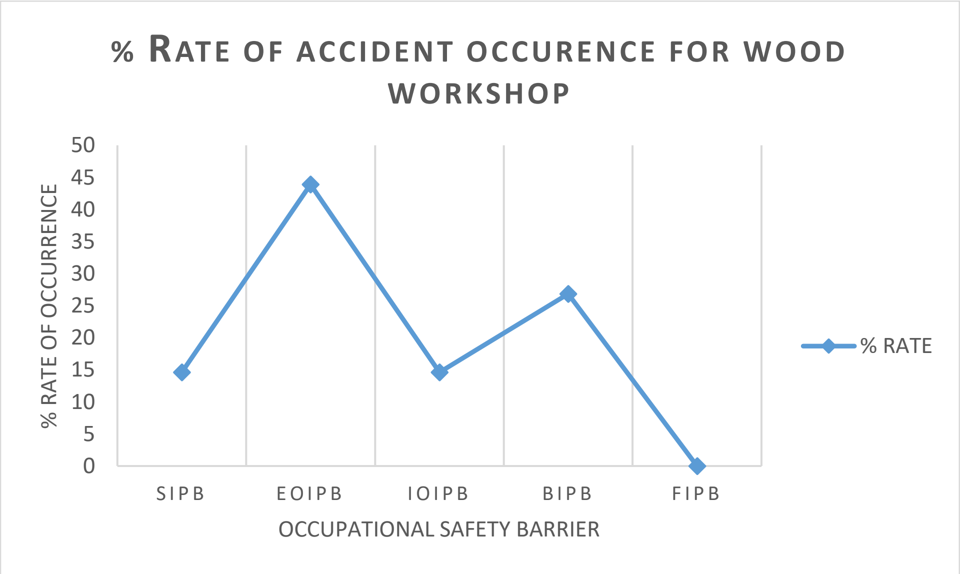


Figure 12 Rate of occurrence for wood workshop

It is observable that the External Organ Injury Prevention Barrier (EOIPB) is the most likely to fail in this scenario. This can be attributed to the fact that the activities carried out in the wood workshop are mostly physical and require hands on approach i.e dierct interaction between man and machine. The Bone Injury Prevention Barrier is the second most likely to fail followed by the Fatigue Injury Prevention Barrier which is non-existent. This implies summarily that a high percentage (almost 50%) of the probable accidents that would likely occur in the wood workshop would be under the class of the External Organ Injury Prevention Barrier. From our event tree analysis, the EOIPB falls under first degree accident which precceds second degree accident implying that the wood workshop has a high degree of uncertainity in terms of predicting when and what type of accident is likely to occur.

5. Conclusion

In this work, a gap was identified through literature review, for a significant need of a model capable of properly predicting an accident prevention status of a small wood processing organisation. Consequently, the research efforts yielded positive results in the development and validation of a quantitative methodology that is of three major components integrated-barrier, fault tree analysis and the Lagrange's multiplier. The accident quantifying aspects of the modified SHIPP model alongside the probability theory is employed in obtaining the probability values of accident occurrence generated from data collated from fault tree analysis. Lagrange equations are then used in obtaining the accident rate of occurrence and hence incorporate into an objective function. From the results obtained, the various classes of accidents follow the same trend in order to severity as the rate of accident occurrence and the results computed from the collected data obtained from a small-scale wood workshop in Nigeria verify the model. Fault tree diagrams were created and were used to compute prior probability values through total probability theory which satisfies the problem of having to assign prior probability values through guess work based on prior knowledge of the industry being considered as encountered in the MSHIPP model. This model not only satisfies prior probability assignment problem but also provides evidence that accidents can be predicted by having a comprehensive knowledge of the facility layout even before the facility commences operation.

In this work, a unique integrated approach for evaluating the current state of a manufacturing system in terms of accident prevention is developed using an integrated barrier-fault tree analysis Lagrange's multiplier approach. The model is optimal in nature and easy to apply in practice by the safety coordinator of a system since it does not require complex mathematics and steps. The robustness and feasibility of applying the model was verified through practical data collection involving the sizes and positions of equipment relative to one another and to the human operation. Fault tree was applied and the Lagrange's multiplier used as a tool, using data from a small-scale wooding workshop domicile in a university of a developing country, Nigeria. The approach provided the advantage of evaluating to what extent the risk associated, in terms of skin, internal organs, external organs, bone as well as fatigue, which are majorly parts of the accident prevention when shielded against accident using the appropriate and designated barriers.

Also, this model has been able to predict impressively the distribution of the rates of accident occurrence in all areas being considered without the use of already existing data unlike the MSHIPP model which depends solely on the availability of existing data in order to predict possible re-occurrence of such accidents in the foreseeable future. The presence of machines in in a centralised location in the wood workshop increases the risk of accident occurrence. Future research should be invested in adapting the current model to other existing industries. The computation of prior probability values due to its tedious and rigorous nature should also be looked into to help in reducing model application time.

6.References

[1] Senders, J., Moray, N., 1991. Human errors: their causes, prediction and reduction. Lawrence Erlbaum associates Incorporated, Hillsdale NJ.

[2] Kjellen, U., 2000. Prevention of accidents through experience feedback. Taylor and Francis, London.

[3] Andersson, R., Johansson, B., Linden, K., Svanstrom, K., Svanstrom, L., 1978. Development of a model for research of occupational accidents, Journal of Occupational Accidents 1, 341-352.

[4] Svenson, G., 1991. The accident evolution and barrier (AEB) function model applied to incident analysis in the process industries, Risk Analysis 11, 499-507.

[5] Lund, J., Aaro, L., 2003. Accident Prevention: Presentation of a model placing emphasis on human, structural and cultural factors, Safety Science, 42, 271–324.

[6] Hollnagel, E., 2004. Barriers and Accident Prevention: Aldershot: Ashgate.

[7] Carter, N., Menkel, E., 2003. Group routines for improving accident prevention activities and accident statistics, International Journal of Industrial Ergonomics 5, 125-132.

[8] Rathnayaka, S., Khan, F., Amyotte, P., 2011a. SHIPP methodology: Predictive accident modeling approach. Part I: Methodology and model description 89, 151-164.

[9] Rathnayaka, S., Khan, F., Amyotte, P., 2011b. SHIPP methodology: Predictive accident modeling approach. Part II. Validation with case study 89, 75–88.

[10] Gyekye, S., 2003. Causal attributes of Ghanian industrial workers for accident occurrence: miners and non-miners perspective Journal of safety research 34, 533-538.

[11] Owoh. U.E., 2012. Application and verification of an accident prevention model. Unpublished B.Sc. Thesis, Department of Mechanical Engineering, University of Lagos, Nigeria.

[12] Chi, S., Han, S., 2013. Analyses of systems theory for construction accident prevention with specific reference to OSHA accident reports, International Journal of Project Management 31, 1027-1041.

[13] Akynz, E., Celik, M., 2014. Utilisation of cognitive map in modeling human error in marine accident analysis and prevention, Safety Science 70, 19-28.

[14] Fonsea, E.D., Lima, F.P.A., Duarte, F., 2014. From construction site to design: The different accident prevention levels in the building industry, Safety Science, 70, 406-416.

[15] Joprgensen, K., 2016. Prevention of simple accident at work with major consequences, Safety Science, 81, 46-58.

[16] Chinniah Y., 2015. Analysis and prevention of serious and fatal accidents related to moving parts of machinery, Safety Science 75, 163-173.
[17] Bakish, A., Khan, F., Gadag, V., Ferdous, R., 2015. Network-based approach for predictive accident modeling, Safety Science 80, 274-287.
[18] Van Nunen, K., Reniers, G., Ponnet, K., Cozzani, V., 2015. Major accident prevention decision-making: A large-scale survey-based analysis, Safety Science, in press.
[19] Cowlagi, R.V., Saleh, J.H., 2015. Coordinability and consistency; Application of system theory to accident causation and prevention, Journal of Loss Prevention in the Process Industries 33, 200-212.
[20] Kongsvik, T., Almkhov, P., Haavik, T, Haugen, S., Vinnmem, J.E., Schiefloe, P.M., 2015. Decisions and decision support for major accident prevention in the process industries, Journal of Loss Prevention in the Process Industries, 35, 85-94.
[21] Albrechtsen, E., 2015. Major accident prevention and management of information systems security in technology-based work processes, Journal of Loss Prevention in the Process Industries 36, 84-91.
[22] Pilot, S., 2016. Back to Basics: What Is a Fault Tree Analysis? Accessed 27th April, [WWW Document] URL www. asq.org/quality-progress/2002/03/.../what-is-a-fault-tree-analysis.html