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Evaluation of Effectiveness of Manufacturing Safety Intervention; A Key to Successful Safety Planning and Management

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Abstract
Safety interventions (which entail a number of activities) are resourceful tools in the control or prevention of workplace accidents. Combination of these interventions achieved more results compared with individual application of these interventions. The cost effectiveness of these safety interventions/strategies is often considered a major interest to the leadership or management of an organization. This work hereby used retrospective accident analysis to determine the effectiveness indices (μ_k) of the identified strategies, thus determining the preventable number of accidents (S_k). Fifteen strategies (S_1 to S_{15}) were determined from the six safety interventions (Personal Protective Equipment (PPE), Training (Tr), Guarding (Gu), Accident Investigation (AI), Awareness (Aw) and Incentives (In)), out of which PPE and Tr were considered prominent. Their respective effectiveness indices (μ_1 to μ_{15}) were hereby calculated. It was revealed that $\mu_{15,}$ μ_{11} and μ_{12} have highest effectiveness indices of 5.50×10^{-06} (Q/₦), 5.46×10^{-06}(Q/₦) and 5. $\times10^{-06}$ (Q/₦) respectively. The effectiveness indices μ_3 and $\mu_{4,}$ however, have the lowest effectiveness indices of 3.50×10^{-06} (Q/₦) and 3.52E$\times10^{-06}$ (Q/₦). The highest effectiveness index reduced the highest number of accidents of 46 while lowest effectiveness index reduced the accidents by 19.
Keywords: Safety Intervention, Effectiveness Index, Safety Strategy.

1. Introduction

Occupational injuries as well as workplace accidents have been worldwide challenges and their impacts are so great that consequences in high-risk industries may be catastrophic, leading to loss of lives , properties, equipment, production hour, raw materials, capital, as well as high compensational cost, emotional losses, psychology trauma and disorganization (Adebiyi and Ajayeoba, 2015; Adebiyi, 2002; Mohan et al, 2004; Adebiyi et al., 2005; Macedo and Silva, 2005; Roudsari and Ghodsi, 2005; Fadier and De la Garza, 2006; Law et al. 2006; Mattila et al, 2006; Perez-Floriano and Gonzalez, 2007; Health and Safety Executive (HSE), 2013; Ma and Yuan, 2009; Payne et al, 2009; Bureau of Labor Statistics (BLS), 2013).

To enhance Safety in manufacturing, there should be improvement on the workforce and the workplace. Ergonomics and safety incentive programme are some ways of improving workforce safety in manufacturing (Sparer and Dennerlein, 2013; Choi et al., 2012 and Erdinc and Yeow, 2011). In workplace, research has shown that integrating various components of safety interventions in order to achieve a high level of safety is effective (Gaustello 1993; DeJoy, 2005). Safety planning has a key position in the field of production planning Zhang et al (2015). Since accidents often show an unanticipated difference between current beliefs about danger and the actual state of it (Henriqson et al, 2014), effective safety planning will however be a great tool to minimize its effects on man and his environment.

Safety intervention effectiveness evaluation could be described as the obtained outcome of an initiative which determines whether a safety intervention achieved its intended effect. In the workplace, needs – assessment could be conducted in order to determine the type of intervention required for a particular safety problem. The evaluation of safety interventions should be a major interest in the area of safety planning and management in any organization. This is important in order to prevent the unnecessary expenditure of resources towards an ineffective safety programme. Fach and Ockel (2009) identified analysis of accident statistics, in-depth studies of real world accidents, case by case evaluation of real world accidents and/or field studies and performance tests and measurements on test tracks as means of measuring the effectiveness of active safety systems. But the most impressive method to prove and quantify the efficiency of an active safety system in real world accident scenarios is clearly the retrospective accident analysis (Fach and Ockel, 2009).

Podgorski (2015) suggested that new approaches are now needed to ensure Occupational safety and Health Management Systems (OSHMSs) effectiveness. These including development of new methods that would facilitate measurement of OSHMS operational status aimed at the genuine improvement of occupational safety and health management practices. Since this research work develops an effective method for the allocation of resources towards safety interventions, it is important to evaluate the effectiveness of the safety strategies. Therefore, retrospective statistical analysis was used to evaluate the effectiveness index of each identified strategy.

2. Methodology

Safety activities of the companies were grouped by Adebiyi and Charles-Owaba (2009), into Personal Protective Equipment (PPE), Training (Tr), Guarding (Gu), Accident Investigation (AI), Awareness (Aw) and Incentives (In). Hale *et al*., (2010) and Adebiyi, (2013) stated that no single safety intervention can bring about the much desired reduction in accidents, rather, a combination of more than two interventions. However, Adebiyi (2013) thus reported that for a safety programme to be effective, training and personal protective equipment (PPE) must be combined with at least one or more of the other interventions.

Therefore considering PPE and Tr as predominant, fifteen strategies (S_1 to S_{15}) were determined from the identified safety activities. Safety data were collected from a bottling company having an organized safety system with a budget of ₦9.23 million for twelve years. Pre-safety accident (X_p) was estimated using the principle of expectation function given by Charles-Owaba and Adebiyi (2006):

$$x_p = \sum_{y=1}^{Z}\sum_{n=1}^{N} P_{ny} a_{ny} \quad \ldots 1$$

Where $X_p = \text{Pre} - \text{safety accident level}$

$P_{ny} = \text{Probability of accident class n in pre} - \text{safety period y}$

$a_{ny} = \text{number of accident class n recorded at the pre} - \text{safety period y}$

$\text{n} = \text{counter accident classes}$

y = counter of pre – safety accidents periods

z = number of operation of pre – safety period

N = number of accident class n.

Based on accident records, the expected number of accident for each year was estimated and the experienced number of accident is then subtracted to give the number of accident averted as a result of safety interventions. A graph of number of averted accident is plotted against the cost of intervention for respective years under the pilot study.

This is given as:

Accident averted = Expected accident – post implementation of safety accident … 2

It is noteworthy that accident prevention is taken exclusively as a function of investment (cost) with an assumption that all interventions achieve desired results without hitches.

The slope of the graph is taken as the effectiveness index of the whole combination of interventions.

$$\text{Effectiveness index } (\mu_{\text{int}}) = \text{slope of } Y_t \text{ against } CS_{\text{int}} \quad \ldots 3$$

Where

μ_{int} is the effective index of all interventions

$CS_{int:}$ cost of implementing all safety interventions

To evaluate the effectiveness index of a strategy therefore, the ratio of an estimated cost of respective strategies to the total cost of the strategy with all interventions is expressed as a proportion of the ratio of the effectiveness index of the strategy to the effectiveness index of the combination of all strategies(μ_{int}).

Mathematically,

$$\frac{\mu_k}{\mu_{\text{int}}} = \frac{CS_k}{CS_{\text{int}}} \quad \ldots 4$$

$$\Rightarrow \quad \mu_k = \frac{\mu_{\text{int}} \times CS_k}{CS_{\text{int}}} \quad \ldots 5$$

Where:

$\mu_k = the\ effectiveness\ index\ of\ Strategy\ k,$

$CS_k = the\ Cost\ of\ Strategy\ k = sum\ of\ cost\ of\ all\ interventions\ in\ strategy\ k$

$CS_{int} = the\ cost\ of\ implementing\ all\ safety\ intervention\ activities.$

The actual budget B_a is a function of proportions of budget (P) and planned budget (B), where B depends on X_p and Budgeting factor (β). Therefore, actual budget spent as given by Charles-Owaba and Adebiyi (2006) and thus related as:

$$B_a = P \times X_p \times \beta \quad \ldots 6$$

Where

$$\beta = \frac{1}{w}\sum_{s=1}^{w}\frac{B_s}{GL_s} \quad \text{… 7}$$

Where B_s = Safety Budget during the safety period
s = Safety period
w = duration of safety period (length of safety period)
GL= Potential accidents

Furthermore, the quantity of accident preventable by strategy (S_k) depends on the effectiveness index (μ_k) of safety strategy and the actual budget (B_a) as given in Equation 8

$$S_k = \mu_k \times B_a \quad \text{… 8}$$

But S_k is a function of whether the actual budget (B_a) could accommodate the cost of the chosen strategy (CS_k) or not depending on the required proportion of budget (P). The Decision (D) is the value of CS_k which is equal or greater than B_a (as shown in the Figure 1).

Thus Equation 8 becomes

$$S_k = \mu_k \times CS_k \quad \text{… 9}$$

3. Results and Discussion

The slope (μ_{int}) of accidents averted against costs of implementation as shown in Table 1 was calculated as 5.49541E-06Q/₦. The μ_k of each combination was derived by implementing equation 5 and was presented in Table 2 while values of CS_k and S_k were calculated as presented Table 3. The effectiveness indices $\mu_{15,}$ μ_{12} and μ_{11}, have highest values of 5.49541×10^{-06} (Q/₦), 5.47488×10^{-06}(Q/₦) and 5.45705×10^{-06} (Q/₦) while μ_3 and $\mu_{4,}$ have the lowest values of 3.50167×10^{-06} (Q/₦) and 3.5195×10^{-06} (Q/₦) respectively. The results also showed that S_{15}, S_{12} and S_{11} have the highest CS_k of ₦8,417,430.43, ₦8,385,984.43 and ₦8,358,667.36 whereas S_3 and S_4 gave the lowest CS_k of ₦5,363,568.57 and ₦5,390,885.64 respectively. Similarly, S_{15}, S_{12} and S_{11} gave the highest accident S_k of 46 accidents each, while S_3 and S_4 gave the lowest accident S_k of 19 accidents each.

4. Conclusion

Therefore, μ_k increases with CS_k as presented in Figure 2. The research work also revealed that apart from PPE and Tr that are prominent, Gu appeared to be highly effective because of its appearance in the leading strategies.

Table 1: Effective Indices Estimation

Year	Post Implementation Accident	Expected Accident	Cost of Implementation	Averted Accident
1st	51	89	7024915	38
2nd	36	89	7573245	53
3rd	28	89	8153296	61
4th	32	89	9238745	57
5th	27	89	9423342	62
6th	22	89	9692509	67
7th	19	89	8105663	70
8th	24	89	7680263	65
9th	27	89	8666254	62
10th	30	89	8620800	59
11th	29	89	8172673	60
12th	26	89	8429762	63
13th	35	89	8387909	54
14th	31	89	8674650	58

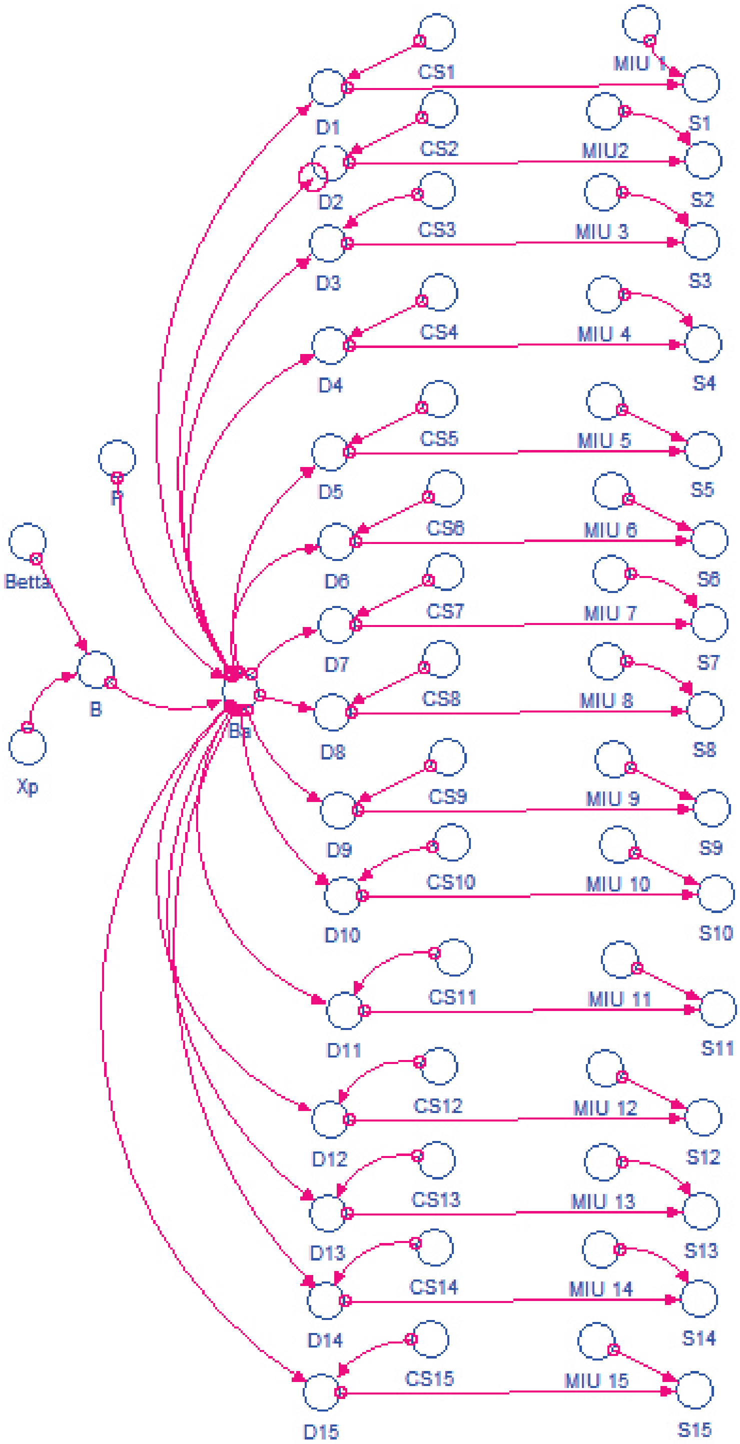

Figure 1: Stock Flow Diagram showing the effect of budget and Effectiveness index on accident prevented

Table 2: Estimated values of effectiveness indices for respective safety strategy

Effectiveness Index	Estimated Value (Q/₦)
μ_1	3.77075E-06
μ_2	5.14691E-06
μ_3	3.50167E-06
μ_4	3.5195E-06
μ_5	5.43652E-06
μ_6	3.79128E-06
μ_7	3.80911E-06
μ_8	5.16744E-06
μ_9	5.18527E-06
μ_{10}	3.54003E-06
μ_{11}	5.45705E-06
μ_{12}	5.47488E-06
μ_{13}	3.82964E-06
μ_{14}	5.2058E-06
μ_{15}	5.49541E-06

Table 3: Estimated Values of Prevented Accidents

S/N	S_k	Intervention Combination	CS_k	μ_k	S_k
1	S_1	PPE, Training, Incentives	5,775,725.71	0.00000377	22
2	S_2	PPE, Training, Guarding	7,883,618.21	0.00000515	41
3	S_3	PPE, Training, Accident Investigation	5,363,568.57	0.00000350	19
4	S_4	PPE, Training, Awareness	5,390,885.64	0.00000352	19
5	S_5	PPE, Training, Incentives, Guarding	8,327,221.36	0.00000544	45
6	S_6	PPE, Training, Incentives, Accident Investigation	5,807,171.71	0.00000379	22
7	S_7	PPE, Training, Incentives, Awareness	5,834,488.79	0.00000381	22
8	S_8	PPE, Training, Guarding, Accident Investigation	7,915,064.21	0.00000517	41
9	S_9	PPE, Training, Guarding, Awareness	7,942,381.29	0.00000519	41
10	S_{10}	PPE, Training, Accident Investigation, Awareness	5,422,331.64	0.00000354	19
11	S_{11}	PPE, Training, Incentives, Guarding, Accident Investigation	8,358,667.36	0.00000546	46
12	S_{12}	PPE, Training, Incentives, Guarding, Awareness	8,385,984.43	0.00000546	46
13	S_{13}	PPE, Training, Incentives, Accident Investigation, Awareness	5,865,934.79	0.00000383	22
14	S_{14}	PPE, Training, Guarding, Accident Investigation, Awareness	7,973,827.29	0.00000521	42
15	S_{15}	PPE, Training, Guarding, Accident Investigation, Awareness, Incentives	8,417,430.43	0.00000550	46

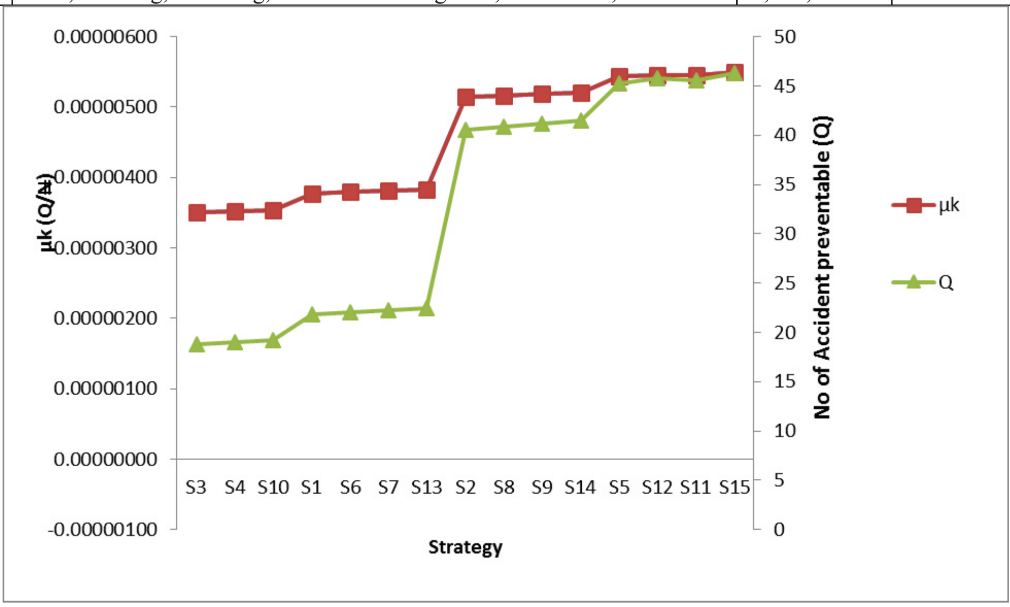

Figure 2: Relationship between effectiveness indices and Number of Accident prevented with type of strategy

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