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A Combinatorial Approach to Planning Manufacturing Safety Programme

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***Abstract*—**Despite many success stories of manufacturing safety, many organizations are still reluctant, perceiving it as cost increasing and time consuming. The clear contributor may be due to the use of lagging indicators rather than leading indicator measures. The study therefore proposes a combinatorial model for determining the best safety strategy. A combination theory and cost benefit analysis was employed to develop a monetary saving / loss function in terms value of preventions and cost of prevention strategy. Documentations, interviews and structured questionnaire were employed to collect information on Before-And-After safety programme records from a Tobacco company between periods of 1993-2001(for pre-safety) and 2002-2008 (safety period) for the model application. Three combinatorial alternatives A, B, C were obtained resulting into 4, 6 and 4 strategies respectively with PPE and Training being predominant. A total of 728 accidents were recorded for a 9 year period of pre-safety programme and 163 accidents were recorded for 7 years period of safety programme. Six preventions activities (alternative B) yielded the best results. However, all the years of operation experienced except year 2004. The study provides a a leading resources for planning successful safety programme

***Keywords*—**Combination, Manufacturing Safety, Monetary Savings, Prevention Strategies.

I. Introduction

THE advent of economic liberation and globalization, leading to increasing complexity of organization's business models, teams' roles and responsibility have plagued the manufacturing industry with up heals. Prominence is workplace injuries which have become daily menaces and destructive to individuals, organizations and society at large [1]. Apart from tragic physical and emotional effects, the economic impact can not be overemphasized. They pose frequent irreparable costs to individuals and; are inordinately costly at an organization level. The national safety council estimated that the workplace injuries cost $146.6 billion per year [2]. Consequently, there are numerous safety programmes; all with sole aim of eliminating or reducing accidents to bearest minimum. Despite all these, alarming in number of accidents occurrence persists, although with reduction in fatality. With many success stories of manufacturing safety programme through scores of published research papers, many organizations are still reluctant at investing on safety programmes. They perceived such attempt as cost increasing and time consuming. But safety should not be viewed as what it will cost, but how much savings that will result.

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One clear contributor to this misperception may be in the use of lagging indicators to identify trends of accidents occurrence. However, there has been increasing evidence to suggest that more attention should be focused on leading indicator measures. It is no longer sufficient to be collecting information on injuries or fracture that has occurred in work place. Thus focusing on individual performance accident rates and time injuries produces knee-jeck responses to safety performance in which an organization is always responding to its latest statistics. The daunting task of measuring performance in this regard in the changing face of manufacturing industries does not seem to have received adequate attention.

However, measuring performance is an important step in the safety improvement process and its effect is to stimulate positive action that results into organization's benefits. These benefits are not limited to reduction in accidents; reduced injury costs, but also reduced labour turnover and absenteeism; improved quality and increased productivity. Potentially, employees do not report all injury events because of inconvenience or belief about the necessity to report the so called minor accident. Also there may be tendency toward reporting only positive outcomes due to fear of loosing jobs on the part of employees.

As by reported Fabiano et al [3] that precarious labour is associated with increased fatalities, occupational injuries and illnesses in various industrial sectors across a number of industries. However, measuring performance is an important step in safety improvement process and its effect is to stimulated positive action that results into organizations' benefits. Although, a review of scientific publications on safety programme performance evaluation shows different approach exert different effects [4]. Interestingly, there is an increasing trend toward performing cost benefit analysis related to safety and health intervention [5, 6]. But, there appears to be growing evidence of suboptimal outcomes because prevention activities are not combined in an appropriate and effective manner. A carefully developed strategy ensures maximization of limited resources and skills. This is not only effective in short term, but can ensure sustained and persistent safety programme which are need for substantial industry's growth thus leading to reduction in production costs and improvement the capacity of the whole system that propriate the achievement of the best industry's economic result.

Therefore this study attempts to develop a combinatorial model that determines the combination of prevention activities that gives the best safety programmes performance.

II. Model Development

A. Model Assumptions

(1) Consistency of operations is guaranteed
(2) No significant difference in preventions in employing each strategy in all the alternatives
(3) Inflationary effect is not taken into consideration

B. The Model

According to Adebiyi and Charles-Owaba [6] safety programme prevention activities are classified into six. These are training, guarding, awareness creation, accident investigation, incentive/motivation and Personal Protective Equipment (PPE). It was also reported that no single activity can make a safety strategy, but least three classes of prevention activities must be present.

Based on this, four alternatives of combinations are identified. These are combining 3 prevention activities; 4 prevention activities five prevention activities and all six prevention activities at once.

However, in Adebiyi and Charles – Owaba [7] all prevention activities are practiced at once. Thus the 3 activities; 4 activities and 5 activities now explored leading to three alternatives discussed.

Employing the combinatorial approach

$$^{m}C_{r} = \frac{m!}{(m-r)!\,r!} \tag{1}$$

where: $^{m}C_{r}$ is possible combination of a number of activities r in available prevention activities m of manufacturing safety programme. Considering different alternative j, the number of strategies in alternative j is given as

$$N_{sj} = \left.\frac{m!}{(m-r)r!}\right]_{j} \tag{2}$$

However, each strategy is accompanied with budgeted expenditure to achieve certain level of safety in terms of prevented accidents. The performance of each strategy is therefore evaluated using the principle of cost – benefit analysis to obtain the money savings in employing specific strategy in specific alternative. The mathematical equations are developed as follow:

Given that Q_{jkr} is expenditure on activity r of k in alternative j

$$NE_{jrk} = \sum_{k=1}^{r} Q_k, \tag{3}$$

Considering the total activities (r) in strategy;

$$NE_{.rk} = \sum_{rk=1}^{m} Q_k, \tag{4}$$

The benefit is operationally defined as value of prevented accidents, thus value of prevented accidents is given as:

$$V_{ij} = \sum_{i=1}^{n} Y_{ij}.C_i, \tag{5}$$

where, Yi is number of accident prevented

C_i = unit cost of accident.

But
$$Y_{ij} = X_{ip} - X_{is} \tag{6}$$

Therefore

$$V_{ij} = \sum_{i=1}^{n} \left(X_{ip} - X_{is}\right).C_i \tag{7}$$

However, the monetary saving in employing each strategy is given as

$$NS_{jk} = V_{ij} - NE_{.jr} \tag{8}$$

Thus, substituting equations 4 and 7 in 8, the monetary saving/loss is given as

$$NS_{jk} = \sum_{i=1}^{n} \left(X_{ip} - X_{is}\right).C_i - \sum_{k=1}^{r} Q_k \tag{9}$$

III. Model Application

Role of performance measure can be identified as providing information to assist both operational and strategic controls. A common method of assessing the performance of a safety initiative is a Controlled Before – After (CBA) study involving a situation where there is contemporaneous data collection before and after the safety interventions indicating the implementation of desired safety initiative. Therefore, the data for the application of the model were obtained from a tobacco company (which remain anonymous) in Nigeria. The choice of the company was based on the existence of organized safety programme and access to required information. The company had a staff capacity of 500 with 350 being permanent staffers and 150 are on contract appointments. The company had no organized safety programme when it was established in 1993. The cases of injuries and accidents are being addressed by the personnel unit of the establishment. However the alarming increases in the occurrence of accidents over the eight years period of 1993 – 2001, led to the emergent of Health, Safety and Environment unit in the company. Documentations, interviews and structured questionnaire were employed to collect information from the company on:

- Safety programme activities being practiced
- Classification of accidents
- Records of accident occurrence (by severity level) for both before and after safety programme
- Annual expenditure on safety programme activities.

According to Adebiyi and Charles-Owaba [6], safety prevention activities are classified into six, namely; Training, Personal Protection Equipment (PPE), Guarding, Incentives, Awareness and Accident Investigation. These are coded as A1, A2, A3, A4, A5 and A6, respectively for ease of combination.

Preliminary investigation carried out through visits to 28 manufacturing companies revealed that two prevention activities (PPE and Training) are predominant in all while at least three prevention activities are being practiced in all. Based on these, the possible number of strategies applicable to the identified classes of prevention activities is identified as:

<u>Alternative A:</u>

Combining three prevention classes making PPE and Training predominant yielded 4 strategies.

<u>Alternative B:</u>

Four prevention classes combined while maintaining PPE and Training yielded 6 strategies.

<u>Alternative C:</u>

Five prevention classes combined and still maintaining the predominance of PPE and Training yielded 4 strategies. Classical statistics was employed to analyse the data to obtain pre-safety accident level and the estimates of other model parameters required for the application.

According to Adebiyi and Ajayeoba [8], the cost of each class of accident is estimated as Fatal (N2, 665,360:00); serious (N232, 750:00); minor (N56,000:00) and Near-miss (N8.750:00).

Adapting these, (12) was then employed to determine the annual monetary savings/losses in the utilization of each strategy in each of the identified alternatives. The results are presented in Figs.1-3.

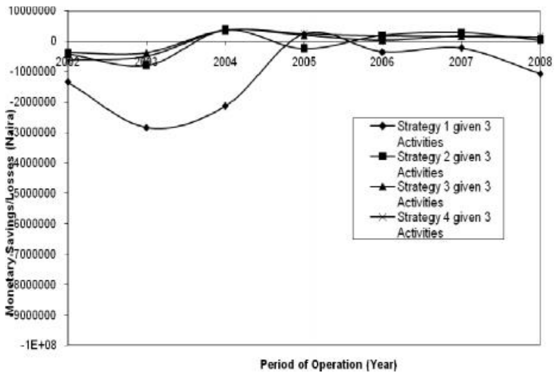

Fig. 1 Monetary Savings/Losses versus Period of Operation

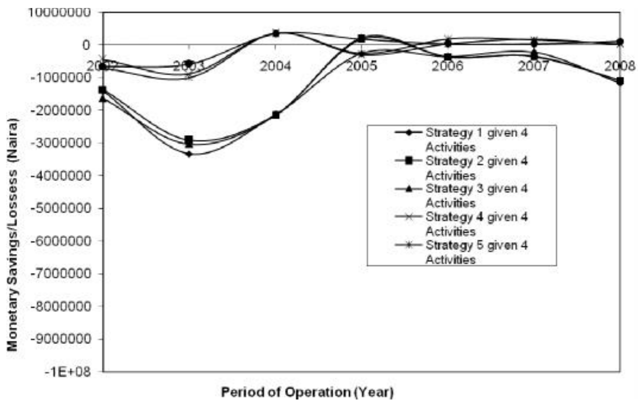

Fig. 2 Monetary Savings/Losses versus Period of Operation

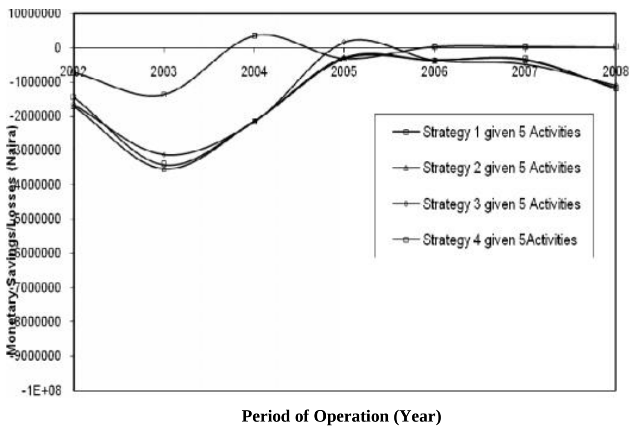

Fig. 3 Monetary Savings/Losses versus Period of Operation

IV. Results and Discussion

Based on the review of relevant document, physical evidence and quantitative analyses, four classes of accidents were identified as: Fatal, Serious, Minor and Near-miss. A total of 728 accidents were recorded for 9 year period of 1993 to 2001 with a mean accident occurrence of 81. This high number could be attributed to labour intensive nature of the company as well as exposure to hazardous operational conditions. Year 1993 recorded highest number of 98 accidents. This being starting year, may be attributed to lack of experience and non-formal training of workers on the job. The analyses revealed that the largest proportion of these accidents was recorded from trivial wounds (54; 12%) while fatal had the least occurrence of 9 accidents (1.24%).This was followed by progressive reduction in accident until 1997 when it abruptly increased to 94 from 72 in 1996. It also drastically reduced to 59 in 1998 and started increasing again in 1999 from 72 to 94 in 2001. The alarming increase of accidents in 1997, findings, suggests may be due to employment of more casual workers, improved production technology without adequate training, and perhaps increase in the volume of jobs. This thereby corroborates the earlier works of [7, 9 and 10] that increase in number of man-hours increase the susceptibility of accident occurrence and that of Villaneva and Garcia [11] that among the noticeable, the risk of fatal consequence of occupational accidents increases with temporary workers, work shift-time and age. Among the noticeable factors adduced for the increasing number of accidents were the absence of organized safety programme, location of factory and overall planning of plant and facilities. According to [11], environmental factor contributes greatly to cause of accidents, in facts, heat exhaustion was reported by Joiner [12] to be responsible for stroke in factory workers. Perhaps, this is one of the major factors while company was relocated in 2002.

TABLE I
PRE-SAFETY PROGRAM ACCIDENT RECORDS (1991 TO 2001)

	1993	1994	1995	1996	1997	1998	1999	2000	2001	Total
Fatal	2	3	1	0	0	1	2	0	0	9
Serious	20	10	15	12	13	9	7	9	14	109
Minor	16	26	23	20	25	19	30	27	30	216
Trivial wounds	56	41	38	40	56	30	33	46	50	390
Total	94	80	77	72	94	59	72	82	94	724

A. Safety Period Accident Record

Contrary to the pre-safety programme period, a total of 163 accidents were recorded for 7 years period with a mean accident occurrence of 23. Expectedly, trivial wound had the highest of 66 (40.4%) while fatal had the least of 2 (1.22%). The year 2002 witnessed the peak period of accidents occurrence 65 (39.9%) followed by year 2003, 40 (24.54%).

However, it is instructive to note that there is significant reduction of accidents in 2004, with recorded number of accidents of 14 (8.59%). The sharp reduction was attributable to the quality of staff (mostly graduate) and more importantly, the existence of established safety programme.

TABLE II
SAFETY PROGRAM ACCIDENT RECORDS (2002-2008)

	2002	2003	2004	2005	2006	2007	2008	Total
Fatal	1	0	0	0	0	0	1	2
Serious	18	20	4	3	0	0	0	45
Minor	20	10	4	6	3	4	3	50

Trivial wounds	26	10	6	7	5	5	7	66
Total	65	40	14	16	8	9	11	163

TABLE III
ANALYSIS OF ANNUAL EXPENDITURE ON SAFETY PROGRAM (2002-2008)

Activities/ Years	PPE	Motivation of Workers	Accidents Investigation	Guarding	Awareness Creation	Training	Total
	#	#	#	#	#	#	#
2002	5,631,000	5,000	10,038,000	7,500,000	3,000,000	920,810	21,463,810
2003	3,635,000	2,100,000	178,200	5,000,000	800,000	204,000	8,282,200
2004	12,000	2,100,000	8,072,000	0	723,000	783,000	11,678,000
2005	4,713,000	1,561,000	85,000	0	600,000	170,000	2,416,000
2006	3,230,500	2,522,000	112,300	5,600,000	1,500,000	40,000	9,774,300
2007	2,000,000	2,046,000	135,000	0	0	1,320,000	3,501,000
2008	1,380,500	2,040,000	128,000	953,000	450,000	70,000	3,641,000
Total	35,786,000	13,964,000	20,623,600	18,500,000	8,300,000	4,832,810	76,115,410

A. Monetary Savings/Losses in the use of Resources During a Safety Programme

Fig. 1 shows the characteristic curve of money savings/ losses in the implementation of strategies obtained in combining 3 activities. All the strategies but strategy 1 predominately produces fair performance.

Expectedly, the early years (2002 and 2003) witnessed poor performance as the strategies recorded monetary losses ranging from N5 million to N30 millions. However starting from 2004, an improvement in performance occurred with average monetary gain of N3 million. The trend of the strategies 2, 3 and 4 reflects that an increment in expenditure on safety more than that of 2004 produces no justification. An alarming outlier of monetary losses of 97millions by strategy 1 in 2006 was attributable to high expenditure on prevention activity A4. This invariably affected the performance of other strategies. Moreover, figure 8 appears to present a worse situation. All the resultant six strategies from combination of four activities exhibit poor performance except strategy 6. However strategies 1, 2, 3 had the worst performance showing the similar trend of strategy 1 of combination of three activities. It was observed that the presence of activity A4 in all these strategies accounted for this ugly performance.

A critical investigation of Fig. 3 showed that the trend is virtually the same for all the strategies except strategy 1. The combination of 5 activities all resulted in the wastage of resources. Monetary losses were experienced during the 7 years period of operation for strategies 2, 3 and 4. Year 2006 witnessed worst performance for all the strategies except strategy 2, with money loss of about N100 millions.

Noticeable is the outlier nature of year 2006 which could be attributable the too much expenditure on Activity A5 activity which is prominent in all these strategies. Although, strategy 1 has better performance to others, however, no significant saving was made except in year 2004 with monetary loss of about N400, 000. This is no match for the monetary losses of N800, 000 and N1.1 million in year 2002 and 2003, respectively.

V. CONCLUSION

This study presents a mathematical model for evaluating the performance of safety programme in terms of monetary savings as a function of parameters that can be practically obtained. Available expenditure on interventions is taken as a quantifiable and variable measure effort applied to the safety programme while value of prevented accidents is taken as the output. Modelling was based on combinational approach and it is applicable to any industry with organized safety programme.

Three alternatives of combination were proposed resulting into 14 strategies with Training and PPE prevention activities predominating in all the strategies. It is concluded that 4 activities provide better performance.

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