Integrated Modeling of Manufacturing Safety Interventions Planning and Management

K.A. Adebiyi and A.O. Ajayeoba

Abstract--Research on safety planning and management has revealed that focusing one safety intervention programme; and use of lagging measures for safety evaluation is not sufficient. This study proposed an integrated model for safety intervention progamme management using system dynamics and combinatorial approaches. Combinatorial analysis was used to determine possible safety strategies while system dynamic software STELLA (version 10.0.3) was used to determine the interactive effects of these strategies on the safety interventions parameters. Factory accidents and preventions were the measures. A typical manufacturing company in Nigeria was thus used for demonstration.

Index Terms—Safety strategy, combinatorial analysis, dynamic model, safety system

I. INTRODUCTION

Occupational injuries as well as workplace accidents continue to be a challenge worldwide [1] and their impacts are so great that consequences in high-risk industries may be catastrophic [2 and 3]. Their effects are seen in loss of equipment, lives, productive hours, raw materials, capital, as well as high compensational cost and emotional losses [4] – [9]. Safety and health protection have become a major positive factor in favour of economic growth and productivity and one area in which the concern for safety is growing rapidly is the manufacturing industries [10] and [11].

Many recent studies advocated that safety and health functions should be integrated into the activities of the industries to increase the chances of reaching safety goals in manufacturing industries and that health and safety protection of the employees during work should be considered as one of management routine activities [3]. There are many approaches to improve workforce safety in manufacturing, amongst which are ergonomics, safety incentive program [SIP], behavior change and culture change approach, building information modeling [BIM], adaptive management, Foucauldian approach and safety climate [12] – [16]. Despite the persistent endeavours to promote manufacturing safety,

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fatalities still plague the industry and absolute safety of humans and property remains an illusion. Recently there had been an emergence of a variety of manufacturing safety research focusing on topics such as safety competency, accident statistics, design for safety, and safety culture.

One of the ways of reducing accident or improving safety is through the use leading evaluation methods of safety interventions and as a result, many modern manufacturing industries have utilized knowledge in engineering to develop intelligent decision supporting systems for improving and strengthening their safety systems. Among these are artificial neural network [ANN], genetic algorithms [GA] and fuzzy logic [FL] and system dynamics [SD] [10], [17] – [19]. However, the cost of safety interventions is perceived to be expensive, and that is one of the reasons the management tends to run away from it. Perhaps the development of an agreeable leading measure is the main challenge. Based on previous research efforts [19 and 20], this study aims to develop a safety management and planning tool that [1] identifies potential safety interventions strategies, [2] dynamically linked the strategies and hazardous conditions that implement prevention system effectively, and [3] improves workers and management perception of visualizing safety as investment. It therefore focused on the use of possible combinations of interventions that will minimize cost but improve safety using systems dynamics which has repeatedly been demonstrated to be an effective analytical tool in a wide range of situations both in academic research and in industrial practice [11].

II. METHODOLOGY

Twenty manufacturing companies with organized safety programmes were critically examined. A combination of data vetting, personnel interviews, physical participation and dynamic group modeling, simulation and retrospective statistical data gathering and analysis was employed to identify accident causing factors and safety interventions which are classified by [17] into Personal Protective Equipments (PPE), Training, Incentives/Motivation, Guarding, Accident Investigation and Awareness Creation.

According to [20] the number of strategies N_{sjk} in alternative j_k in safety period s is given as:

$$C_T = \sum_{j_k=1}^{j_k=4} N_{sj'} = \sum_{j_k=1}^{j_k=4} {}^l C_p{}^{m-l} C_h$$

Applying system dynamics rules (17) the causal loop and; stocks and flow diagrams for manufacturing safety

system was developed using Stella System Dynamic Software as shown in Fig. 1 and 2

The required models for factory accidents (X_t) and prevented accident (Y_t), are determined from the results of the causal loop and the stock and flows diagrams delineation.

$$X_t = Y_t - X_p \left(1 - \ell^{-ht\left(1-\ell^{-\lambda(qf-y_t)}\right)}\right) - X_o \ell^{-1ht\left(1-\ell^{-\lambda(qf-y_t)}\right)}$$

$$Y_t = X_p \beta P \mu_k \left[1 - \ell^{-\ell^{-[(qf-Y_t)\lambda]t}}\right] + Y_o \ell^{-\ell^{-[(qf-Y_t)\lambda]t}}$$

Table 1 summarizes the data of the case study organization. Two sets of factory data: pre–safety programme (1979-1990) and safety programme (1999-2012) data were collected from production, clinic, safety and personnel departments of the establishment through vetting of records, structured questionnaire, and personal interaction with heads of units and departments. The data on the occurrence of accidents before safety programme were collected from the clinic and personnel units..

The collected data were used to estimate the following safety system model parameters: budgeting factor for safety programme, potential accident, total man-hours of workforce, accident proneness factor, prevention time lag, accident causing factor, and proportion of prevented accidents class n as presented in Tables 2.
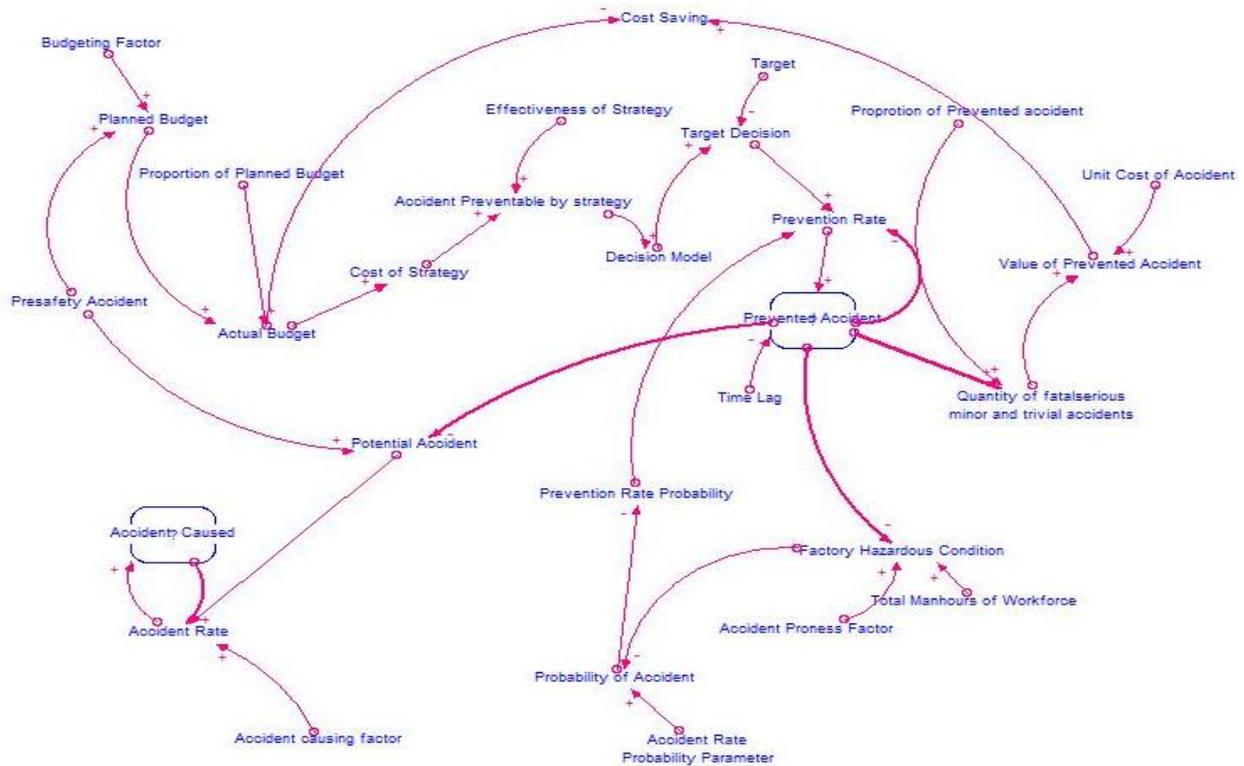

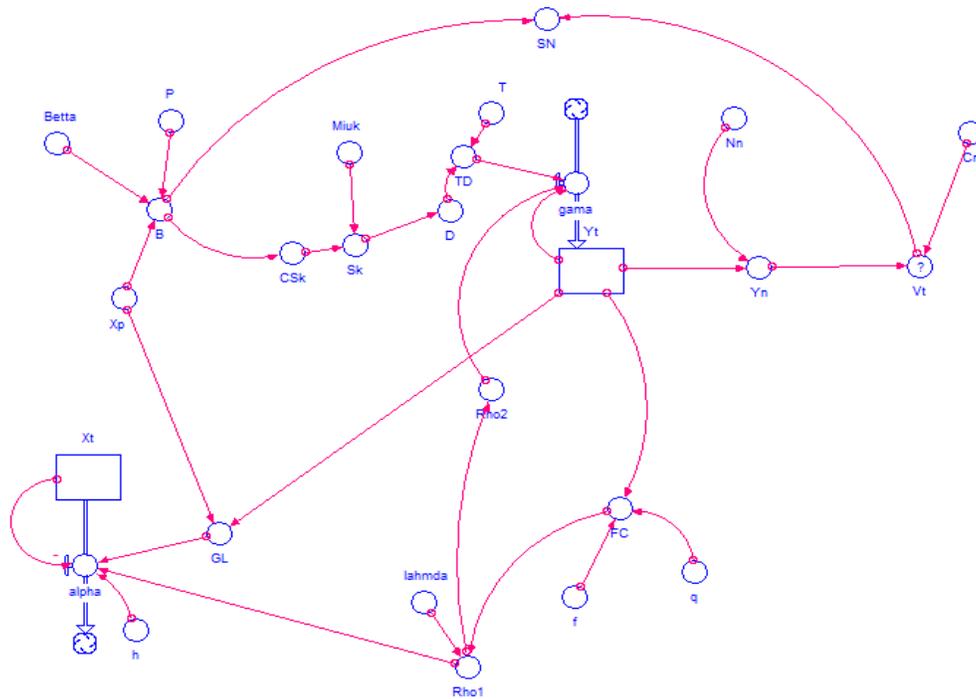Fig. 1: Causal Loop Diagram of Manufacturing Safety Programme

Fig. 2: Simplified Stock Flow Diagram of Manufacturing Safety Programme

TABLE I SUMMARY OF THE CASE STUDY DATA

Size of workforce [Persons]	145
Number of shifts	2
Working hours per day	16
Number of working days/year	241 days
Production Capacity of the plant	
Size of manufacturing equipment (Heavy duty/light duty)	Light duty
Identified types hazards	Work at Height, Body traps in moving machine parts, enclosed surfaces, machinery related accident
Level of expertise of the workers	Intermediate
Type of Equipment	Majorly semi-automatic
Safety Certification	Health & Safety (OHSAS 18001), Environment (ISO 14001)
Welfare and Compensation Package	Effective

TABLE II ESTIMATES OF MODEL PARAMETERS

S/N	Safety System Input Parameters	Symbol	Estimated values
1	Budgeting factor for safety programme	β	103728 [Naira/ Accident]
2	Potential accident	X_p	89 Accidents
3	Total man-hours of workforce	q:	561660 man-hours
4	Accident Proneness Factor	f:	$1.585\,e^{-4}\,Q[MHR]^{-1}$
5	Prevention Time lag	T	0.25 [Year]
6	Accident causing factor	h	0.083 $[T^{-1}]$
7	Proportion of Prevented Accidents n	N_n	Fatal [0.01]; Serious [0.11]; Minor [0.26]; and Trivial wounds [0.62], respectively

III. DISCUSSION OF RESULTS

The successful simulation run, at 0.6 proportion of budget (P) and 10% reduction target (T) as shown in Fig. 3, the safety programme chooses strategy 3, which is a combination of 3 different intervention activities; PPE, Training and Accident Investigation, as the cost effective strategy to fulfill the 10% reduction target. However, it shows that there is a gradual reduction in accident per year from the beginning of the first year to the end of the 3rd quarter of the 6th year, reducing the

accident from 0 to 8 and no accident was reduced again till the middle of the 8th year when reduction started till the last quarter of the same year when the 10% target reduction was achieved Similarly, as the accident is prevented, factory accidents reduce. Meanwhile, the graph of prevented accidents shows an exponential growth while that of the experienced display the random nature of accidents (periodic up and down number of accidents).

Also, the number of accident started from 89 being the pre-safety accident and remained constant over the first 6 months of strategy implementation. This is not to say that the strategy was redundant over the first 6 months and had no effect, rather this period will be a period of evolving a safety climate that will plunge into significant safety gains on the long run. There was a sharp decline in the number of accident within the first 4 years of safety strategy implementation with accident reducing by 8 within this period (from 89 to 81). A much slower trend is observed over the next 3years and 9 months; between the 4th and the 7.75th year of safety strategy implementation. Given the accident reduction target and implementation level, the number of accidents remained constant from the beginning of the last quarter of the 8th year to the 12th year of the simulation period with a potential factory accident being at 80.

This constant trend was set to continue except investment is made on the safety programme, the investment will however bring about a further reduction in quantity of accident witnessed. For safety managers, it will interest them to know the year of redundancy of their safety programme. This can be read off from the graph of the factory hazardous condition (FC) over the simulation period (Fig. 4), which is 3years and 3 months i.e. from the third quarter of the 8th year to the 12th year.

IV. CONCLUSION

An integrated dynamic model for manufacturing safety programme was developed in terms of pre-safety accident level (X_p), budgeting factor (β), proportion of budget (P), effectiveness factor (μ_k), Factory workforce (q), Accident proneness factor(f), Prevented Accidents (Y_t), Accident causation probability (λ) and Proportion of prevented accidents(N_n). The developed models provide an interactive interface which serves as a useful tool for predicting and achieving factory accident, prevented accident, setting and achieving accident reduction targets and identifying various combinations of safety activities that can fulfill their targets.
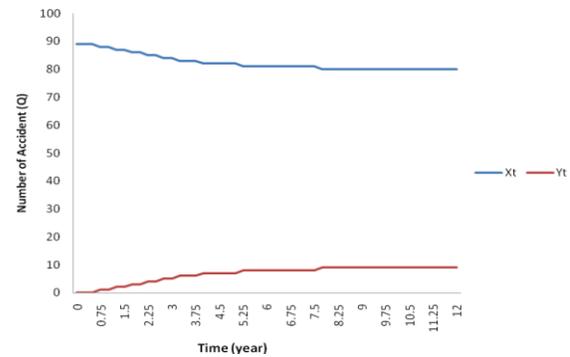
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Fig. 3: Simulation run of prevented accidents and factory accidents at P = 0.6 and T = 10% prevented and potential accidents.
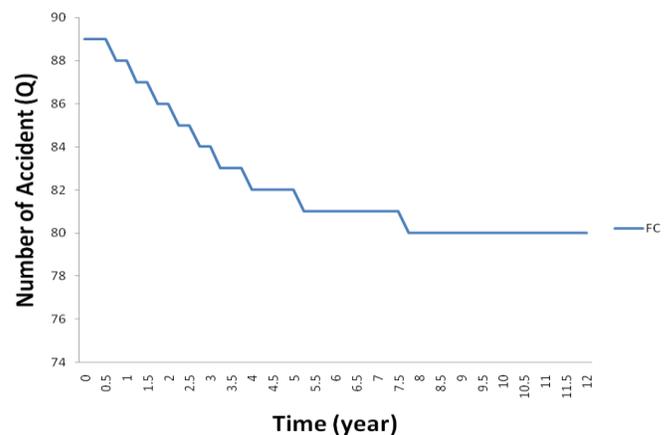

Fig. 4: Simulation run of factory hazardous condition at P = 0.6 and T = 10%.

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