

# Modeling the Impact of Hazardous Conditions in a Manufacturing Safety Program.

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## ABSTRACT

Industry seems to have developed a bad impression of current governmental approaches to enforcing occupational health and safety regulations, feeling that it is bureaucratic, legalistic, and costly and lacks scientific content. Unfortunately, failure to effectively regulate health and safety conditions at the workplace may result in much higher accident costs.

One approach for reconciling industry and government agencies is to develop and apply scientific instruments capable of advising industry on the most cost effective way to control occupational hazards. It is the main goal of this study to develop a mathematical approach for setting and sustaining a profitable industrial safety program. Accordingly, many manufacturing firms were preliminarily observed and accident-causing components and modes of prevention were identified. Based on this, the system-dynamics methodology was applied to develop accident causal and action flow diagrams. Hence, a system of equations depicting the dynamics of accident causes and prevention elements was derived. These were transformed into a safety program cost performance function in terms of accident causes and safety management parameters. The model's validity and sensitivity were verified using data from a bottling company in Nigeria. Its validity was established and the model shown to be sensitive over a wide range of operating parameter values

(Keywords: workplace safety, system-dynamics, performance functions, hazardous conditions).

## INTRODUCTION

Scientific progress has made life more comfortable. Most establishments are now characterized by computer operations, centralization, and automation, as well as rapid technological advancement. However, there exists the potential for permanent anatomical or physiological damage due to workplace hazards especially among industrial workers. Workplace accidents have been identified to be destructive to persons industry and society at large (Honston and Richardson, 2008; Fullarton and Stokes, 2007). Consequently significant amounts of money are being wasted on healthcare and rehabilitation (Akgugör and Yildiz, 2007).

Bazroy et al. (2003) reported that traumatic occupational injuries lead to 10,000 deaths globally. Occupational injuries have been identified as one of the leading causes of adult mortality and a major contributor to permanent disability among low income countries such as those of South Asia and Africa; and an estimated 50 million work related injuries occur every year or 160,000 every day.

Gardner et al. (1999) and Druchi et al. (2004) stated that the manufacturing industry has a high incidence of workplace injuries in comparison to other industries. Fadier and De la Garza (2006) reported the occurrence of 862,500 occupational accidents on France in the year 2000 alone, while Mattila et al. (2006) also stated that Finland recorded 20,016 hospitalizations for injuries between 1990 and 1999.

According to the Nigerian Institute of Safety Professionals (2000) overall, 11,000 people were injured due to on-the-job accidents each year in chemical industry alone in Nigeria. Also, Adebisi

et al. (2005) estimated the cost of accidents in agro-allied industries in south-western Nigeria at 87.89 millions dollars annually.

Basically, there exist three approaches to the regulation of occupational health and safety (Cam, 2005). The first involves the promulgation of rules prescribing or proscribing specific policies and practices by employers. The evidence of effectiveness of adherence to the regulatory rules and its enforcement is uncertain. The argument on regulations and enforcement policies revolves around the cost of regulations and enforcement, versus the actual benefit in reduced worker injury, illness and death.

The second approach emphasizes the use of economic incentives that reward or punish employer on the basis of safety and health outcomes rather than behaviors. This approach is embodied in experience rating. However, Benichoum et al. (2008) stated that no perfect or near perfect indicators of injury exist.

The third approach is based on internal responsibility. This involves workers right to refuse unsafe work or organizing a joint labor-management safety and health committee. Here, an individual measures performance using indicators such as self efficacy, safety awareness, and safety behavior (Hsu, 2008). It is possible that because of the level of poverty in areas such as Nigera, there is tendency for workers to be subjected to more risky work and workers may have a greater fear loosing their jobs if they complain about safety.

Despite extensive state and federal government occupational health and safety regulations, and other measures there is still widespread apathy among employers, employees, and the community about health and safety in the workplace. The industry impression is that health and safety management is bureaucratic, legalistic, and costly to introduce and also lacks scientific content. Although, literature is replete on the measures of safety and health (Lortie and Rizzo, 1999; Flin et al, 2000; Shepherd and Kahler 2000; Adebisi et al 2007; Hollnagel, 2008; Polinder et al, 2008), however, there is need for movement away from lagging measures of health and safety that is based on retroactive data. This is because safety tends to determine the value of any work and a deficit in safety is considered to result in a cost (beyond the cost of addressing safety in the first place).

One approach for reconciling industry and government agencies is to develop and apply scientific instruments capable of advising industry the most cost effective way to control occupational hazards. It is the main goal of this study to develop a mathematical approach for setting and sustain profitable manufacturing safety programmes.

## MATERIALS AND METHOD

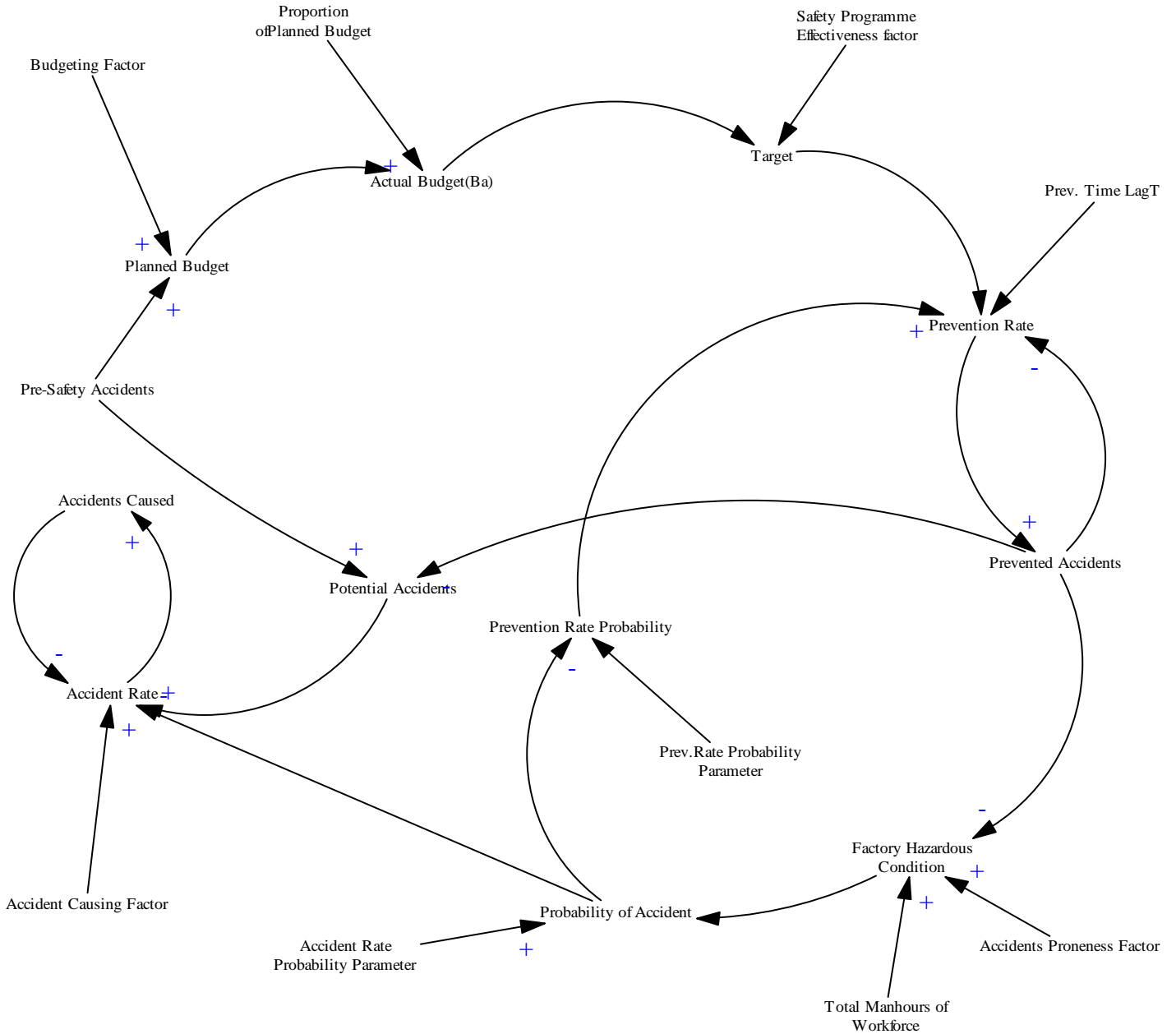
In pursuing the goals of the study, a number of manufacturing firms were critically observed to identify:

- Number and types of accidents causing activities,
- Types of accident prevention activities,
- Safety program inputs and outputs
- Couplings between accidents causing factors, prevention activities, inputs and outputs, and
- Control parameters..

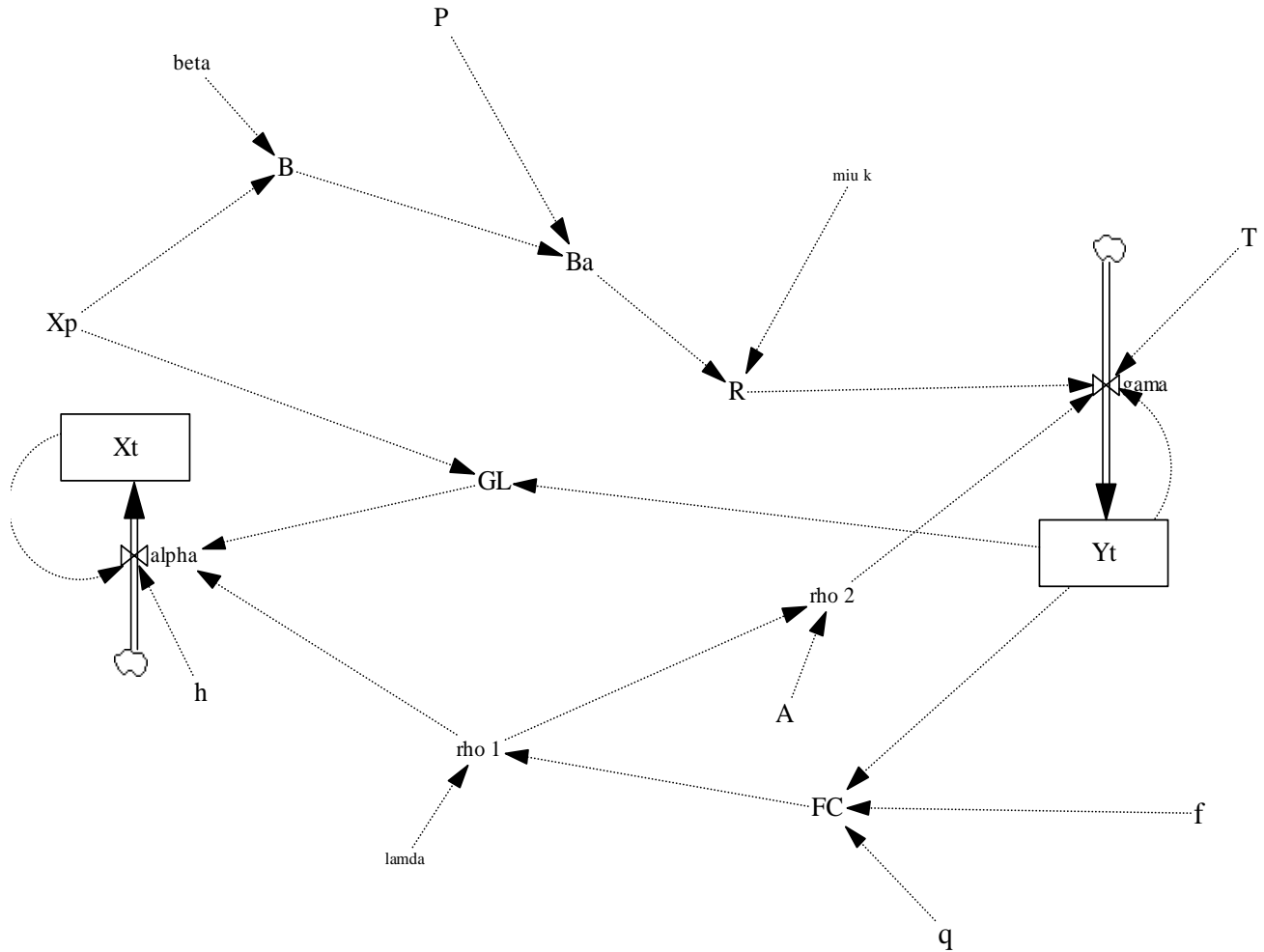
In the process audio and visual inspections, data vetting; personal interviews, reviews, review of previous work; adoption of mathematical modelling technique; statistical data gathering and parameter value estimation, procedures more adopted.

It was observed that accident causing components were contributed by human factors, deficiency in maintenance of facilities, and the overall working environment. The accident prevention activities were found to come from the following: training, awareness creation, guarding, accident investigation, motivation and use of personal protective equipment. Extracting from both categories of activities, the manufacturing safety system variables, parameter inputs/outputs were identified. Following the system dynamics paradigm of Forrester (1973), the causal loop diagram of manufacturing safety programme was developed. The resulting diagram is as shown in Figure 1.

Based on casual loop diagram, a flow diagram depicts the dynamic relationships of the components of a system was developed. The dynamics of accident causation and control of manufacturing safety programme is presented in Figure 2.



**Figure 1:** Causal Diagram of Manufacturing Safety Program Simulator.



**Figure 2:** Manufacturing Safety Program Simulator Flow Diagram.

Based on Marquis – Favre (2006) the system dynamic equations depicting the outputs of the manufacturing were developed as follows:

The number of periodic accidents experienced ( $X_t$ ) in terms of factory hazardous conditions, workforce, accident proneness and the probability of accidents and is described below:

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

The number of prevented accidents ( $Y_t$ ) in terms of budgeting factor; proportion of implemented budget; effectiveness in SP activities (including training, use of personal protective devices, machine guarding, accident investigation, safety incentives and personnel awareness) and SP action-result time lag :

$$Y_t = X_p \beta \rho \sum_{k=1}^M U_k \mu_k \left[ 1 - \ell^{-\ell^{-[(qf-y_t)\lambda] \frac{1}{T}}} \right] + Y_o \ell^{-\ell^{-[(qf-y_t)\lambda] \frac{1}{T}}}$$

An SP cost saving/loss performance function:

$$SN = X_p \beta \rho \left[ \left( \sum_{k=1}^M U_k \mu_k \sum_{i=1}^N n_{i1} C_{i1} \right) \left( 1 - \ell^{-\ell^{-[(q-y_i)z] \frac{1}{T}}} \right) - 1 \right] + Y_o \left[ \sum_{i=1}^N n_{i1} C_{i1} \right] \ell^{-\ell^{-[(q-y_i)z] \frac{1}{T}}}$$

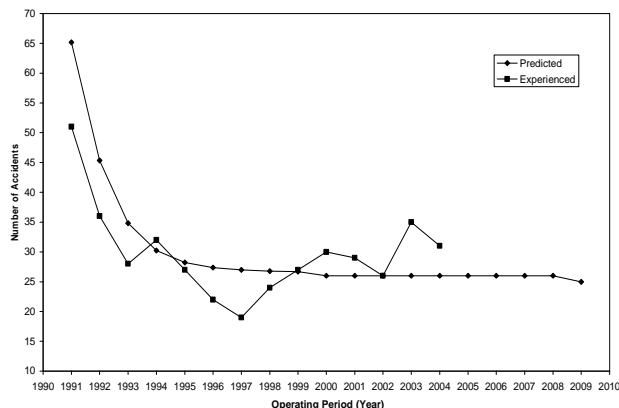
These equations were run on VENSIM PLE systems dynamic software. A soft drink manufacturing industry was used for its application by collecting two sets of factory data:

- Pre-safety (1979 – 1990)
- and safety programme (1991 – 2004).

Using the data, the model parameters were estimated and simulation model was run for 12 years first for pre-safety and then 14 years for the safety programme period. Simulation experiments were carried on the effect of hazardous conditions on numbers accidents and preventions program using one variable at a time (OVAT) technique. Characteristics curves were drawn to depict the interactions between the accident proneness factor and the outputs. The result of simulation run using the estimated input parameters for both pre-safety and safety programme were shown in Figures 3 through 5.

## DISCUSSION

The exponential decay in number of accidents and corresponding growth in number of predicted preventions shown in Figure 3 is expected because an effective safety program reduces hazardous conditions and improves safety.



**Figure 3:** Safety Program Accidents against Operating Period.

The number of accidents approaches equilibrium as the accident probability approaches zero. Correspondingly, the number of predicted preventions approaches equilibrium as potential accidents approaches zero. The proportion of available budget (P) controls the mechanism of the safety system. When the industry or establishment is not ready to invest in safety (P = 0%), the accident records revert to the pre-safety level. The graph of predicted accidents shows exponential growth while the experienced displayed the random nature of accidents (periodic up and down number of accidents). The predicted accidents started with 85 accidents as against 83 actually experienced in 1979. But, in 1990, the predicted accidents were 89 while the experienced were 92. However, the means and standard deviations of the predicted and the experienced accidents were 88 and 7.8; and 89 and 10.8, respectively.

As the proportion of the planned budget (P) was increased to 80%, the predicted accidents started reducing from pre-safety level of 89 to 65 in 1991 and 27 in 1996 through 2000 while approaching steady state at 26 in 2001 (see Figure 3). Although, there was a decrease in number of accidents experienced in 1991, the marginal effect had no positive impact on the safety program. This is evidenced from a monetary loss of ₦ 1.38 millions predicted in 1991.

The number of predicted preventions and corresponding SP benefits graphs show sigmoid trends (Figure 4.). At transient stage the number of predicted preventions started with 22 in 1991, grows exponentially to 40 in 1992, followed by asymptotic in growth afterwards to 60 in 1996 and became stabilized till 2004. The mean number of predicted prevented accidents was calculated at 55. A comparison of predicted and experienced accidents to safety programme (SP) period indicates that the qualitative change of the model behaviours is similar to pre-safety period. But quantitatively, the means and standard deviation of the predicted and experienced accidents were 32 and 3.12; and 30 and 7.68,

respectively. Consequently, the t-test showed that there was no significant difference at the 5% level between the experienced and the predicted as the t values calculated of 1.0 (Pre-Safety) and 0.88 (Safety period) are less than critical value of 2.87.

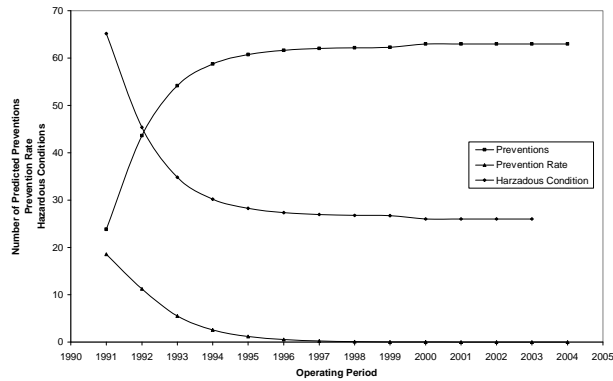


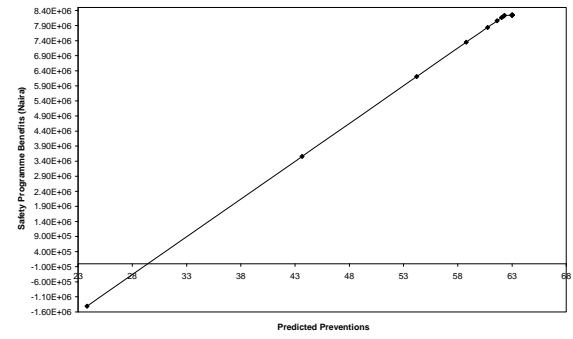
Fig.4: Comparison of Preventions, Prevention Rate and Hazardous Condition against Operating Period

**Figure 4:** Comparison of Preventions, Prevention Rates, and Hazardous Conditions against Operating Period.

As expected, the number of predicted preventions shows a linear relationship with safety program benefit, (Figure 5) indicating that the SN is directly proportional to the number of accidents prevented. As the number of predicted preventions increases the prevention rate (activities) decreases as shown in Figure 4. Consequently, the relationship between both quantities tends to deviate from linearity. The reason for this behavior is not far fetched. As the activities of safety program are maintained for some years, the hazardous conditions are removed to an appreciable extent. Hence, any further effort no longer yields much, indicating a steady state safety program. Indeed, this depicts the reality of an effective safety program.

On the other hand, the proneness factor (f) shows significant change with the number of accidents at different levels of proneness factor over the period of operation following exponential decay (Figure 6). For an effective program, as the willingness to commit to safety is maintained and level of implementation increases, the number of accidents decreases. Further increase in proneness factor produces marginal effect on the number of accidents. But, as the proneness decreases while the willingness is maintained, the level of implementation reduces and a significant effect is noticed on the accident occurrence. This

is because the hazardous conditions are now reduced leading to decrease in accidents.



**Figure 5:** Safety Program Benefit against Predicted Preventions.

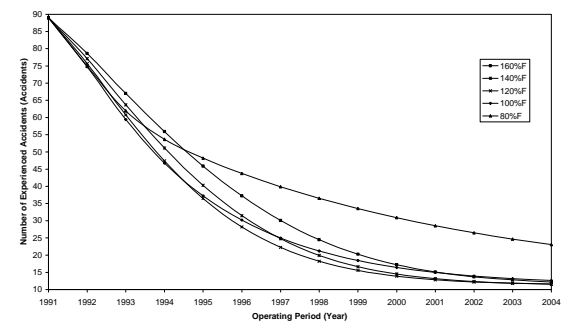


Fig.6: Number of Experienced Accidents Vs Operating Period for given Levels of Accident Proneness Factor (F)

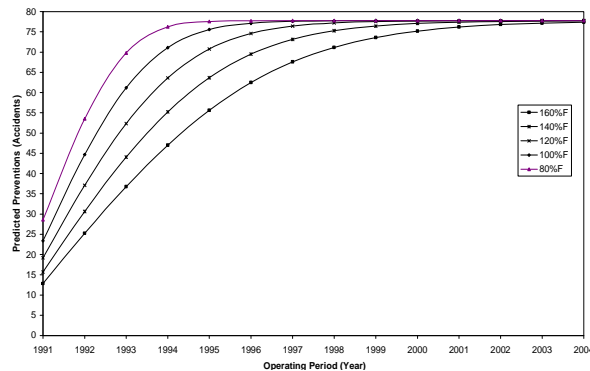
**Figure 6:** Number of Experienced Accidents vs Operating Period for given Levels of Accident Proneness Factor (F).

Predicted preventions show a sigmoid trend with changes in accident proneness factor (Figure 7). Changes in the value of proneness factor show no significant change in the programme benefit behaviour. Although, the programme benefit (SN) decreases slightly with increase in proneness factor over the period of operation (Figure 8).

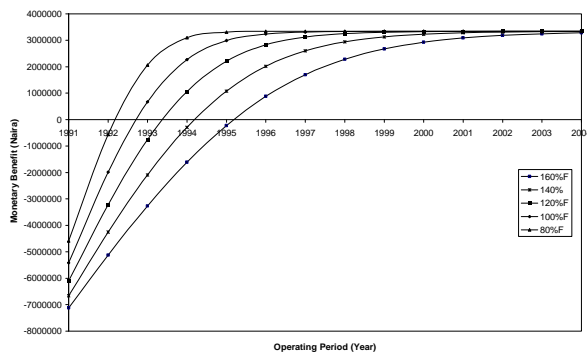
**CONCLUSIONS**

In this study the possibility of developing a manufacturing safety program simulation model was investigated. In the process, manufacturing systems were examined and safety engineers interviewed. Manufacturing accident causing factors and safety program accident prevention activities were also identified. The principles of systems–dynamics were used to identify the

relevant safety related components of a manufacturing system.



**Figure 7:** Predicted Preventions vs Operating Period for Given Levels of Accident Proneness Factor (F).



**Figure 8:** Monetary Benefit vs Operating Period for Given Levels of Accident Proneness Factor (F).

Applying the concept of causality analysis, a casual loop diagram indicating how accident prevention activities may eliminate hazardous conditions was developed. This was then transformed into a flow diagram from which three equations representing safety outputs were formulated. The simulations in expressions ( $Y_t$ ), ( $X_t$ ), and (SN) are sensitive to a wide range of manufacturing hazardous conditions. This shows that the model is potentially useful for selecting SP effective strategies.

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