A Risk Analysis Model for Fire Disasters in Commercial Complexes in Nigeria.

V.O. Oladokun, Ph.D.* **and F.A. Ishola, M.Sc.**

Department of Industrial and Production Engineering, University of Ibadan, Ibadan, Nigeria.

*E-mail: vo.oladokun@mail.ui.edu.ng

ABSTRACT

The frequent occurrence of fire accidents in commercial complexes has become a serious problem in Nigeria. The development of a quantitative tool for evaluating the proneness of a commercial complex to so called 'market fires' is the focus of this study. A rigorous review of the literature was carried to identify and characterize some existing risk analysis models applicable to the problem. Some past fire disasters were analyzed. Using the insight gained from the above, a mathematical model incorporating the modularization features of the Optimum Risk Analysis (ORA) model was developed. Graphical User Interface (GUI) based computer software of the model was developed and used to analyze some existing complexes in Lagos and Ibadan cities of Nigeria and results compared with past record of fire accidents. The application of the model and the associated software indicates its suitability in predicting fire accidents. Insurance companies and other stakeholders will find it useful.

(Keywords: fire accident, risk analysis, market fire, fire protection, optimum risk analysis)

INTRODUCTION

The frequent occurrence of major fire accidents in commercial buildings, shopping malls, and markets in Nigeria has become a serious threat to the nation's fragile economy. Many major markets and commercial buildings have been gutted by these 'market fires' destroying lives and properties worth several billions of naira (NEMA, 2006). The socio-economic impacts of these accidents are aggravated by the fact that victims of such fire disasters, mostly small scale traders and artisans, are without adequate insurance cover. These 'market fires' have continued to render many jobless, damage the environment, disrupt economic activities and worsening the problem of poverty. The effective prevention of these accidents will require enhancing the capacity of the relevant regulatory institutions in the evaluating the proneness of any complex to fire accidents. The development of a quantitative tool for such evaluation is the focus of this study. The specifics objectives of this study are: (1) To develop a risk analysis model for predicting the proneness of a complex to fire accident and (2) To develop computer software of the model for ease of application.

Risk analysis is a systematic method for hazard identification and assessment (Khan and Abbasi, 1995). It is a process, which includes both qualitative and quantitative determination of risks and their social evaluation (Khan and Abbasi, 2001). Effective fire safety management requires recognizing all the potential risks associated with the premises and effectively carrying out an assessment of the adequacy of the measures provided or needed to combat the risk (Khan and Abbasi, 1995). A risk analysis indicates the proness to fire outbreak and spread of fire and thus decide what measures must be taken to provide suitable arrangements for protecting people in the premises from fire, and should ensure that the risk of fire occurring is reduced to the absolute minimum as well as the risk of fire spreading is minimized (Buchanan, 2001).

BRIEF REVIEW OF SOME AVAILABLE RISK MODELS

Extensive and varied studies on risk analysis have been carried out and reported in the literature. Various risk analysis methodologies have been developed in the last three decades. Concepts such as ISD, hazard identification, evaluation, and hierarchization have been used in the study fire safety improvement (Gupta and Edwards, 2003; Oven and Cakici, 2009). However, most of these studies reported in the literature have focused on the risk management of industrial plants and facilities especially chemical plants (Tixier et al., 2002). There have been relatively very few studies and risk models for commercial complexes or markets (Cheng and Hadjisophocleous, 2009). Moreover, the major limitations of existing methodologies as summarised in Tixier et al. (2002) include the following:

- The more general methods tend to ignore specificities of cases while the more specific methods lack robustness of applications across different cases.
- High knowledge and competency levels are mostly required of people participating in the analysis.
- In many situations the complexity of methods requires specific training for their implementation.
- For some methodologies, the operational application is difficult to realise because of the lack of description or guide book to explain how methodologies could be used.

Generally risk analysis models broadly fall into two clasess; qualitative and quantitative methods. The qualitative methods of risk analysis basically seek to improve the awareness of risks and the posture of the system being analyzed using descriptive and non mathematical tools. Quantitative analysis, which is the basis of this work, is based substantially on independent objective processes and metrics requiring increased degree of effort (Khan and Abbasi, 2008; Reason, 1997). Each group can be divided into three categories: pure deterministic, pure probabilistic, and a hybrid of deterministic and probabilistic approaches. Our work adopts the hybrid approach.

Also risk analyis models consist of any or all of the following three phases; an identification phase, an evaluation phase, and a hierarchization phase. However a risk analysis methodology may not necessarily contain these three phases. It can be constituted by only the following combinations: an identification phase, identification, and evaluation phases; or identification, evaluation and hierarchisation phases. Whatever the methodologies used to carry out a risk analysis, three kinds of elements are required: the expected output data, available input data, and the selected method. The identification phase establishes the bases of the risk analysis as it generate data that will be the input of the evaluation and/or hierarchization phases. Our model adopts the four steps of: i) hazard identification and screening, ii) hazard assessment, iii) quantification of hazards or consequence analysis, and iv) risk estimation similar to the Optimal Risk Analysis ORA used in (Khan and Abbasi, 2001). Specifically our model incorporates the modularization features of the Optimum Risk Analysis (ORA) model. However, we have developed different more appropriate and easy to use methodologies for realizing each of the stages.

The type of data and the framework for uploading such data constitute a major factor in the characterisation of the various existing models. For instance in a review of some existing risk analysis models (Tixier, et al., 2002) seven data types were identified such that the input data can relate to any of the following:

1) plans or diagrams,
2) process and reactions,
3) substances,
4) probability and frequency,
5) environment,
6) policy and management, and
7) text and and historical knowledge.

Procedurally users collect information concerning the studied system (input data available), and then choose the method appropriate for the evaluation phase. Beacuse most of the existing models deal with accidents in industrial establishments and transportation of dangerous goods, existing methods are not adequate for the risk analysis of a typical Nigerian market environment where many shop owners are illitrate and do not have records of safety related activities. Furthermore the application of most techniques in the literature relies heavily on the input (using group discusion and brainstorming sessions) of operators in setting problem parameters. Knowledge of people who are participating in the risk analysis is quite important (different types of competences and levels of people involvement). Therefore a risk analyis model that can work well in such environment must only depend minimaly on the participation of these opeartors. Infact the inputs into to the proposed model are such that are based on the onsite assesment of the modellers and allow for some degree of subjectivity in input quantification.

MODEL DESCRIPTION

The proposed model, as illustrated in Figure 1, involves four steps: (i) modularization of the complex into units, (ii) identification of possible fire accident causing factors in each unit, (iii) quantification of the fire disaster factors, and (iv) estimation of risk index.

The complex to be examined is modularized into segmental units such that a unit is either physical and/or operational heterogeneous. For instance a typical Nigerian commercial complex is usually in blocks containing a range of 6 to 12 rooms (shops); a block can then form a unit. In the case of multi story buildings each floor could form a unit. The modularization is subject to the convenience of the model user.

Generally, for a fire to start there must be a simultaneous combination of fuel, oxygen, and a source of ignition or fire starting materials (Henderson and MacKay, 2009). Fuel basically includes flammable solids, liquids, and gases. Once started, fires spread slowly at first on combustible surfaces, then spread more rapidly as the fire grows, providing radiant feedback from flames and hot gasses to other potential fuel.

Therefore for the occurrence of a fire disaster, two major factors must be present; fire ignition and fire sustainable factors, tagged factor A and factor B, respectively. Potential fire ignition factors are those elements, actions or possible errors which can bring for an incipience of a fire. However, fire sustainable factors involve any element that can sustain a spark or an incipience to become a full flared fire outbreak. The effect of the occurrence and interactions of the two factors, for each unit, is termed fire occurrence probability.

To account for domino or ‘cascading’ effects a third factor, C, termed the fire spread factor is introduced. A fire reachability matrix is developed to give the spread factor index for the complex. The reachability matrix is really a function of the complex architectural structure and wall materials.

The third stage involves the quantification of these factors using relevant mathematics while the last stage of the risk analysis model is estimation of the probability of fire accident. The risk level is classified as shown in Table 1.

Table 1: Classes of Fire Disaster Risk FR.

Probability Range	Probability Range
0.70 –1.00	Very high risk (Danger)
0.50 – 0.69	High risk
0.31 – 0.49	Low risk
0.00 – 0.30	Very low risk (Safe)

Parameter Quantification

The model is such that problem or complex related input parameters are mostly of the 0-1 form (or present or absent). The two probalities quantities in the model are general process dependent. Their respective values can be fixed by using inputs from experts based on general day-to-day observation of such process.

Assignment of probability scale to each component is done based on the experience of the modeller using the fire occurrence information data of such complex or another complex with a similar operational feature.

Identification of the components of each of the fire disaster factors by critical examination and observation of constituents of each of the identified units considering the fire hazard potential in all the units as a function of material, capacity, type of unit operation, operating conditions, and surroundings (degree of conjunction, location of other hazardous units, to mention a few).

For factor A, the possible fire ignition source may include naked fire, welding activities, gas-fired activities, electrical sources and sparks.

Also for factor B, the identifiable components may include any fuel or fire aiding elements such as flammable solids and flammable gases. Spread factor is determnined by architectural and design attribute of complex and the level of fire venting and fire-fighting facilities.

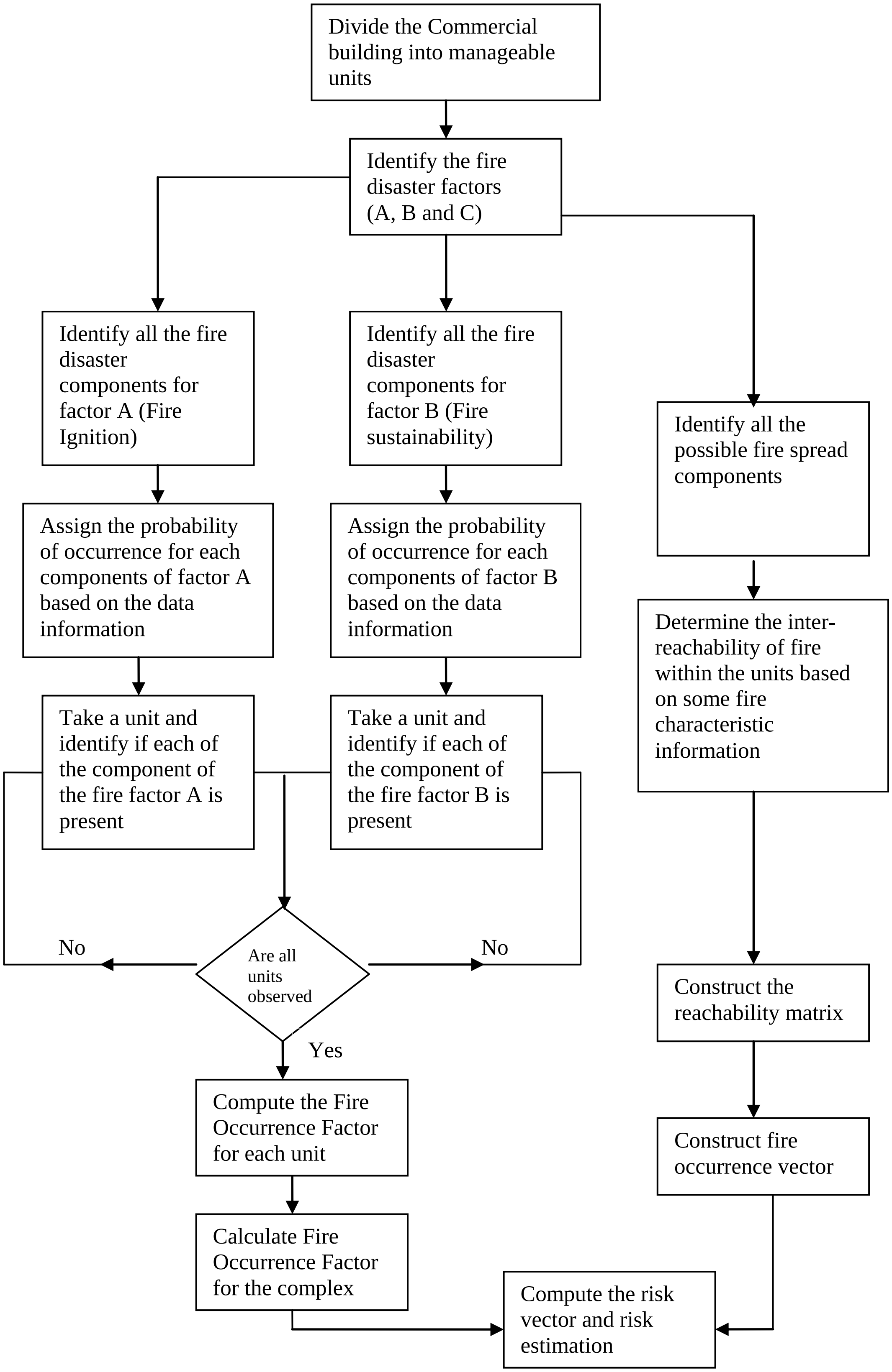


Figure 1: Algorithm of the Model.

MODEL DEVELOPMENT

Notations

A= Fire Ignition Factor; where A = { $A_1, A_2, \ldots, A_M$ }

B= Fire Sustainable Factor; where B= { $B_1, B_2, \ldots, B_q$ }

Let i= index identifying factor's components such that for factor A; i= 1,2,3……m

and factor B; i= 1,2,3……q where

m = number of identified ignition causatives

q = number of identified fire sustainable factors

N = total number of units in the complex under investigation

j = index identifying units making up the complex such that j = 1, 2, 3……, N

P_{Ai} = Assigned Probability of ignition factor component i causing ignition

P_{Bi} = Assigned Probability of sustainable factor component "i" sustaining ignition

$M_{ij}^{A}(t)$ = the multiplier quotient for factor A;

$M_{ij}^{B}(t)$ = the multiplier quotient for factor B

P_{Aij} = Intensity of ignition factor component's i in unit "j"

P_{Bij} = Intensity of sustainable factor component's i in unit "j"

P_{Aj} = Probability of having an ignition from unit"j"

P_{Bj} = Probability of having ignition sustained in unit "j"

P_{Fj} = Probability of fire occurrence in unit j

R_{xy} = Fire Reachability loop from one unit to another

F_j = Fire Risk Estimate for each unit

F = Fire Risk Estimate for the whole complex

The following relationships hold:

Given $M_{ij}^{A}(t)$ as the intensity of factor A_i

$M_{ij}^{B}(t)$ as the intensity of factor B_i

$P_{Aij} = P_{Ai} \times M_{ij}^{A}(t)$

$P_{Bij} = P_{Bi} \times M_{ij}^{B}(t)$

to account for multiple presence of A_i in j to start a fire and B_i in unit j to sustain a fire at given time t, such that:

$$P_{Aij} = \begin{cases} P_{Aij}: \text{if } M_{ij} = 1 \\ 0; Otherwise \end{cases}$$

$$P_{Bij} = \begin{cases} P_{Bij}: \text{if } M_{ij} = 1 \\ 0; Otherwise \end{cases}$$

$$P_{Aj} = \sum_{i=1}^{m} P_{Aij}; \quad 0 \leq P_{Aj} \leq 1$$

$$P_{Bj} = \sum_{i=1}^{m} P_{Bij}; \quad 0 \leq P_{Bj} \leq 1$$

This implies that:

$\sum_{i=1}^{m} P_{Ai} = \sum_{i=1}^{m} (P_{Ai} \times M_{ij}^{A}(t)) = 1;$ if all the m components of factor A are present in unit j.

$\sum_{i=1}^{m} P_{Bi} = \sum_{i=1}^{m} (P_{Bi} \times M_{ij}^{B}(t)) = 1;$ if all the q components of factor B are present in unit j.

Therefore the Probability P_{Fj} of fire occurrence in unit j is:

$P_{Fj} = P_{Aj} \times P_{Bj} \qquad 0 \leq P_{Fj} \leq 1$

Accepting the fact that; once there is a fire in any unit "j" with P_{Fj} then fire has occurred in the complex. Then P_F probability of fire occurrence in the complex of N units is:

$P_F = 1- [(1-P_{F1})(1- P_{F2})\ldots(1- P_{FN})]$

Now there is the need to account for the domino effect in the model :

Assumptions

(i) Fire involving no explosive spreads directly from a unit to other units connected by combustible materials.

(ii) Fire involving explosives spreads directly from a unit to other any units.

The risk factor F_j for a given unit j is influenced by the spread of fire from other units and this accounted for by the interaction of fire occurence factor and spread factor inherent in the complex. The reachability matrix R measures the ease of a fire spreading within the complex. With matrix element R_{xy} difined thus:

$$R_{xy} = \begin{cases} 1: \text{If Fire will spread under the stated condition} \\ 0; \mathit{Otherwise} \end{cases}$$

Where, $1 \geq X \leq N$; $1 \geq Y \leq N$ Such that:

$$R = \begin{bmatrix} R_{11} & R_{12} & R_{13} & \ldots & R_{1N} \\ R_{21} & R_{22} & R_{23} & \ldots & R_{2N} \\ R_{31} & R_{32} & R_{33} & \ldots & R_{3N} \\ \cdot & \cdot & \cdot & & \cdot \\ \cdot & \cdot & \cdot & \ldots & \cdot \\ \cdot & \cdot & \cdot & & \cdot \\ R_{N1} & R_{N2} & R_{N3} & \ldots & R_{NN} \end{bmatrix}$$

Now if the Probability of Fire occurrence in a unit "j" is P_{Fj} then vector P_F is a characterisation of the ease of fire occurence of the whole complex such that:

$$P_F = \begin{bmatrix} P_{F1} \\ P_{F2} \\ P_{F3} \\ . \\ . \\ . \\ P_{FN} \end{bmatrix}$$ is the Fire Occurrence Vector.

which measures the fire occurence risk factor, for the complex.

Fire Accident Risk Factor

We propose that the Risk Factor, F, a good measure of the pronness of the modulirised complex to fire accident, is an intraction of the Fire Spread and Occurence Factors defined as follows: Risk Factor F; $F = R \times P_F$

$$F = R \times P_{Fj} = \begin{bmatrix} R_{11} & R_{12} & R_{13} & \ldots & R_{1N} \\ R_{21} & R_{22} & R_{23} & \ldots & R_{2N} \\ R_{31} & R_{32} & R_{33} & \ldots & R_{3N} \\ \cdot & \cdot & \cdot & & \cdot \\ \cdot & \cdot & \cdot & \ldots & \cdot \\ \cdot & \cdot & \cdot & & \cdot \\ R_{N1} & R_{N2} & R_{N3} & \ldots & R_{NN} \end{bmatrix} \times \begin{bmatrix} P_{F1} \\ P_{F2} \\ P_{F3} \\ . \\ . \\ . \\ P_{FN} \end{bmatrix}$$

and $$\frac{F}{N} = \begin{bmatrix} \frac{F_1}{N} \\ \frac{F_2}{N} \\ \frac{F_3}{N} \\ . \\ . \\ . \\ \frac{F_N}{N} \end{bmatrix}$$

So that if $R_{xy} = 0$ or 1 and $0 \geq P_{Fj} \leq 1$ then $0 \geq F_j \leq N$ or $0 \geq \frac{Fj}{N} \leq 1$

$\frac{Fj}{N}$ being the probability of fire accident for an individual unit j.

Therefore $0 \leq \sum_{i=j}^{N} \frac{F_j}{N} \geq N$, so that:

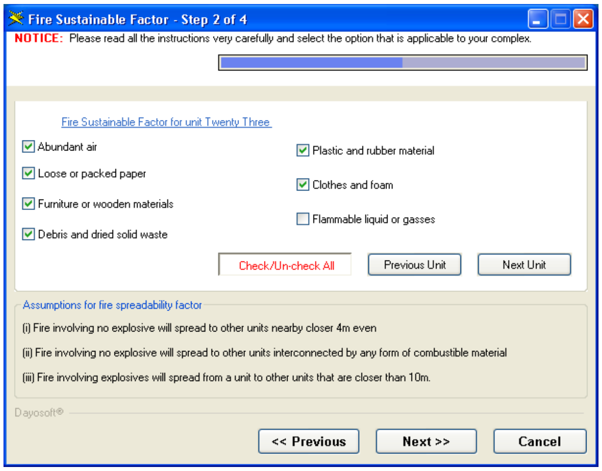
$$0 \leq \frac{\sum_{j=1}^{N} F_j}{N^2} \geq 1$$

Where $FR = \frac{\sum_{j=1}^{N} Fj}{N^2}$ is the fire risk index for the complex.

COMPUTER IMPLIMENTATION

The software was developed using Microsoft Visual Basic®. The source code for the program is available in (Ishola, 2009). The computer program has a graphical user interface for ease of use. A sample interface is shown in Figure 2. The software program simply provides the risk estimation of the commercial complex under investigation in few seconds, regardless of the number of units involved thus saving time and rigor of manual calculations and at the same time eliminating error during calculation.

The software program is segmented into four major steps by which in each step the operation described by the model was carried out on each of the units registered.


Fire Sustainable Factor - Step 2 of 4

NOTICE: Please read all the instructions very carefully and select the option that is applicable to your complex.

Fire Sustainable Factor for unit Twenty Three

☑ Abundant air
☑ Loose or packed paper
☑ Furniture or wooden materials
☑ Debris and dried solid waste
☑ Plastic and rubber material
☑ Clothes and foam
☐ Flammable liquid or gasses

Assumptions for fire spreadability factor

(i) Fire involving no explosive will spread to other units nearby closer 4m even

(ii) Fire involving no explosive will spread to other units interconnected by any form of combustible material

(iii) Fire involving explosives will spread from a unit to other units that are closer than 10m.

Figure 2: A Typical User's Interface of the Software.

CONCLUSIONS

A risk analysis model, incorporated into robust software application, was developed for predicting the proneness of a commercial complex to fire accident which could be used for planning control strategies for regulatory bodies, insurance companies, estate managements, users of the commercial complex, and other stake holders to help in reducing the frequency of fire disaster occurrence in the commercial sector of the country.

Four classes of risks were defined: very high risk, high risk, low risk, and very low risk. The model was then further validated by applying it to evaluate and estimate the risk of fire disaster for some other commercial complexes in Ibadan and Lagos, Nigeria.

From the outcome of the study, the developed risk analysis model and as well the software application is found most useful for evaluating the proneness of a commercial building to fire accident which is much needed for planning control strategies development by regulatory bodies, insurance companies, estate managements, users of the commercial complex, and other stake holders in arresting the reoccurrence of the unwanted fire disaster.

APPENDIX: Numerical Example

The model presented above was applied to the analysis the fire pronness of two typical Nigerian commercial complexes. the data and calculations for one of the complexes **W** follows:

The complex was modularized into nine units, labeled 1 to 9. The complex is a three floor storey building; the modularization was done such that it has three units in each floor. Each unit has at least 10 shops with different commercial activities ranging from selling of all sorts of engines and engine parts, household plastic materials and utensils, fabrics, mattress, furniture, stationeries, confectionaries, etc.

There are service ativities like like tailoring, internet café, fast foods, law chamber, business consultancy. Assigned probability of ignition factors and respective unit strenght are shown in Table 2, while Table 3 shows coresponding values for the sustainable factors.

Table 4 shows data for the fire occurrence for each unit within complex W.

Table 2: The Complex W's Factor A Characteristics.

I	**Fire incipience factor i**	**Assigned probability (PAi)**	**Factor i strength in unit j: $M_{ij}^{A}(t)$**									
			J	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1	Naked fire	**0.25**		1	0	1	1	1	1	0	1	0
2	Welding activities	**0.06**		1	1	0	1	1	1	1	0	1
3	Gas-fired activities	**0.11**		0	1	1	1	1	1	1	1	1
4	Hot bearing and other frictional heating	**0.03**		1	0	1	1	1	1	1	1	1
5	Electrical sources (overloaded conductors)	**0.14**		1	1	1	1	1	1	1	1	1
6	Cigarettes and/or matches	**0.04**		1	1	1	0	0	1	0	1	1
7	Sparks resulting from rapid of metals	**0.10**		1	1	1	1	1	1	1	1	0
8	Static discharges	**0.11**		1	1	1	1	1	1	0	1	0
9	Smoking activities	**0.09**		1	1	0	0	1	1	1	0	0
10	Hot surfaces and chips	**0.07**		1	0	0	0	0	1	1	0	0
	$\sum_{i=1}^{m} \mathrm{P}_{\mathrm{Aij}} = \sum_{i=1}^{m} (\mathrm{P}_{\mathrm{Ai}} \times M_{ij}^{A}(t))$			0.89	0.65	0.80	0.80	0.89	1.0	0.65	0.84	0.63

Table 3: The Complex W's Factor B Characteristics.

I	**Fire sustainable factor**	**Assigned probability (PBi)**	**Factor i strength in each unit j: $M_{ij}^{B}(t)$**									
			J	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1	Abundant air	0.20		1	1	1	1	1	1	1	1	1
2	Loose or packed paper	0.20		1	1	1	0	1	1	1	1	1
3	Furniture or wooden material	0.20		1	1	1	1	1	1	0	1	1
4	Debris and dried solid waste	0.10		0	1	1	0	1	0	0	1	1
5	Plastic and rubber material	0.10		1	0	1	1	0	1	1	1	1
6	Clothes and foam	0.10		1	1	1	0	1	1	1	0	1
7	Flammable liquids/gasses	0.10		1	0	1	1	1	1	0	1	1
	$\sum_{i=1}^{m} \mathrm{P}_{\mathrm{Bij}} = \sum_{i=1}^{m} (\mathrm{P}_{\mathrm{Bi}} + M_{ij}^{B}(t))$			0.9	0.8	1.0	0.6	0.9	0.9	0.8	0.9	1.0

Table 4: The Fire Occurrence for Each Unit for Complex W.

Probability of Fire Occurrence for Each Unit									
Units	1	2	3	4	5	6	7	8	9
$\sum_{i=1}^{m} P_{Aij}$	0.90	0.65	0.80	0.80	0.89	1.0	0.65	0.84	0.63
$\sum_{i=1}^{m} P_{Bij}$	0.9	0.8	1.0	0.6	0.9	0.9	0.8	0.9	1.0
$P_{Fj} = P_{Aj} \times P_{Bj}$	0.81	0.52	0.80	0.48	0.80	0.90	0.52	0.76	0.63

Risk Analysis

From Table 5 the Rxy matrix is obtained while the occurence vector P_{Fj} is exracted from the bottom row of Table 4.

$$R_{xy} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 0 & 1 & 0 & 0 \\ 1 & 1 & 1 & 1 & 1 & 1 & 0 & 1 & 0 \\ 1 & 1 & 1 & 0 & 1 & 1 & 0 & 0 & 1 \\ 1 & 1 & 0 & 1 & 1 & 1 & 1 & 1 & 0 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 & 1 & 0 & 1 & 1 \\ 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 0 & 1 & 1 & 1 & 1 & 1 \end{bmatrix}$$

$$\text{Occurrence Vector, } P_{Fj} = \begin{bmatrix} 0.81 \\ 0.52 \\ 0.80 \\ 0.48 \\ 0.80 \\ 0.90 \\ 0.52 \\ 0.76 \\ 0.63 \end{bmatrix}$$

Table 5: Reachability Matrix.

		TO UNITS									
		1	2	3	4	5	6	7	8	9	Rxy
FROM UNITS	1	1	1	1	1	1	0	1	0	0	
	2	1	1	1	1	1	1	0	1	0	
	3	1	1	1	0	1	1	0	0	1	
	4	1	1	0	1	1	1	1	1	0	
	5	1	1	1	1	1	1	1	1	1	
	6	0	1	1	1	1	1	0	1	1	
	7	0	0	0	1	1	1	1	1	1	
	8	0	0	0	1	1	1	1	1	1	
	9	0	0	1	0	1	1	1	1	1	

Therefore the Risk Factor for the complex:

$F = R_{xy} \times P_{Fj}$

$$Fi = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 0 & 1 & 0 & 0 \\ 1 & 1 & 1 & 1 & 1 & 1 & 0 & 1 & 0 \\ 1 & 1 & 1 & 0 & 1 & 1 & 0 & 0 & 1 \\ 1 & 1 & 0 & 1 & 1 & 1 & 1 & 1 & 0 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 & 1 & 0 & 1 & 1 \\ 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 0 & 1 & 1 & 1 & 1 & 1 \end{bmatrix} \times \begin{bmatrix} 0.81 \\ 0.52 \\ 0.80 \\ 0.48 \\ 0.80 \\ 0.90 \\ 0.52 \\ 0.76 \\ 0.63 \end{bmatrix}$$

$$\text{Fi} = \begin{bmatrix} 0.81+0.52+0.80+0.48+0.80+0+0.52+0+0 \\ 0.81+0.52+0.80+0.48+0.80+0.90+0+0.76+0 \\ 0.81+0.52+0.80+0+0.80+0.90+0+0+0.63 \\ 0.81+0.52+0+0.48+0.80+0.90+0.52+0.76+0 \\ 0.81+0.52+0.80+0.48+0.80+0.90+0.52+0.76+0.63 \\ 0+0.52+0.80+0.48+0.80+0.90+0+0.76+0.63 \\ 0+0+0+0.48+0.80+0.90+0.52+0.76+0.63 \\ 0+0+0+0.48+0.80+0.90+0.52+0.76+0.63 \\ 0+0+0.80+0+0.80+0.90+0.52+0.76+0.63 \end{bmatrix}$$

Then with N=9,

$$\text{FR} = \frac{\sum_{i=1}^{N} \text{Fi}}{\text{N}^2} = \frac{40.67}{9^2} = 0.50$$

This fire risk estimation for the complex belongs to "high risk" class according to Table 1.

REFERENCES

1. Bobos, A.G. and Protonotarios, E.N, 1978. "Optimal System for Equipment Maintenance and Replacement under Markovian Deterioration". *European Journal of Operational Research*. 2:257-264.

2. Buchanan, A.H. 2001. *Structural Design Fire Safety*. John Wiley and Sons: West Sussex, UK.

3. Gupta, J.P. and Edwards, D.W. 2003. "A Simple Graphical Method for Measuring Inherent Safety". *Journal of Hazardous Materials*. 104(1):5-30.

4. Henderson, J. and MacKay, S. 2009. "Retail Availability of Fire-Starting Materials and their Misuse by Children and Adolescents". *Fire Safety Journal*. 44(1):131– 134.

5. Ishola, F.A. 2009. "A Risk Analysis Model for Fire Disasters In Commercial Complexes In Nigeria". An Unpublished MSc Project, Department of Industrial Engineering, University of Ibadan.

6. Khan, F.I. and Abbasi, S.A. 2001. "Risk Analysis of a Typical Chemical Industry using ORA Procedure". *Journal of Loss Prevention in the Process Industries*. 14:43–59.

7. Khan, F.I. and Abbasi, S.A. 1995. "Risk Analysis: A Systematic Method for Hazard Identification and Assessment". *Journal of Industrial Pollution Control*. 9(2):88-96.

8. Khan, F.I. and Abbasi, S.A. 2001. "Studies on the Probabilities and Likely Impacts of Chains of Accidents (Domino Effect) in the Fertilizer Industry". *Proceedings Safety Progress*. 19(1):45-60.

9. NEMA. 2006. "National Platform for Disaster Risk Reduction, Nigeria. Disaster Reduction and Prevention in Nigeria". A report prepared under the directorship of National Emergency Management Agency, NEMA: Lagos, Nigeria.

10. Oven, V.A. and Cakici, N. 2009. "Modelling the Evacuation of a High-Rise Office Building in Istanbul". *Fire Safety Journal*. 44(1):1-15.

11. Reason, J. 1997. *Managing the Risks of Organizational Accidents*. Ashgate Publishing Company: Burlington, VT.

12. Tixier, J., Dusserre, G., Salvi, O., and Gaston, D. 2002. "Review of 62 Risk Analysis Methodologies of Industrial Plants". *Journal of Loss Prevention in the Process Industries*. 15(1):291-303.

ABOUT THE AUTHORS

V.O. Oladokun is a Senior Lecturer in the Department of Industrial and Production Engineering, Faculty of Technology, University of Ibadan, Nigeria. He graduated with a B.Sc. (Hons) in Mechanical Engineering from the Obafemi Awolowo University (OAU) Ile-Ife. He has an M.Sc. and Ph.D. in Industrial Engineering from the University of Ibadan. He is a member of the Nigerian Society of Engineers and the Nigerian Institution of Engineering Management. He research interest includes enterprise models development and production systems optimization in a developing economy.

F.A. Ishola has a B.Tech. degree in Mechanical Engineering and an M.Sc. Degree in Industrial and Production Engineering from the University of Ibadan, Nigeria. He currently works as a service engineer in Nigeria.

SUGGESTED CITATION

Oladokun, V.O. and F.A. Ishola. 2010. “A Risk Analysis Model for Fire Disasters in Commercial Complexes in Nigeria”. *Pacific Journal of Science and Technology*. 11(2):376-386.

Pacific Journal of Science and Technology