MANAGING OCCUPATIONAL HEALTH AND SAFETY USING DYNAMIC LEARNING SYSTEMS

G. Nawar

School of Civil and Environmental Engineering, The University of New south Wales, Australia
E-Mail G.Nawar@unsw.edu.au

ABSTRACT:

A conceptual method for engineering the risks associated with human interactions in organizational systems is suggested. The method is presented in a knowledge based approach to organizational learning with a dynamic interactive feed-back. A binary algorithm is used to develop a generic unit of knowledge, structured on a fault tree to be applicable to all disciplines. Fuzzy logic is utilized in fault tree analysis to estimate the causation and probability of accident events. The generic unit can be learnt in organizational systems through storage and retrieval of cumulative combinations of this unit in a chain leading to the occurrence of accident events. Its application in managing Occupational Health and Safety is outlined in detail.

Keywords: OH&S, Learning systems, Dynamic systems, Management

INTRODUCTION

Dealing with risk at work in the different disciplines has been confined to crisp boundaries with prescriptive rules, based on the accumulated experiences in each discipline. These boundaries gradually became less defined, while communities' expectations continued to expand, and the need for a multi-disciplinary approach began to evolve. OH&S has normally been an important characteristic of all disciplines, to the extent that some argue that it provides a common bond between the work systems in various disciplines. The Occupational Health and Safety Act (1983) presented a single performance based legislation aiming to "*maintain the safety of workers by encouraging enterprise level participation to create a safe and healthy systems of work*". The participation of workers or their representatives in the development and management of such systems, has been central to the management philosophy of safety in the work place as introduced in the OH&S act. It represented a move away from prescriptive health and safety requirements towards performance based standards. The process is essentially self regulating and relies on the introduction of a dynamic system of consultation and feedback while giving management the ultimate responsibility to maintain a legal prescription of minimum safety standards.

Workers are rightly expected to have the main motivation and knowledge to assess risks and identify appropriate controls in their work systems. Participation from other systems of various disciplines and cultures at different times and levels has resulted in numerous approaches to the evaluation and management of health and safety risks at work. This paper introduces an alternative systemic approach to the traditional management of OH&S in the work place. The proposed procedure deals with OH&S risks as an engineerable quantum to be used to develop dynamic work systems, that are compatible with human interactions. The main notions in this approach are:

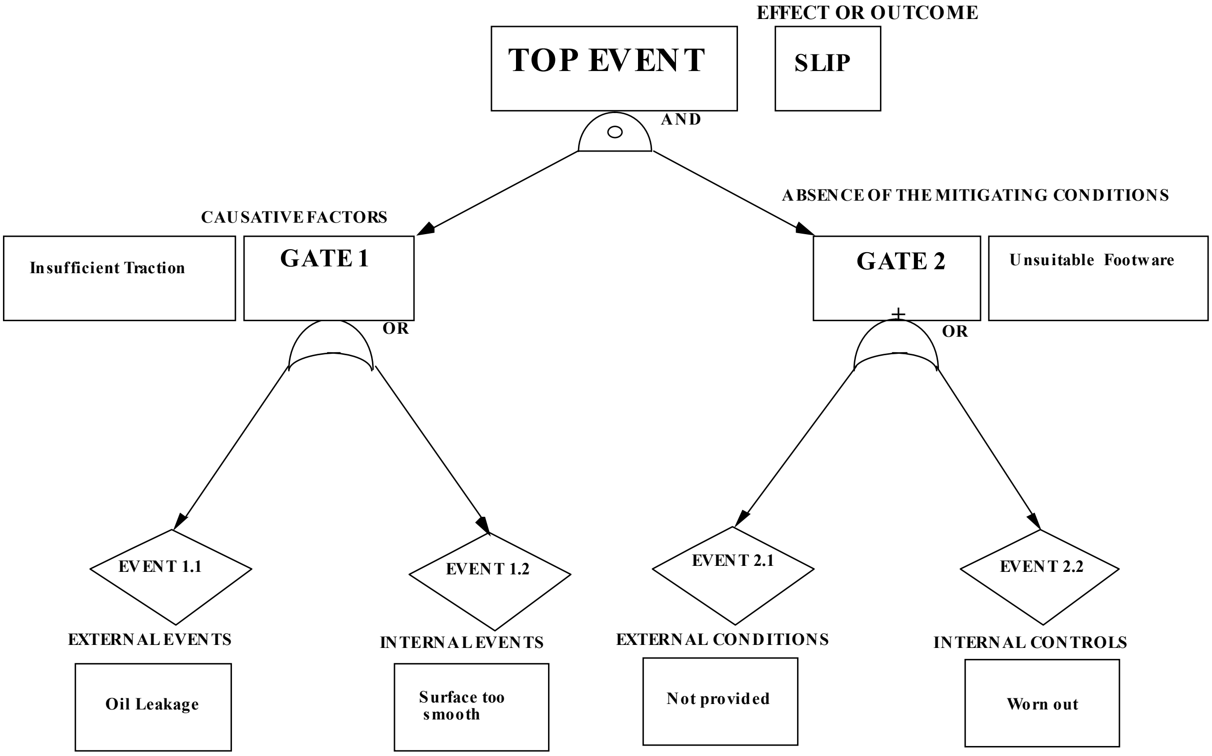
1. OH&S risks can be more efficiently engineered when modelled on a number of generic elements, that are applicable to dynamic systems;
2. The decision-making process in dynamic systems can be based on the control of risks at all levels of the system's hierarchical order;
3. The control of system risks can be made more efficient by engineering compatibility between humans and the systems with which they interact.

The limitation in calculating numerical assessments of risk is generally recognised. Numerical assessments of risk however can be helpful to increase understanding of the nature and relativity of risk. The application of fuzzy probability in Fault Tree Analysis is utilised to identify the link between risks, and relate the above three notions, with regard to Systems, Decisions, and the Human Domain.

FAULT TREE ANALYSIS "FTA"

Fault Tree Analysis has traditionally been used to model the relationship between system's failure and the events which lead to such failure. Probabilities for the failure of various events are assigned and combined to quantify the probability of failure of the total system. 'Dual Fault Tree Analysis' on the other hand, is employed to describe the conditions leading to the non-occurrence of failures and could therefore be used to analyse the degree of robustness in a project system.

In OH&S, the advantages of "FTA" can be easily demonstrated (see for example Ming, 1990, Singer, 1990 and Bossche, 1991). It allows managers to appreciate safety in the work system through the identification of risks in a simple, step-by-step procedure that is compatible with the decision process and suitable for computer-based analysis. Traditionally, "FTA" involves both graphical and logical representations of sequential and mutual events. These events could, in both normal and fault circumstances, lead to the non occurrence of a 'Top Event' as the OH&S objective. In this context, "FTA" may be used to model a hierarchy of management decisions which lead to the achievement the OH&S objectives. Probabilities are assigned to leaf events and are combined through modular passages or branches to the top event through logic gates. Figure 1 shows the basic elements of a generic fault tree as a knowledge module.



Fingure 1: AN EXAMPLE OF A GENERIC KNOWELDGE MODULE BASED ON CAUSE AND EFFECT

In OH&S applications, the top event is taken to represent a fault in the work system to achieve the desired OH&S performance. The subsequent level in the hierarchy is linked by an "AND" gate and is used to represent the causative factor and absence of contingency. The third level in the generic module is linked by "OR" gates which are used to describe one internal and one external component in both the causative and contingency factors. The binary structure of the proposed module aids in maintaining a disciplined formation of the tree and guides both the identification and treatment processes. Further levels in the hierarchy can build on the objectives of subsequent stages which are limited only by the desired level of details.

The same procedure can also be used to model the robustness and safety of work systems by converting the fault tree into a dual fault tree. A dual fault tree is thus used to analyse the robustness of a system in terms of the non-occurrence of sequential fault events. Conversion from fault to robustness analysis is achieved by a simple algorithm, which exchanges the "AND" & "OR" gates and uses the complements of each probability of occurrence of basic events to quantify the likelihood of the non-occurrence of fault events. Figure 2 shows the basic elements of a robustness tree which corresponds to the modular fault tree in figure 1 as previously illustrated.

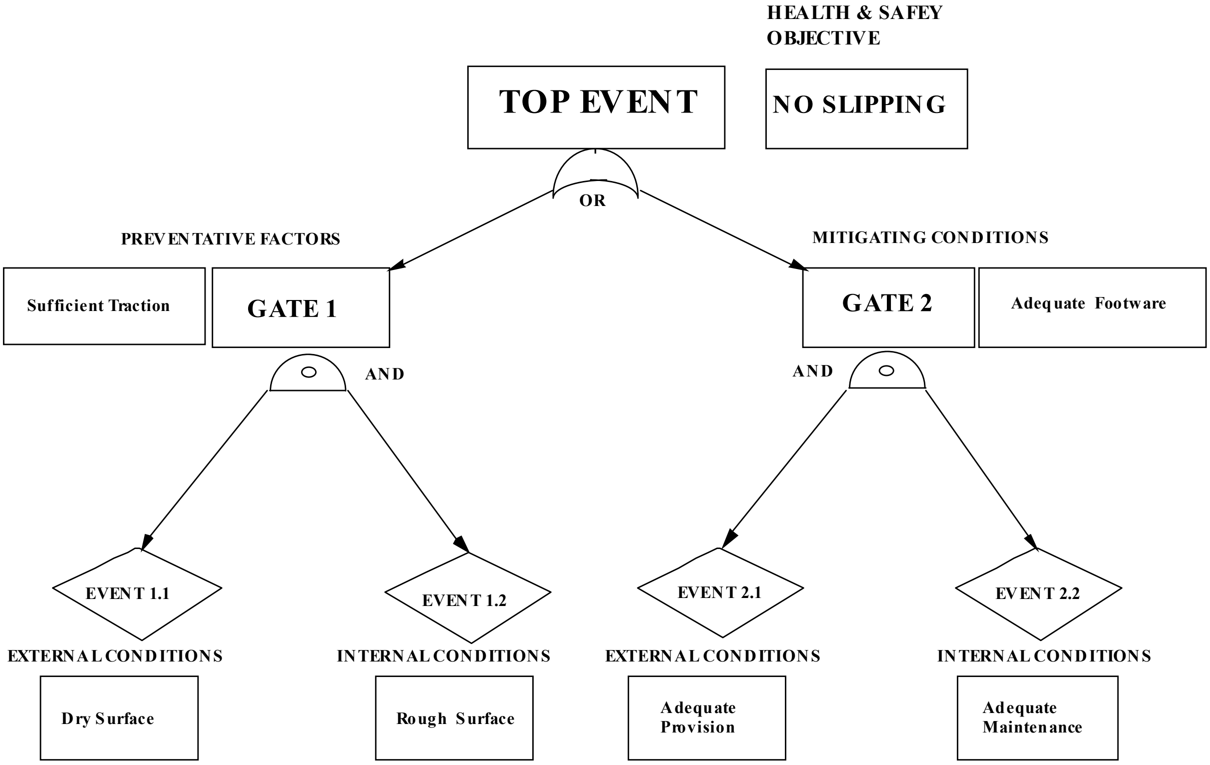


Figure 2: EXAMPLE OF A ROBUSTNESS MODULE BASED ON CAUSE AND EFFECT

The top event in this example corresponds to the OH&S objective of avoiding unintended slippage in a given process withe the system of work. The subsequent gate 1 corresponds to the prevention sub-objective of providing sufficient traction, which is caused by ensuring the conditions of a dry and a rough surface. Similarly, the subsequent gate 2 deals with the mitigation sub-objective which provides a contingency to insufficient traction by ensuring adequate provision and maintenance of suitable foot ware. This procedure leads to a systemic approach for identifying faults that are present within a system, and provides a suitable mechanism for numerical analysis in quantitative risk assessment. The application of "FTA" is demonstrably dependent on personal experience in the identification of basic events and failure modes, when there is a lack of sufficient failure data, particularly in new systems. The difficulty in accommodating partial failures, coupled with the reliance of the "FTA" on rigid definitions of success or failure, can result in misleading or a false sense of confidence in the results (Ming, 1990, Singer, 1990 and Bossche, 1991). Lee and Brown (1993), documented the inability of the "FTA" algorithm to deal with uncertainty in estimates of probability and the documentation of a user's confidence. Bossche (1991) showed that the treatment of a large number of events can be significantly improved when computer-based analytic techniques are employed to handle the large volume of data. The Fuzzy Fault Tree Analysis technique is suggested in this application because it can be coded in a computer based procedure which accommodates human cognition and overcomes the drawbacks of the traditional "FTA".

DEFINITION OF A FUZZY SET

Fuzzy logic enables uncertainty in the quantification of risks to be incorporated into the mathematical modelling of OH&S decisions. Fuzzy set theory uses the concept of truth or membership functions to define the degree of certainty with which an event is likely to occur. This membership lies between zero and unity as suggested in Gmytrasiewicz et al. (1990). Quelch and Cameron (1993) suggest that fuzziness in the failure modes may be related either to the human uncertainty in understanding the nature of events, or in the measurement of the intensity of events. In (FTA), every event is given a single probability of failure, which assumes that the probability of occurrence of the OH&S risk event is equal to the assumed value with 100% certainty. This can be a severe simplification, which reduces the usefulness of the statistical model as demonstrated by Patterson-Hine et al. (1989). To overcome this limitation, the probability of occurrence of a risk event is approximated to a range which is the basis of fuzzy logic. Figure 3 describes the basic premise of fuzzy logic as applied to a pentagonal membership function for a fuzzy probability of around P_m. In a pentagonal membership function, the fuzzy probability is represented by a matrix $\{q_l, p_l, p_m, p_r, q_r\}$. In this matrix, P_m represents the most likely probability by having a membership value of one. p_l, and p_r, represent the tolerances in the estimate of the probability to the left and right of P_m. while q_l, and q_r correspond to the lower and upper limits on the estimate of p_m consecutively.

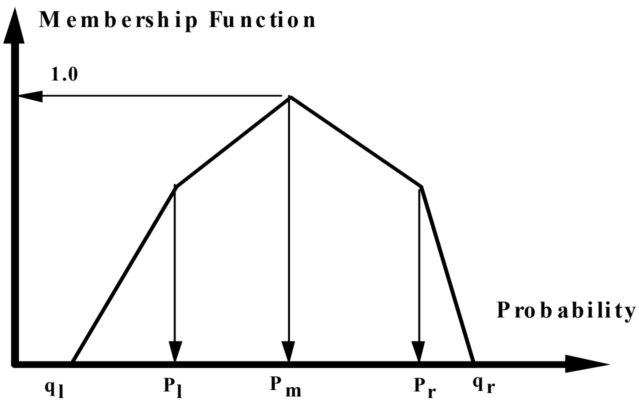


Figure 3: Elements of membership in a Fuzzy set

It is also possible to use three points to define a simpler triangular membership in terms of $\{q_l, p_m, q_r\}$ or four points to define a quadrilateral membership in terms of $\{q_l, p_l, p_r, q_r\}$, depending on the perceived significance of such details. A quadrilateral approximation of the membership function has a physical meaning relating to membership, by indicating that the probability of occurrence is known to be limited by the range between q_l and q_r, and that it is most likely to fall between p_l and p_r with a linear variation in certainty between p_l to q_l and p_r to q_r. A triangular membership may also be approximated using the mean and range to define a triangular membership, where (q_l) is the minimum value, (p_m) is the mean value and (q_r) corresponds to the maximum value.

APPLICATION OF THE PROPOSED FUZZY FAULT TREE

The proposed method classifies OH&S risk events as leaf events, if they are not to be analysed, otherwise events are classified as branch gates. A set of fuzzy probabilities is estimated for each leaf event which describe the workers confidence in the likelihood of occurrence of each event. The method approximates a fuzzy set from a given probability distribution if such a distribution is known for some events. The procedure is limited to two events for each branch gate in a single module. Large or complex systems can be modelled by integrating any number of moduli both horizontally and vertically depending on the required degree of details.

A library of basic event moduli can be compiled in a database, to allow continuous additions and modifications to its entries in a specific tree for each OH&S risk events. Each module is classified in the database according to its nature, which helps to facilitate the risk identification process. Sensitivity assessments is carried out at the end of the analysis to rank each leaf and gate event according to its impact on the top event of the compiled tree. The proposed method is generally made applicable to the engineering of OH&S risks in the workplace by grouping both the horizontal and vertical branches of the tree to correspond to the hierarchical structure in the workplace sub-systems.

ALGORITHM OF FAULT TREE ANALYSIS

In all fault tree-type-analyses, Singer (1990) showed that basic leaf events must be assumed to be independent and not mutually exclusive unless they are connected through a single branch where the extent of dependence can be described in the relationship between the different elements of this branch.

Algorithm of a Deterministic Fault Tree

The algorithm is verified in (Ming, 1990). The Boolean logic is based on two types of relationships between events, namely, 'AND' gates for consecutive or series relationship, and 'OR' gates for simultaneous or parallel relationships. The logic relies on the assumption that single probabilities of occurrence for basic events can be determined as independent and not mutually exclusive. In this case, it is assumed that a number of basic events say (X_1), (X_2), (X_3)...to...(X_i) lead to the occurrence of the fault events at each gate (G) which, in turn, lead to the occurrence of the top event. The probability of occurrence at each gate (G_n) can be evaluated on the basis of the probability of occurrence (P_i) of events (Xi), depending on whether it is the outcome of an 'AND' or an 'OR' gate. The following equations are suggested by Ming, (1990) to evaluate the probability of gates (G_n) :

$$For-AND-Gates$$
$$G_n = x_1 \cap x_2 \cap ......x_i ....(1)$$
$$For-OR-Gates$$
$$G_n = x_1 \cup x_2 \cup ......x_i ....(2)$$

Using De Morgan's rule which states that the complement of unions of probabilities equals the intersection of complements of the same probabilities, equations (1) & (2) above can be re-written in (3) & (4) as follows:

$$For-AND-Gates$$
$$P_{G_n} = P_{x_1} * P_{x_2} * ......P_{x_i} ....(3)$$
$$For-OR-Gates$$
$$P_{G_n} = 1-(1-P_{x_1})*(1-P_{x_2})* ......(1-P_{x_i}).....(4)$$

Algorithm of a Fuzzy Fault Tree

In a fuzzy fault tree, the single deterministic probability of occurrence used in the deterministic fault tree is replaced by a fuzzy set which defines the uncertainty in the estimation of the probability of each event. The principal mathematical algorithm remains similar except that fuzzy logic is used in the equations to describe a single probability in a fuzzy set. A pentagonal fuzzy set for the fuzzy probability $(\tilde{P})$ is presented by equations (5) to (7):

$$\tilde{P} = (q^l, p^l, m, p^r, q^r).................(5)$$
$$and$$
$$\tilde{P}_{xi} * \tilde{P}_{xk} = (q_i^l * q_k^l, p_i^l * p_k^l, m_i * m_k, p_i^r * p_k^r, q_i^r * q_k^r).................(6)$$
$$where$$
$$1-\tilde{P} = ((1-q^r),(1-p^r),(1-m),(1-p^l),(1-q^l)).................(7)$$

SUMMARY

Managing Occupational health and safety in work systems can be supported by grouping generic moduli of a fault tree. The moduli are grouped to generate an expansive fault tree which simulates the management system of a workplace environment and aids in the decision process to achieve optimum safe systems of work. A dynamic learning process is developed based on continuous feed-back of causes and effects that are integral with the selected work methods. Moduli are developed through workers participation from various disciplines and stored to form the collective learning experience of safe work methods. Robust safety systems are learnt, and applied to minimise the probability of accident occurrences through the following steps.

1. Identify the top event of a single module. The top event may be presented as a fault to be minimised using a fault tree, or as an OH&S objective with desirable consequences to be maximised using a dual fault tree. In either case, the top event should be described in a manner which makes it possible to identify its cause in the system's hierarchy, represented by the tree sub-branches.

2. Identify one single cause and one single contingency to the top event. This step initially relies on the experience of the participants. Other causes with corresponding contingencies are used to form additional moduli as they develop.
3. Identify external and internal events and estimate their probability of occurrence. Use fuzzy probability to model users uncertainty in the estimated probabilities.
4. Evaluate the probability of occurrence of gates and the top event based on the estimated event probabilities. This step provides a numerical evaluation of the module using the algorithm described by equations (1) to (7) and stores the results of a single module in the database.
5. Recall and group relevant moduli to construct an expansive fault tree, that is project specific, to model the OH&S robustness in the analysed workplace methods of that project.
6. Evaluate the sensitivity of the top event to each of the external and internal events.
7. Ranking can be utilised to assist in developing an optimisation strategy.
8. Evaluate and store (learn) system robustness using the dual fault tree. The robustness moduli may be recalled and utilised to assist in further system analysis. It may also be used in other applications in which the top event, could correspond to similar branch gates. The storage and retrieval of generic fault tree moduli simplify the procedure by reference to a database structured in a library of events with fuzzy probabilities compiled from past experiences.
9. In many applications, the check list may not be initially comprehensive, the data base will grow by accumulation of organisational learning through various analyses as they are undertaken on continuous basis. The procedure may also allow the deletion or addition of events from the library to generate an up-to-date and customised data base that is relevant to various usage as a personalised, knowledge based expert system.

CONCLUSION

This paper described an analytical procedure for the engineering of OH&S in management systems using "FTA". Fault Tree Analysis is employed as a suitable tool in systems thinking and managerial decision making applications because it enables modelling of the management processes in a hierarchical structure where the top event can be correlated with management objectives. OH&S presented one such application, as an objective in "FTA", in which subsequent branch gates corresponded to a sequence of causes and effects. Various alternatives can be compared at the different levels of the system's hierarchy to analyse the sensitivity of OH&S performance to each alternative within the overall management system. A dynamic learning method can evolve through this process with potential for many different applications.

REFERENCES

Bossche, Andre (1991), "Computer-Aided Fault Tree Synthesis Iii Real-Time Fault Location". *Reliability Engineering & System Safety*, V33 N2, P161-176, Elsevier, Great Britain.

Gmytrasiewicz, Piotr, Hassberger, Jere A. And Lee, John C. (1990), "Fault Tree Based Diagnostics Using Fuzzy Logic". *IEEE Transactions On Pattern Analysis And Machine Intelligence*, V12 N11, Ieee, Usa.

Lee, D.A. And Browne, J.M. (1993), "Implications Of Varying Probability In Fault Tree Analysis". *Probabilistic Risk And Hazard Assessment*, P165-170, Balkema, Holland.

Ming Liu, C. (1990), "Fault Tree Analysis - Using Spreadsheet". *Proceedings Of The Annual Reliability And Maintainability Symposium*, Pp 513-516, Ieee, Usa.

Nawar, G. (1997), "The Application Of Systems As A Universal Model In The Minimisation Of Project Risks". *International Project Management*, Vol. 3, No. 1 Pp 32-40.

Nawar, G. (1997), "A System's Approach To The Management Of Project Risks". *Proc. Second National Conference Of The Risk Engineering Society*, Canberra

Nawar, G. (1998), " Fractals In Dynamic Decision Systems" *Proc. International Conference On System Dynamics, Indian Institute Of Technology*, Khargagpur, India.

Patterson-Hine, F.A. And Koen, B.V. (1989), "Direct Evaluation Of Fault Trees Using Object-Oriented Programming Techniques". *IEEE Transactions On Reliability*, V38 N2, P186-192, Ieee, Usa.

Quelch, J. And Cameron, I.T. (1993), "Dealing With Model Uncertainty In Quantified Risk Assessment". *Probabilistic Risk And Hazard Assessment*, P171-178, Balkema, Holland.

Singer, D. (1990), "A Fuzzy Set Approach To Fault Tree And Reliability Analysis". *Fuzzy Sets And Systems*, V34 N2, P145-155, Elsevier, Holland.