

A MODELLING APPROACH FOR ANALYSING THE BARRIER EFFECTS THROUGH THE EVENT TREES ANALYSIS

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Abstract:

This paper reviews the theoretical bases of the barrier modelling analysis, and introduces a novel approach for considering the barrier effects on the probability of the events through the event tree analysis. A structure for modelling barrier sets is developed. Using the techniques of the reliability analysis, an approach for calculating the effects of the barriers on the probability of events is introduced. This model is used to develop a risk analysis workbench in an industrial design application system, which can be used to analyse the risk during industrial systems design phases.

Keywords: Risk, Barrier, Industrial production systems, Virtual reality, Event tree

1 INTRODUCTION

Each part of an industrial system, including: technical solutions, products, materials, tools, consumables, environment or human can be a source of a threat. It is supposed that threats will be carried out in the form of an accident if a series of the events, which lead to exposing a target to a harmful agent, occur at the same time. Each one of these events has a probability of occurrence, which is estimated using the previous frequency of the occurrences, failure rate databases, or expertise estimations. Using an event tree, the logical relations between the events and the accident are defined, and therefore it is possible to calculate the probability of the accident. Knowing this probability and the severity of an accident, we can calculate the accident risk index, as a quantitative result of risk analysis, which is an indicator of the expected loss that may be produced by the accident.

When avoiding or eliminating the dangerous agent and hazards is not possible, the designer is forced to add a series of safety barriers to reduce risk of the undesired outcomes to an acceptable level (Trost and Nertney 1995). The main objective of adding safety barriers is to reduce gravity and/or frequency of the dangerous phenomena (Dianous and Fiévez 2006), however, generally, adding each of these barriers, also increases the cost (Leveson, 2004) and the complexity of the system by reducing system productivity and operator comfort (Polet 2002).

Barrier analysis is the process of selecting, optimising, and verifying the barriers (Kjellén and Sklet 1995), and to determine how these barriers or controls may fail (USONSPS 1992). It is a structured way to consider the events related to a safety system failure (Livingston et al. 2001), and helps to identify more clearly which scenarios have an insufficient level of risk control (Dianous and Fiévez 2006).

This paper present one part of the efforts concerning develop a risk modelling technique, for applying through the design process. Particularly, it presents a new structure for event tree and a method for integrating the barriers in this structure. This approach aims to provide a probability barrier model to be integrated in the industrial design application. Based of this model a safety analysis workbench is developed in the DELMIA V5©Dassault-Systèmes platform.

2 RELATED WORKS

2.1. Barrier

The theories utilised in barrier analysis were originally based on the successive works of Hienrich's domino theory back in the 1930s, Haddon in 1966 and Gibson in 1961, which developed the concept of an accident as an abnormal or unexpected release of energy (Livingston et al. 2001). The barrier concept is derived from analysing the accident processes as the contact between the dangerous agent (energy) and target (a vulnerable and valuable object) (Kjellén and Sklet 1995, Trost and Nertney 1995), and therefore a barrier was defined as the protector of the target from one or several hazards (Guldenmund et al. 2006 and Livingston et al. 2001). In the context of fault and event trees and the notion of 'defence in depth', the barrier concept also includes the barriers that prevent some sorts of "loss of control" (Guldenmund et al. 2006). Polet (2002) and Zhang et al. (2004) state that the barriers are used to prevent events or accidents but also include the measures that are predicted to resurrect the target and mitigate the severity of negative consequences. According to (Hollnagel 1999) knowledge and skills, and supervision are also considered as barriers. Hollnagel (1999) and Dianous and Fiévez (2006) distinct passive, active, and procedural barriers. Polet (2002) and Zhang et al.(2004) used other classification, presented by Hollnagel (1999) as material, functional, symbolic, and immaterial barriers. In an organisational view, Guldenmund et al. (2006) regroup the different elements of the hardware and behaviour barriers. According to Dianous and Fiévez (2006) the frequency of occurrence of the events is reduced proportion of the reliability of the barriers.

2.2. Event tree

Event tree analysis (ETA) is a symbolic logic technique that explores system and enables assessment of the probability of an unfavourable outcome (Huang et al. 2001, Rausand 2005a). It is used to illustrate the cut sets related to different consequences. A cut set is a set of basic events whose simultaneous occurrence ensures that the top event occurs (Rausand 2005a). Figure 1 presents a conventional event tree with the binary events. The letters T and F demonstrate the occurrence or non-occurrence of the events respectively, and the numbers in the parentheses are the probability of the events. By this analysis, multiple faults/failures can be analysed. Applying event tree analyses, we need failure rates for relevant equipment, therefore analysis. The failure rate of a

component is treated as a random variable to describe the failure rate variability and uncertainty (Huang et al. 2001).

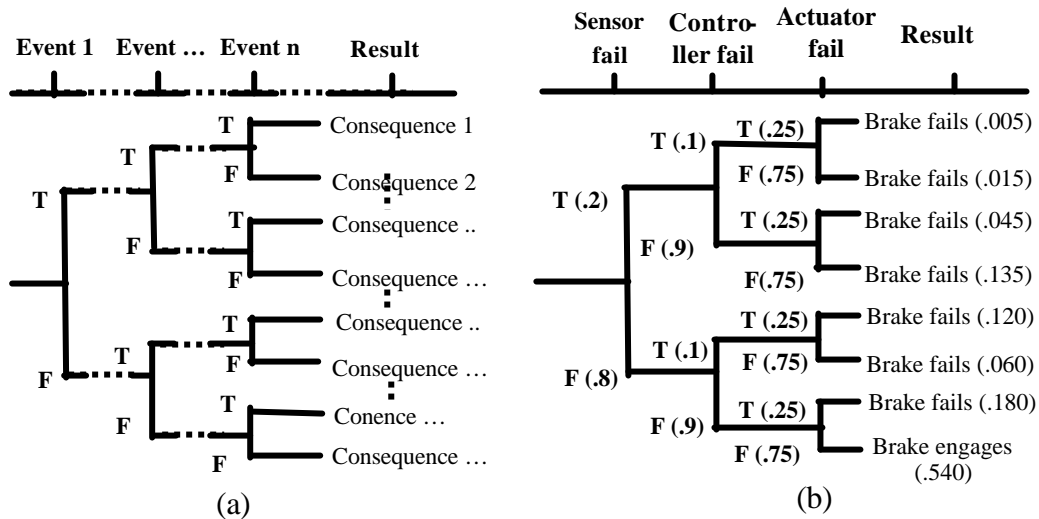


Figure 1: (a) Schematic demonstration of event tree and (b) an example of event tree

3 MODEL DESCRIPTION

In the framework of IVGI (virtual engineering for industrial engineering) project, a model for perform risk analysis through the design process is introduced. Here one part of this project concerning model accident process is describing. A modified form of event tree is developed, by applying a transformation on the conventional event tree. This model is integrated in the entity tree, used in an industrial design application. In contrast of the conventional event tree structure, all events relating to a particular unfavourable result (top event) are regrouped in a separate tree. The root of this tree is a top event, which is characterised by a “risk”, and the branches are the events. A risk is associated to one or several system parts including: technical solutions, products, tools, materials, consumables, human, environment, and even barriers.

Figure 2-a demonstrates a schematic form of the proposed model, and figure 2b illustrate the event tree of the previous example, in modified format. Like of

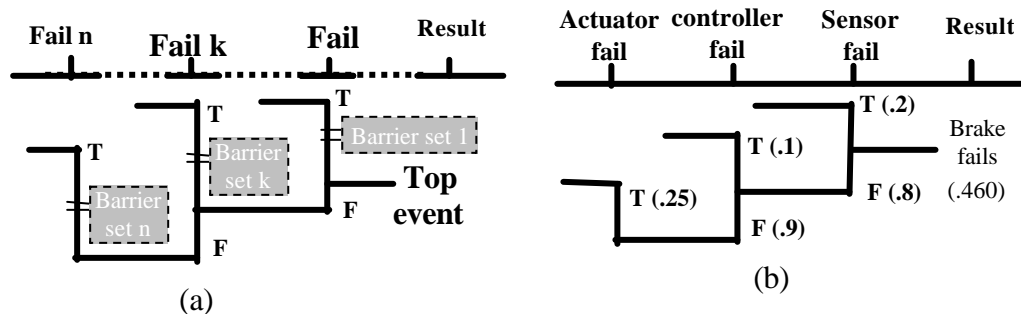


Figure 2: schematic form of transferred event tree (a), and an example for it (b)

conventional event tree, in this model the accident probability is calculated, simply, by multiplying the probabilities of the events, which imply independencies of the events

(see (Zio 2002)). However applying the barriers reduces the probability of the events, as:

$$P(e_k^+) = P(e_k^-)(1 - P_k)$$

P_k is the prevention factor of barrier set associated to the event k . Prevention factor of a set of barriers for an event is defined as the factor of reduction of the event probability after applying barrier set. The positive and negative signs for the events are used to separate the probability of the event after and before applying the barriers, respectively. The barriers that are demonstrated in the event tree are only the barriers that have effect on the probability of the events (probability barriers). Other methods are needed to model the barriers that have effect on the accidents severities (see Shahrokhi and Bernard (2006)). A probability barrier set is, as illustrated in figure 3, includes of serial and parallel barriers.

The relation of the barriers in this example can be demonstrated rationally as:

$$B1. OR. ((B5. AND. B4). OR. (B5. AND. B3)). AND. B2$$

AND relation and **OR** relations demonstrate the substitution and complementation relation, respectively.

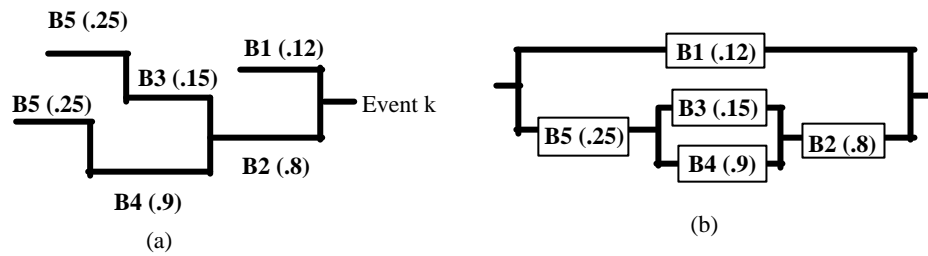


Figure 3: Barrier structure (a), and its equivalent in the reliability dia gram form (b)

The numbers in the parentheses, for each barrier, is product of barrier reliability and the barrier availability. Total prevention factor of a barrier structure is calculated by using the same calculation method, which is used for calculating the reliability of a set of components, by dividing the structure to the separated group of serial and parallel barrier. Total prevention factor, P , for the n parallel barriers is calculated as:

$$P = \prod_{i=1}^n r_i p(a_i), \text{ where } p(a_i) \text{ is estimation of the probability of availability of the}$$

barrier i , when the event is occurred. Prevention factor for n serial barriers is calculated as:

$$P = 1 - \left(\prod_{i=1}^n (1 - r_i p(a_i)) \right)$$

Note that the reliability of a barrier is a parameter related to the barrier capability to prevent the event, and it is defined for each event separately. However the probability of the availability of barrier is related to “time between failure (MTBF)”, “mean time to repair (MTTR)”, and other operational parameters.

4 DISCUSSION

The introduced approach uses the basic reliability engineering techniques, to model the probability barriers effects.

Based on this model, a safety analysis module is developed in the DELMIA V5©Dassault-Systèmes platform. Figure 4 presents a screen shot of a schematic application of this module. An information system is designed to facilitate the risk analysis process. A template library of the event and the barrier entities are developed, and in this way these entities can be embedded directly in the Delmia specification tree. Based of introduced data structure, a visual basic procedure is developed to define the entities parameters and calculate the accident probabilities. However, more examination will be taken to prove applicability of this model in the real design environment.

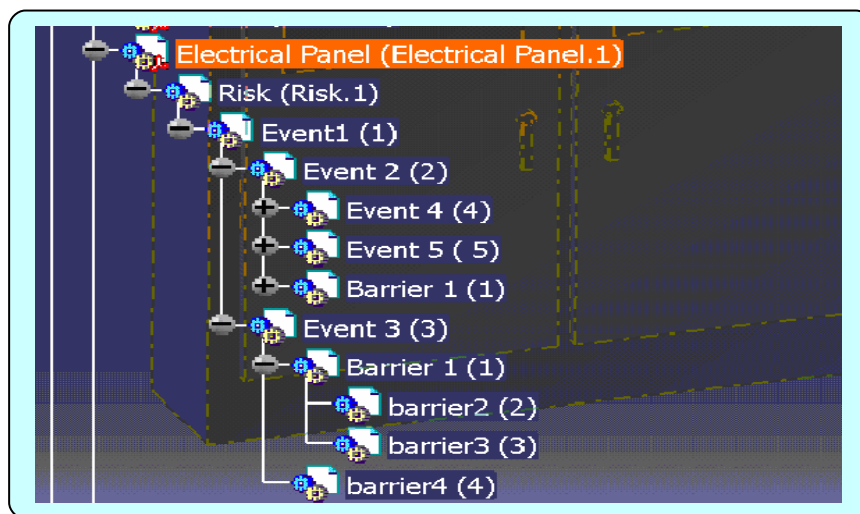


Figure 4: Developed event tree in Delmia platform

Like many of the reliability analysis approaches, barriers are modelled by considering two states: functioning and failure. In this way, occurrences of the events are illustrated as the Bernoulli random variables, with the corresponded probabilities.

Like the other event tree methods, the severity of the accidents is considered as the known parameters. A model for estimate the severity of accidents is provided in Shahrokhi and Bernard (2006), which is used concurrently with the presented model to calculate the risk indexes for the accidents.

5 CONCLUSION

In this paper we have reviewed the barrier concept in industrial workplaces and have developed an event analysis approach, including an modified event tree model and an structure to modelling barriers in the event tree. The methods used in the reliability analysis are used to calculate the prevention effects of the barriers on the event tree. Based of this model an risk entities template library and a workbench for calculation the accident probabilities are developed in the DELMIA V5©Dassault-Systèmes platform. These models can be used in order to make risk analysis, through the design process of the industrial systems.

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