The Bowtie Method For Safety Management: A Literature Review

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Abstract- *The Bowtie has become popular as a structured method to assess risk where a quantitative approach is not possible or desirable. Bowtie analysis combines aspects of fault-tree analysis and event tree analysis to identify an initiating event; its causes and consequences; and potential preventive and mitigating control measures or barriers. The approach is mostly used in the hazard identification and the contents lists available at development of the hazard register, to link hazard barriers and operational systems and procedures in place to eliminate the hazard or reduce its frequency of occurrence, or mitigate its potential consequences.*

Key Words:
Bow-tie, Safety management, Hazard Analysis,

I. INTRODUCTION

The bowtie method of analysis is a qualitative analysis incorporating management system techniques. The bowtie has become popular as a structured method to assess risk where a quantitative approach is not possible or desirable. The approach is mostly used in the hazard identification and the development of the hazard register, to link hazard barriers and operational systems and procedures in place to eliminate the hazard or reduce its frequency of occurrence, or mitigate its potential consequences. Since the Bowtie methodology originates from the fault tree and event tree analysis, the diagram could be directly derived from these. In practice, however, the diagram is commonly developed based on brainstorming sessions [Lewis, and S. Lessons2010]. The Bowtie method is a qualitative incorporating management system technique. Its essence is to establish how many safety barriers there are available to prevent, control or mitigate the identified scenarios, and the quality of those barriers. When the fault tree is drawn on the left hand side and the event tree is drawn on the right hand side with the hazard drawn as a "knot" in the middle the diagram looks a bit like a bowtie as shown This method of analysis uses the risk matrix to categories the various scenarios, and then carries out more detailed analysis (in the form of fault and event trees) on those with the highest risks (Gifford, Giltert et al.2003). The essence is to establish how many safety barriers there are available to prevent, control or mitigate the identified scenarios, and the quality of those barriers.

Barriers, also referred to as ‘controls’ or ‘layers of protection’, are a means of prevention or mitigation for any negative outcome and can reduce the occurrence likelihood of the latter. (Sklet S.2006) defined safety barriers as “physical and/or non-physical means planned to prevent, control, or mitigate undesired events or accidents”. Depending on their purpose, barriers can be either on the left or on the right side of the Bowtie diagram. Prevention barriers are placed on the threat branches between the causes and the top event. Their function is to prevent the top event and ultimately the release of the hazard (De Dianous, Vet.al 2006 and Abdi, Z et.al 2016). In contrast, mitigation barriers, also called recovery or protective barriers, aim to reduce the likelihood or minimise the severity of the consequences (Badreddine, A et, al.2014 and Jacinto, C. and Silva, C2010). Thus, these barriers are positioned on the consequence branches between the top even and negative outcomes. Barriers are not entirely effective or may not be permanently effective. Conditions that have the potential to adversely affect the effectiveness of a barrier are called escalation factors (Visser, J.P.1998). These factors are depicted as sub-branches from the main barrier path in the Bowtie diagram. To prevent the escalation factors from leading to barrier failure, additional controls, also called escalation factor barriers, are put in place (Manton, M.et,al 2017). These are drawn on the sub-branch of the escalation factor they are trying to prevent or mitigate.

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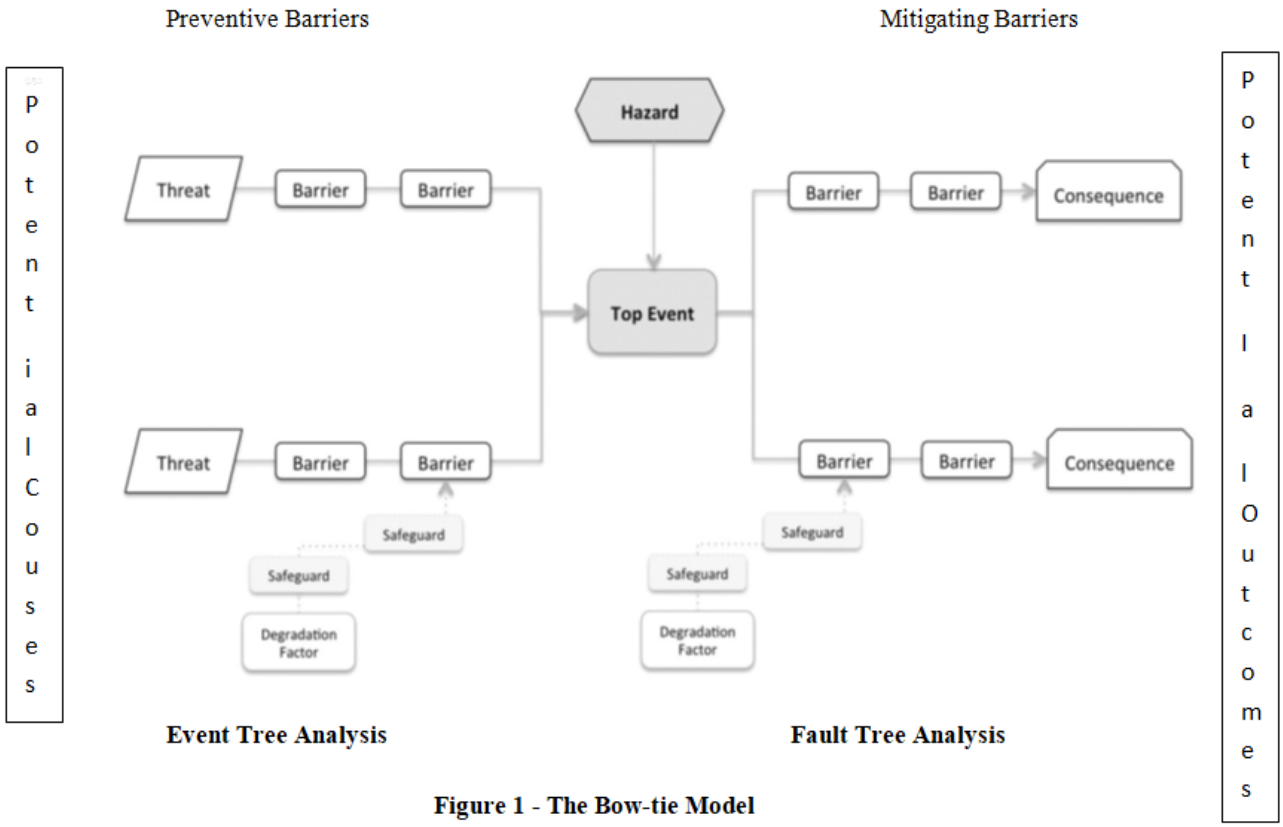

Figure 1 - The Bow-tie Model

The Bow-Tie diagrams and other risk assessment techniques have been used due to effective implementation in many real world applications such as accident risk assessment (Montano, D. 2014. Gowland, R. 2006, Khan, F. 2001 Chevreau, F. R., Wybo, J. L., & Cauchois, D. 2006). human error risk analysis (Deacon, T., Amyotte, P.R., Khan, F.I. 2013 and Deacon, T., Amyotte, P.R., Khan, F.I. 2010). dynamic risk analysis (Khakzad, N., Khan, F., Amyotte, P. 2012). risk management (Cockshott, J.E. 2005 and Duijm, N. J. 2009). Safety barrier implementation (Badreddine, A., Ben HajKacem, M.A., Ben Amor, N. 2014, Dianous, V., Fivez, C. 2006 and Mokhtari, K., Ren, J., Roberts, C., Wang, J. 2011). However, the applications of all these techniques aren't efficient in terms of satisfying results because the safety risk data are often vague, imprecise or incomplete to determine risk levels (Preeda S., Min A. 2015). In this study, combination of Fault Tree Analysis (FTA) and Event Tree Analysis (ETA) is introduced as Bow-Tie analysis to solve the risk assessment problem using fuzzy numbers to deal with uncertain and vague information.

The Bowtie method also used within the oil and gas, petrochemical, aviation and mining domains (Achield & Weaver, 2012; Burgess-Limerick, Horberry, & Steiner, 2014; Pitblado & Weijand, 2014; Saud, Israni, & Goddard, 2014; Dodshon, & Limerick, 2015). In Australia, the use of bowties is an accepted way to graphically demonstrate whether organisation controls have reduced the risk of a major incident so far as is reasonability practicable (Safe Work Australia, 2012; Dodshon, & Limerick, 2015).

Sukran Seker (2019) analysized the risk analysis is a systematic and widespread methodology to analyze and evaluate risks which are exposed in many working areas. One of the Quantitative Risk Analysis (QRA) methods for risk assessment is Bow-Tie analysis which combines features of fault-tree analysis and event-tree analysis to identify the top event; its causes and consequences (outcomes); and possible preventive and protective control measures or barriers.

II. DEFINITIONS

Hazard - Potential source of harm to people, assets, the environment and company reputation
Top Event - The incident that occurs when a hazard is realized
Threats - What could cause the top event to occur?
Consequences - What could happen if the top event occurs?
Barrier - What directly prevents or reduces the likelihood of a threat?

Recovery Measure - What prevents minimizes or helps recovery from the consequence?

Escalation Factor - What could prevent the barrier or recovery measure from working as intended?

Escalation Factor Control - What prevents or minimizes the chance of barriers or recovery measures becoming Ineffective?

III. THE BOWTIE PROCESS

The process involves the systematic identification of hazards and effects, assessment of the associated risks and the specification of the control and recovery measures which must be in place and maintained in place. The bowtie process is iterative and is often carried out by a team. The steps are (Lewis, Smith 2010):

Step1. Identify the bowtie hazard

A bowtie hazard consists of two items, the hazard and the event that will occur. Hazard: The hazard has the potential to cause harm, including ill health and injury, damage to property, products or the environment, production losses or increased liabilities. Examples of hazards include: Hydrocarbons, Elevated Objects, and Toxic Substances. Event: The event is the undesired event at the end of the fault tree and at the beginning of an event tree. The release of the hazards .Example Events include: Loss of Contaminant, "Structural Failure, and Dropped Objects.

Step2. Assess the Threats

The threats are at the far left hand side of the diagram. A Threat is something that will potentially cause the releases of the identified hazard. Example Threats may include: Thermal (high temperature), Chemical (corrosion)

Step3. Assess the Consequences

The consequences are at the far right hand side of the diagram. Threats are the conditions that may lead to the Top Event. Example consequences include: Fire and explosion, Environmental Pollution.

Step4. Control

The control is the protective measure put in place to prevent threats from releasing a hazard. On the bowtie diagram they sit between the threat and the hazard. All controls be them preventing threats, consequences or threats to the control each hazard and to reduce the risk to a level As Low As Reasonably Practicable (ALARP). Examples of Controls could be: Guards or Shields (Coatings, Inhibitors, and shutdowns), Separation (time and/or space).

Step5. Recover

The recovery controls sit between the Hazard and the Consequence. Recovery Controls are technical, operational, and organisational measures that limit the chain of consequences arising from an Event. Examples of recovery controls are: Systems to Detect and Abate Incidents (gas, fire & smoke alarms, ESD, deluge), Systems Intended to Protect the Safeguards (fire & blast walls, protective coatings, drain systems).

Step6. Identify threats to the controls

Threats to the Control are conditions that lead to increased risk by defeating or overriding a control. On the diagram these are displayed under and off to the side of the control. Example Threats to the Control are: Abnormal Operating Conditions (maintenance mode, testing of equipment), Operating outside Design Envelope (corrosion).

Step7. Identify the controls for the threats to the controls

Controls for the threat to the control should be put in place to ensure that the threat to the control does not cause the control to fail.

IV. CONCLUSION

Bow-tie analysis is widely used in high hazard industries (e.g. aviation, chemical, petro-chemical) as a risk analysis technique which combines elements of fault-tree analysis and event-tree analysis (Chevreau, Wybo et al. 2006; Duijim 2009; De Dianous, Fievez2006). Bowtie analysis is becoming more prevalent in the high risk industries (and other industries), as a tool to define the major accident hazards of a process, the potential causes (threats) and consequences of the major hazards and the barriers to reduce the likelihood of the causes and reduce the consequences. The use of bowties is also an important process safety training tool because it helps the participants to understand the basis of safety of the hazardous process and hence why the barriers and mitigation measures are important.

A BowTie is a diagram illustrating proactive and reactive risk management at any working environment. This case study applied the bowtie method to provide a simple visual analysis of the hazards that caused fatal accidents at Kaziwiziwi coal mine on 2nd November 2012 and 15th November 2019. Two coal miners were killed on the spot and others injured due to failure of a bucket hoisting system and hanging rock fall. The authors demonstrated that the bowtie method is an effective visualization tool that can be used to analyze the hazard, top event, threats, consequences, barriers and escalation factors of mining accidents; and therefore give an overview of everything not wanted around a certain hazard (Jabulani Matsimbe et al 2020)

Our experience has shown that the bow-tie is ideal for structured assessment and communication of risks, clearly demonstrates the link between control measures and management system arrangements and can be used to qualitatively assess and demonstrate control of all types of risk (Lewis, Smith 2010).

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