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Review article

The Bowtie method in safety management system: A literature review

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ABSTRACT

The Bowtie method is a qualitative incorporating management system technique. The theory behind the bow tie approach can be found in the "Swiss cheese model" of Reason. The Royal Dutch/Shell Group was the first major company to integrate fully the total bow-tie methodology into its business practices and then the bowtie has become popular as a structured method to assess risk where a quantitative approach is not possible or desirable. 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.

1. Introduction

Bow tie approach was originally devised to energies the safety management system. The theory behind the bow-tie approach can be found in the "Swiss cheese model" of Reason(Reason 1990). The exact origins of the bow-tie methodology are a little hazy. The earliest mention appears to be an adaptation from the ICI plc Hazan Course Notes 1979, presented by The University of Queensland, Australia. Undoubtedly, the Royal Dutch/Shell Group was the first major company to integrate fully the total bow-tie methodology into its business practices (Gower-Jones, van der Graaf et al. 1996; Primrose, Bentley et al. 1996; Primrose, Bentley et al. 1996)and is credited with developing the technique which is widely in use today. The primary motivation was to seek assurance that fit-for-purpose risk controls were consistently in place throughout all operations world-wide. This 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. As such it also a hazard and risk control display tool(July 2007). The success of the diagram is that it is simple and easy for the non- specialist to understand. The idea is a simple one of combining the cause (fault tree) and the consequence (event tree) (Chevreau, Wybo et al. 2006; Duijim 2009; Burgess-Limerick, Horberry et al 2014; De Dianous, Fievez 2006). 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.

Bow-Tie Diagrams are a technique used to conduct Risk Identification and Risk Analysis in a number of different industries, such as Petrochemicals (Zuijderduijn 2000), Air Travel(2009), Ship Building (Jacinto, Silva 2010) and even in Finance (McConnell, Davies 2004). In most known uses of the Bow-Tie technique, it is utilized as part of FSA-type assessments that are undertaken with a view of reducing accidents based on equipment failure, such as in Zuijderduijn (Zuijderduijn 2000) or in Trbojevic and Carr (Trbojevic, Carr 2000). Nordgård (Nordgård 2008) describes a case where Bow-Tie diagrams were applied in the Energy industry to calculate residual risk levels for various scenarios. Jacinto and Silva (Jacinto, Silva 2010) applied some quantitative techniques to enhance their qualitative risk assessment to study accidents at a ship yard. Other Examples of bow-tie analysis have been published by the UK defense industry (Gifford, Gilbert 2003), the French government (Couronneau, Tripathi 2003) , the UK Health and Safety Executive , an Australian State Regulator (2002), the Land Transport Safety Authority of New Zealand (June 2004), petroleum industry international associations (2000; December 2008) and international standards (October2006), the European aviation industry (March 2009) and US Federal Aviation Authority , and in the banking industry(McConnell, Davies 2004).

2. Bow-tie Method

The bow-tie method provides a readily understood visualization of the relationships between the causes of business upsets, the escalation of such events, the controls preventing the event from occurring and the preparedness measures in place to limit the business impact (Figure 1).

Figure 1 - The Bow-tie Model

The method for building a bow-tie diagram is well-documented (Primrose, Bentley et al. 1996;2002;Primrose, Bentley et al. 1996;Lidstone 1998;Trbojevic 1999;Kandola, Sullivan October 2003),hence it is only covered briefly here. In its most common use, the ultimate aim is to demonstrate control of health, safety and environmental (HSE) hazards; it is therefore necessary, firstly, to identify those hazards requiring bow-tie analysis. Most companies involved in hazardous activities have an HSE management system (1996;1999;July 1994) within which there will be formal procedures and/or guidance for identification of potential hazards and assessment of risks. Similarly, other companies have systems and standards for management of commercial, security, business continuity and corporate governance issues (2003;2003) to which the bow-tie method is equally applicable. Once hazards have been identified, the bow-tie method can

be applied to further assess risks and provide a framework for demonstrating their effective control. Typically bowties aredeveloped by asking a structured set of questions which build up the diagram step-by-step (Figure 2).

3. 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, 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 hazard.Example Events include:Loss of Containment, Structural Failure, 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, 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.

4. 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). The main advantage of the Bowtie concept is that it provides a visual representation of risk, including not only each applicable element, but more importantly, the relationships between them. It is this relationship illustration that enables many of the benefits of the concept when compared with textual or tabular risk information (in a similar way to the use of GSN for safety arguments). It allows areas of concern, such as inadequately controlled Threats or Consequences, to be readily identified and subsequently targeted for further treatment (Weaver 2012).

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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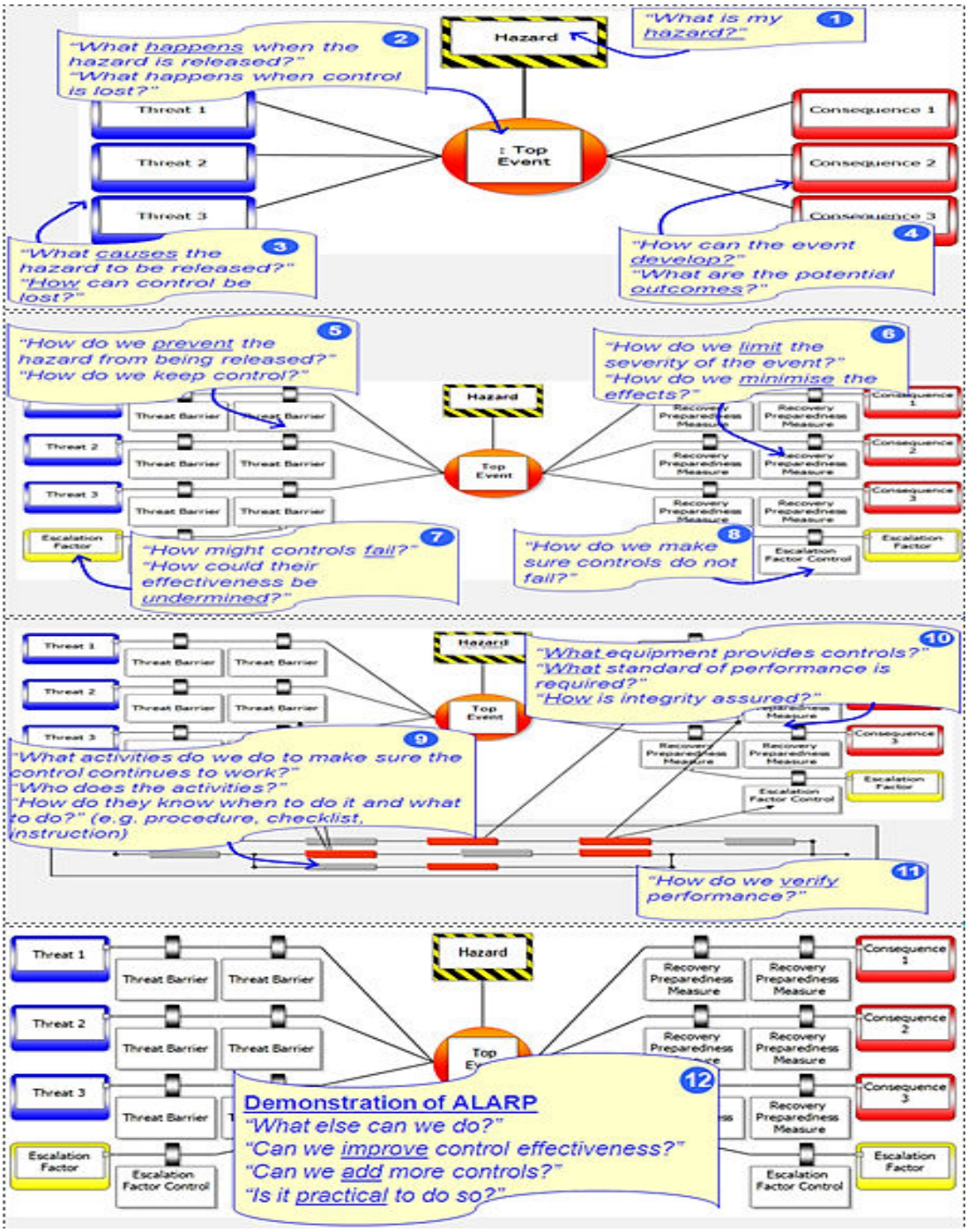

Fig. 2. Building the Bow-tie.