

Practical Application of Bowtie Analysis; Enhancing Traditional PHA

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Abstract

The benefits of using bowtie diagrams for risk management have been realised by organisations world-wide across a variety of business sectors. They provide a readily understandable visualisation of the relationships between the causes of business upsets, the escalation of such events to a range of possible outcomes, the controls preventing the event from occurring and the preparedness measures in place to limit the consequences. More importantly, the preventive and mitigative measures are linked to tasks, procedures, responsible individuals and competencies, thereby demonstrating the crucial connection between risk controls and the management system for assuring their ongoing effectiveness.

This paper, and accompanying presentation, draws on Risktec's unparalleled experience in applying the bowtie methodology and is intended to be of interest to those who are new to the technique and experienced users alike. With the growing popularity of bowtie in North America, this paper focusses on application of the methodology and describes in detail its practical uses and benefits as well as potential pitfalls. Of particular note is resolution of the following, commonly asked, question: "What does bowtie do that PHA doesn't?"

Keywords

Bowtie Analysis, Barriers, Safeguards, Process Hazard Analysis (PHA), HAZOP

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1 Introduction

The exact origins of the bowtie 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^[1].

Undoubtedly, the Royal Dutch Shell Group was the first major company to integrate fully the total bowtie methodology into its business practices^[2,3,4] 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.

Use of bowties has spread between companies, industries, countries and from industry to regulator, some examples of which are provided below:

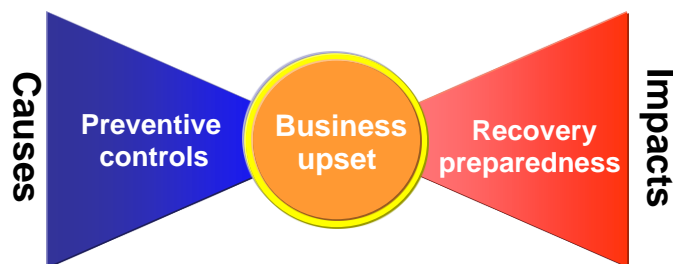
- UK defence industry^[5];
- French government^[6];
- UK Health and Safety Executive^[7,8,9a,9b];
- Australian State Regulator^[10];
- Land Transport Safety Authority of New Zealand^[11a];
- Petroleum industry international associations^[11b,11c];
- European aviation industry^[12a], and;
- Banking industry^[12b].

This paper aims to demonstrate the practical uses and benefits of this versatile tool which can be used to qualitatively assess and demonstrate control of all types of risk in many industries and business sectors.

2 The Bowtie Method

The bowtie 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 (see Figure 1).

Figure 1. Bowtie Diagram



The method for building a bowtie diagram is well-documented^[2,3,13,14,15,16,17], 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 bowtie analysis. Most companies involved in hazardous activities have an HSE management system^[18,19,20] within which there will be formal procedures and/or guidance for identification of potential hazards and assessment of risks. Similarly, many companies have systems and standards for management of commercial, security, business continuity and corporate governance issues^[21,22], to which the bowtie method is equally applicable.

Once hazards have been identified, the bowtie method can be applied to further assess risks and provide a framework for demonstrating their effective control. Typically bowties are developed by asking a structured set of questions which build up the diagram step-by-step (Figures 2 - 4):

Figure 2. Building the Bowtie – Steps 1 - 4

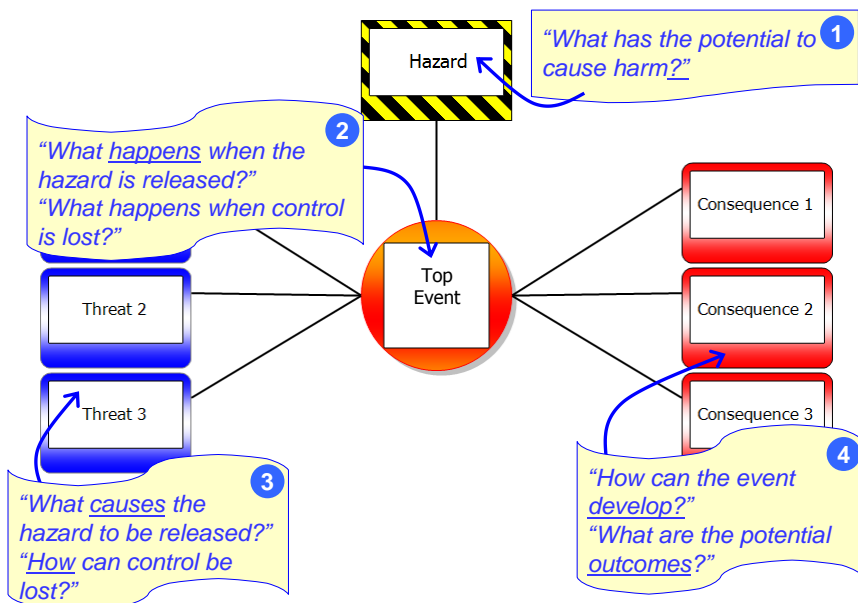


Figure 3. Building the Bowtie – Steps 5 - 8

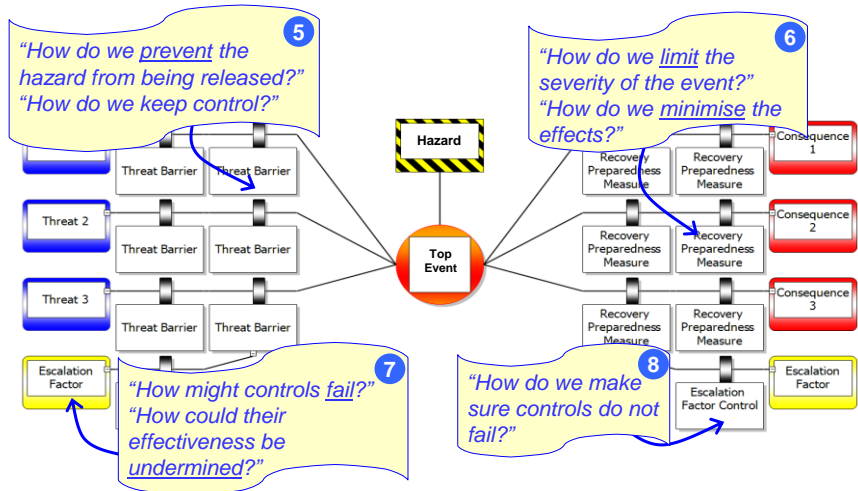
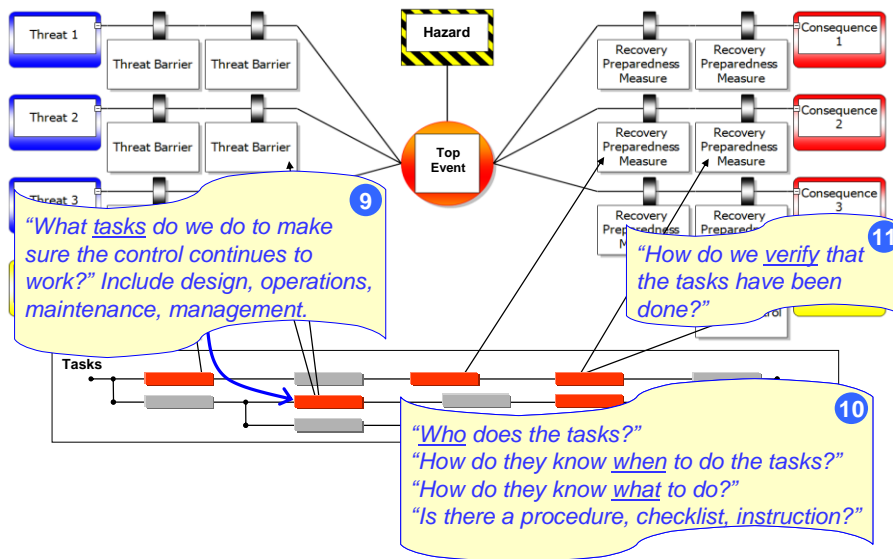


Figure 4. Building the Bowtie – Steps 9 – 12



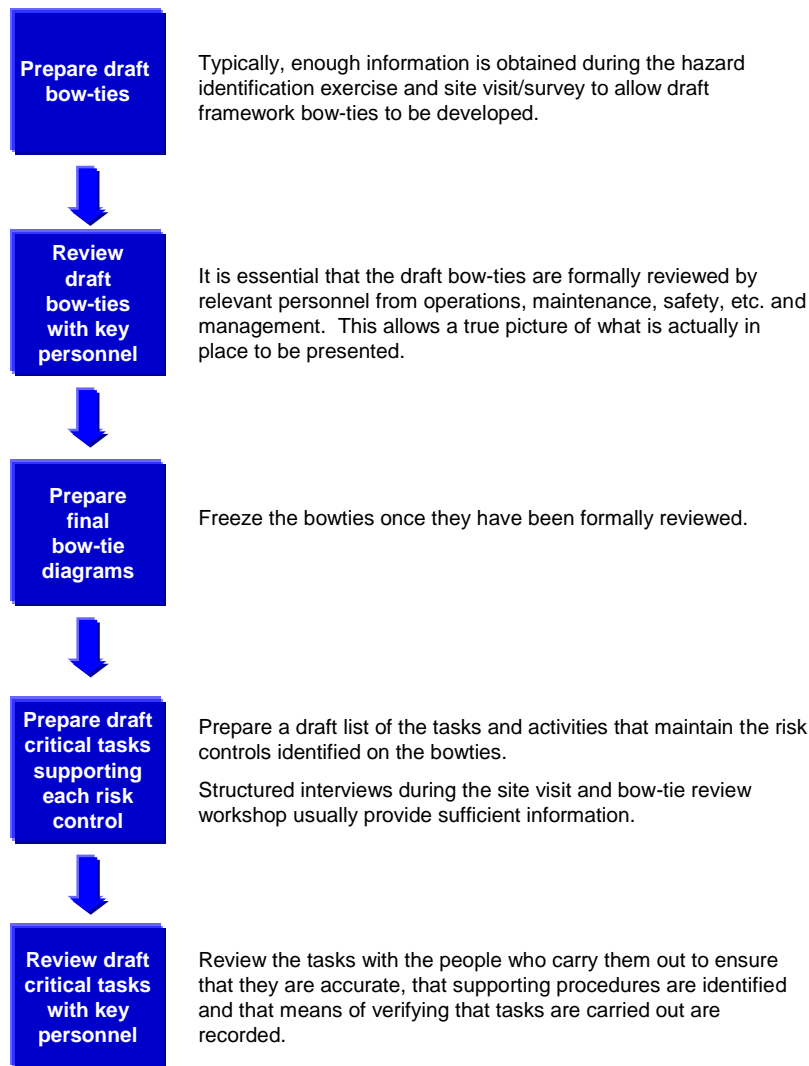
3 Application of the Bowtie Technique

Developing bowtie diagrams should be carried out in a structured manner in order to obtain quality information and best represent the actual risk control arrangements. Figure 5 summarizes an effective bowtie building process, which has been developed and refined through experience with a variety of companies, industries and work groups.

Facilitated workshops involving people who are regularly confronted with the risks have proven to be the most effective way of identifying real controls and capturing past incidents and current practice. Openness is an essential ingredient during these sessions if any weaknesses in controls are going to be uncovered. To encourage free discussion, the workshop needs to be run in an honest and engaging fashion, and, like HAZOP study for example, an independent facilitator can often help to create such an environment.

As is depicted in the first of the below steps, it is often possible to develop a series of 'framework' bowties to help facilitate discussion during the workshop. These framework bowties can be pre-populated using existing information generated through hazard identification / assessments exercises, and by mapping-out industry standard scenarios and their corresponding safeguarding.

Figure 5. Application of the Bowtie Technique



4 Practical Uses of Bowtie

The bowtie technique is incredibly versatile and has proven to be successful in many applications.

Logical Structured Approach

The structured approach of the bowtie forces an assessment of how effectively all initial causes are being controlled and how well-prepared the organization is to recover should things start to go wrong. This logical approach often identifies gaps and issues that are missed by other techniques.

Complete Risk Management

Risk assessments can have a tendency to concentrate on the level of risk only, rather than considering all aspects of the management of risk. The bowtie method however highlights the direct link between the controls and elements of the management system (see Figure 6). As such, it covers a much wider scope than HAZOP study, quantitative risk assessment (QRA), etc. alone.

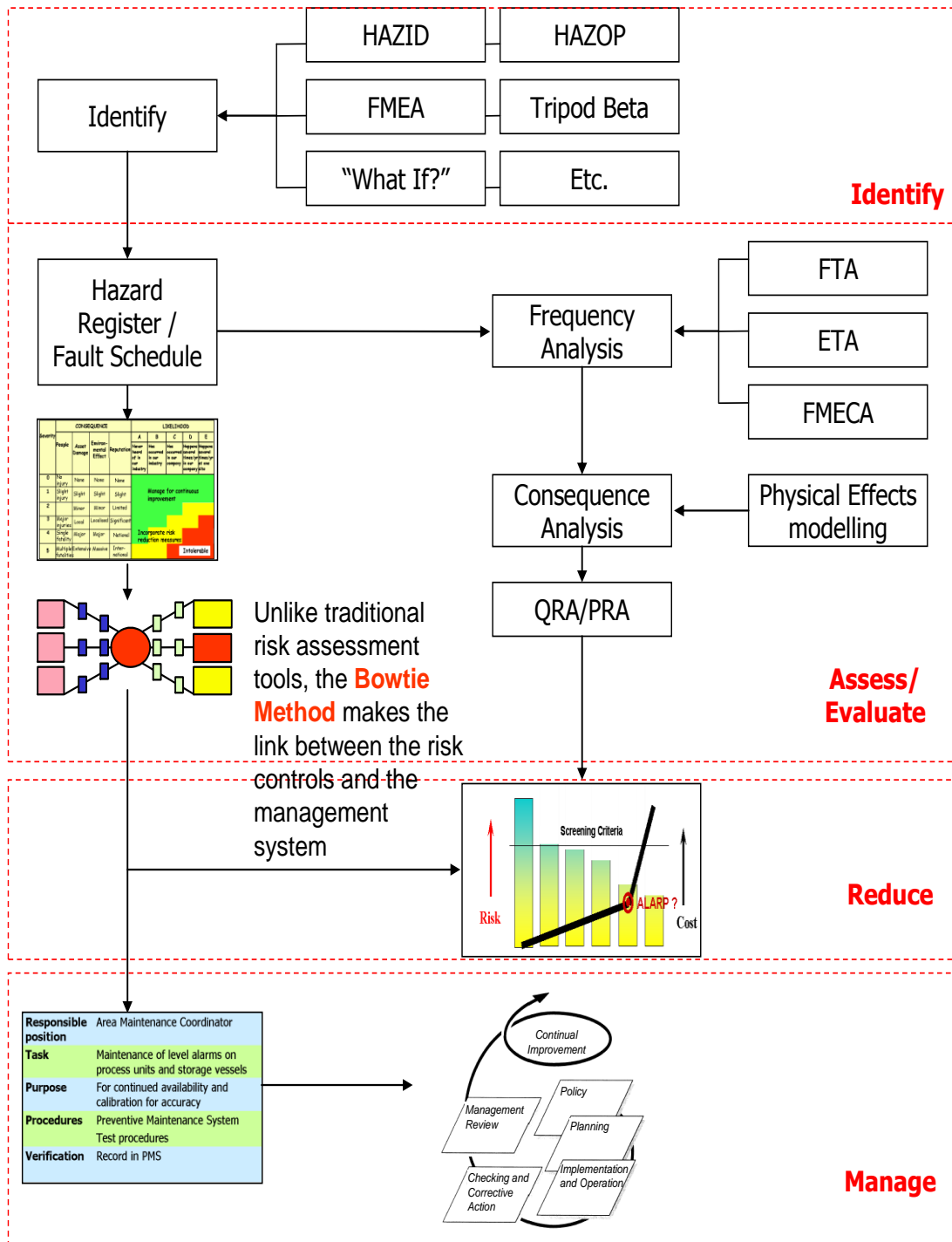
Demonstration

Due to their origin, bowties are most commonly used where there is a requirement to demonstrate that hazards are being controlled, and particularly where there is a need to illustrate the direct link between the controls and elements of the management system (see Figure 6). For example, bowties have been used successfully in safety reports produced for compliance with the UK onshore chemical industry Control of Major Accident Hazard (COMAH) Regulations^[23,24]. Indeed, the Competent Authority has stated that bowties are an acceptable means of demonstrating a systematic approach to hazard assessment^[25].

The COMAH Regulations require that "The demonstration should provide a clear link between the various accident scenarios identified and the measures which are in place to defend against them. The safety report should demonstrate how the necessary measures will prevent foreseeable failures which could lead to major accidents. There should also be a clear link to the SMSs which keep the necessary measures in place."^[26].

There are other means by which such a link can be demonstrated (e.g. tables) but the bowtie provides the clearest graphical illustration which is easy to understand.

Figure 6. Bowtie Linkage to Hazard Assessment / HSE MS



Communication

In its simplest, graphical form, the diagram can be understood by personnel at all levels of an organization, including those who are not connected with the day-to-day business operation being assessed. The bowtie lends itself to being displayed on posters highlighting key risk control issues. Pocket books and leaflets have

also been produced for dissemination of the risk management message. There are examples of bowties being included in web-based HSE/Safety Cases as part of on-line training and information systems.

It is not always necessary to use sophisticated publishing techniques to get the most out of the bowtie method. Talking through the components of a particular scenario (causes, consequences, controls, tasks) whilst simultaneously sketching a bowtie layer by layer can clearly illustrate how the hazard is managed effectively, particularly to those who may not be familiar with the details of the operation. This approach has been used successfully during safety workshops, pre-job planning meetings, discussions with regulators and interested members of the public.

Bowties provide a robust, comprehensive yet simple means of 'rolling out' the main points from a risk assessment exercise or HSE/Safety Case. Workshops involving workforce teams can be taken through the bowties step by step, in order that they understand the significant risks associated with their place of work, the measures taken to manage these risks and the importance of their individual role in preventing and mitigating hazardous events.

Once personnel are comfortable with the bowtie technique, building a bowtie becomes a viable alternative to traditional hazard assessment tools such as checklists and prompts. The bowtie structure provides an excellent framework for 'brainstorming' sessions.

Critical Systems

Critical hardware systems can be defined as those which cause, prevent, detect, control or mitigate a hazardous event. The nature of a bowtie diagram means that these critical systems are clearly illustrated along the threat and consequence branches, providing a ready means of identifying systems which are critical to ensuring ongoing asset integrity. Critical systems can be linked to defined performance standards and means of verification.

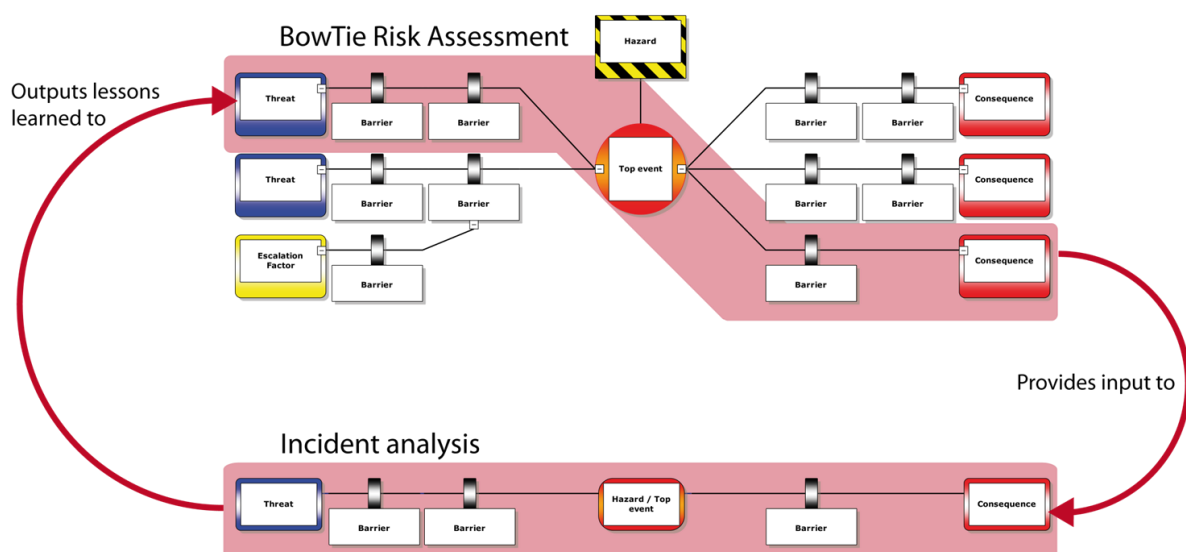
Organizational Improvements

It is possible to use bowties in conjunction with organizational and cultural survey techniques to highlight the branches of the bowtie where organizational control is weak, i.e. controls are not effective. Recognizing that organizational failures are the main cause of accidents, bowtie allows for proactive, sustainable strategies for reducing and managing risk to be focused on weak spots, for example a higher level of inspection or auditing.

Similarly, bowties have also been used to ensure that no critical controls "fall through the cracks" after a company re-organization, merger or acquisition.

Also, the bowtie can be linked to incident investigation techniques which identify the organizational failures that enabled risk controls (defences) to fail (Figure 8).

Figure 8. Link to Incident Investigation



Specific Risks

Bowties are of value not only to meet formal regulatory or corporate standards but for undertaking thorough analysis of specific risks (e.g. non-routine activities or particularly problematic areas) to provide reassurance that everything that can reasonably be done to reduce and manage risk is actioned.

Procedures and Competence

A completed bowtie analysis includes a list of critical tasks undertaken to ensure ongoing integrity of the risk controls. As a minimum, the tasks need to be reviewed with the individuals responsible for carrying them out, but they also lend themselves to being incorporated into procedures, work instructions, individuals' job descriptions, etc. A thorough bowtie analysis can also detail, for each task, the input procedures required to undertake the task correctly and any records which verify completion of the task, as well as competence requirements for the role responsible for undertaking the task. The tasks can therefore be used to verify the adequacy of a company's competence assurance system; the competencies defined for an individual or role should align with the bowtie controls. In this fashion, bowties have also been used to manage handover and new-starter responsibilities.

Layer of Protection Analysis

Bowtie diagrams have also been used for conducting Layer of Protection Analysis (LOPA), a simplified risk assessment tool for determining if sufficient protection is in place and quantifying the residual risk where it is insufficient^[27]. Well-constructed bowties, together with clearly defined rules for applying failure data for hardware and human intervention barriers, enable conservative estimates of residual risk to be compared against risk tolerability criteria. The approach tends to work well during design phases.

It is also possible to make direct links between the engineered safeguards on the bowties and specific work orders in a preventive maintenance scheduling and tracking system. In this way, critical hardware systems essential for ongoing risk management are prioritized.

5 Benefits of Bowtie Methodology

The bowtie method has three main benefits:

1. Clear communication and improved understanding - Visually illustrating the hazard, its causes and consequences, and the controls to minimize the risk, the bowtie can be readily understood at all levels, from senior managers and operations personnel, to regulators and members of the public. Bowties keep sight of the big picture and can capture the sequence of events as well as previous incidents.
2. Greater ownership - Recognizing that effective risk management is only possible if people are assigned responsibilities for controls. Bowtie workshops encourage participation and stimulate communication between key stakeholders, whether from the company, contractors or external parties, who all have a role to play in managing risk and yet may not be involved in more traditional techniques. When people feel involved they tend to 'buy-in' to the process. When action is taken based on what they say, people will take ownership. Bowties should especially be considered where lack of ownership of process safety by all levels of operations personnel may be an issue.
3. Efficiency gains – Realizing efficiency improvements through a number of different ways, for example: the method is less labor intensive than many other traditional techniques; it identifies where resources should be focused for risk reduction (i.e. prevention or mitigation); it can reduce the volume of safety analysis – it is true that a picture paints a thousand words; it can lead to a potential reduction in unnecessary/lower importance barriers (where fully justified); it helps to target maintenance, inspection and testing activities on critical hardware barriers; and it provides a 'corporate memory' to avoid reinventing the wheel every few years.

The approach also has a number of other benefits:

- 'Future proof' risk management - Illustrating not only what controls are currently in place today, but, through the use of critical tasks, why they will still be there tomorrow.
 - Fit-for-purpose management system - Linking the elements of the organization's management system to specific controls to show how it ensures the ongoing management of risk. This avoids the development of over-burdensome management systems and unnecessary procedures, by focusing on those procedures required to support risk control.
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- Practical approach - Focusing on risk management by people on a day-to-day basis, rather than analytical studies by technical risk specialists. All too often, risk analysis can become progressively more complex leading to 'analysis paralysis' which overwhelms the need to take positive action.
- Workforce involvement - Risk management is the responsibility of line managers and their people; all staff can see why what they do is critical for risk control.
- Logical structured approach - Considering all aspects of the management of risk, from initial cause to final consequence in a sequential manner. This logical approach often identifies gaps and issues that are missed by other techniques.
- Auditable trail - The diagrams and critical task lists provide a protocol around which auditing by internal departments or regulators can focus on what people are actually doing rather than the condition of physical systems.
- International application – The graphical-based approach is easy to implement with multi-national teams where language difficulties may otherwise hinder progress.
- All risks – The technique is not limited to assessment of HSE risks. Bowties have been developed for demonstrating management of security, information technology, business interruption and project risks. The possibilities are endless.
- 'Living case for safety' – Comprehensive bowtie assessments can be captured in a relational database which supports ready and wide access across an organization, and enables easier periodic updating. Links to current safety-critical procedures help to maintain any case for safety as a live tool rather than a document for risk practitioners that sits on the shelf.

6 Limitations of Bowtie Methodology

Of course, bowties are not the panacea for all risk management problems. If you want to quantify your level of risk in absolute terms then the bowtie method will not help directly. If you want to model complex inter-relationships between your risk controls, there are better ways than using bowties. If you want to identify individual safeguards for every line of every section of every unit of your process facility, then HAZOP study is the solution. But if you want to remove the mystique of risk management and obtain insights into your risk controls that are easy to understand and easy to communicate, and at the same time realize some efficiency gains, there is no better method than bowties.

7 HAZOP vs. Bowtie Analysis

As touched upon a number of times within this paper, a range of methods/techniques/tools exist whereby which risk assessment of a particular process, facility or task can be undertaken. One of the more common techniques applied throughout industry is HAZOP and, due to its status as a well understood proven technique, is often assumed to cover / encompass the range of information / analysis which would be contained within bowtie analysis; "If I'm already undertaking HAZOP/PHA, why do I need to perform bowtie analysis? What does bowtie do that PHA doesn't?"

- **HAZOP:** Excels at performing a detailed, structured review of the operation of a process, identifying the possible causes of a deviation from the design intent, the consequences and the engineering safeguards present.
- **Bowties:** Very flexible, graphical risk analysis method that allow for visualization of the relationship between Cause – Loss of Control – Consequence and the barriers in place to manage the sequence.

The following key differences between HAZOP and bowtie analysis exist:

- The graphical representation of bowtie allows for a much clearer, easier to understand representation of the risks and how they are managed. By making it easier to understand, it allows for more personnel to engage with this process which leads to better risk management; as the organisation understands what they are relying on and how well it is working, the better they can understand how it is performing and what the weaknesses are.
 - Bowties are a very flexible method, and in addition to looking at process risks (which is generally where HAZOPs are employed), are also applied to a far wider range of risks including logistics,
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construction, security etc. allowing for a common representation and understanding across an entire organisation.

- Bowties consider the full range of barriers that an organisation is relying on. HAZOPs tend to concentrate on the engineered safeguards in place, whereas Bowties will consider a wider range of safeguards e.g. training & competency, external protection, inspection & maintenance, etc.
- HAZOPs focus predominantly on what is happening inside the process, whilst providing a degree of assessment for external impacts and human factors (as directed by OSHA regulation). However, the flexibility of the bowtie approach allows for greater consideration of external events e.g. external impact, weather, human error etc.
- HAZOPS will tend to concentrate on the preventative safeguards employed to stop a sequence from happening i.e. to keep the process within the containment; Bowties allow for consideration also of the mitigative controls to model what happens once process containment is lost e.g. the emergency response measures such as detection, alarm, mitigation, firefighting, emergency plans etc.
- HAZOPs tend to stop with the static representation of risk i.e. what safeguards are present. Bowties allow for a deeper interrogation of the safeguards, to ask not only what is there, but why it will still work in the future. So Bowtie barriers can be linked to the persons responsible for performing maintenance, or to the performance requirements of critical equipment. This can then be further interrogated e.g. competency requirements for personnel to keep the barriers functioning, maintenance status of critical equipment.

None of the above is intended to say the Bowties should replace HAZOP. They are complementary tools. There is nothing better than HAZOP for ensuring that process systems are designed fit for purpose. Bowties follow on from this to allow for a through life picture, applicable to all levels of personnel, that can be applied to all risks.

8 Conclusions

This paper presents the lessons learned from application of the bowtie method across a number of business sectors. Our experience has shown that the bowtie 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.

Bowtie should be used as a complimentary tool to the more established forms of PHA such as HAZOP. Bowties will take a robustly assessed design which has going through the appropriate level of assessment (e.g. via HAZOP, LOPA etc.) and ensure that the risk profile is being managed throughout the life of the facility.

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