Lessons Learned from Real World Application of the Bow-tie Method

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Abstract

The benefits of using bow-tie diagrams for risk management have been realized by organizations world-wide across a variety of business sectors. Also known as barrier diagrams, they provide a readily understandable visualization 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 mitigating measures are linked to tasks, procedures, responsible individuals and competencies. This demonstrates the crucial connection between risk controls (whether hardware or human intervention) and the management system for assuring their ongoing effectiveness.

This paper draws on Risktec's unparalleled experience in applying the bow-tie methodology and is intended to be of interest to those who are new to the technique and experienced users alike. It summarizes the history of the bow-tie method, gives an overview of how to apply it and describes in detail its practical uses and benefits as well as potential pitfalls and guidelines for success.

1. Introduction

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[1].

Undoubtedly, the Royal Dutch/Shell Group was the first major company to integrate fully the total bow-tie 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.

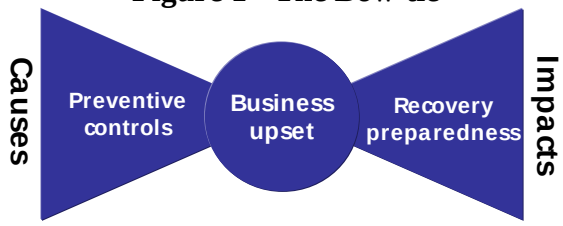
Use of bow-ties has spread between companies, industries, countries and from industry to regulator. Examples of bow-tie analysis have been published by the UK defense industry[5], the French government[6], the UK Health and Safety Executive[7,8,9a,9b], an Australian State Regulator[10], the Land Transport Safety Authority of New Zealand[11a], petroleum industry international associations[11b,11c] and international standards[11d], the European aviation industry[12a] and US Federal Aviation Authority[12b], and in the banking industry[12c].

This paper aims to demonstrate, through reference to actual case studies and examples, 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. 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

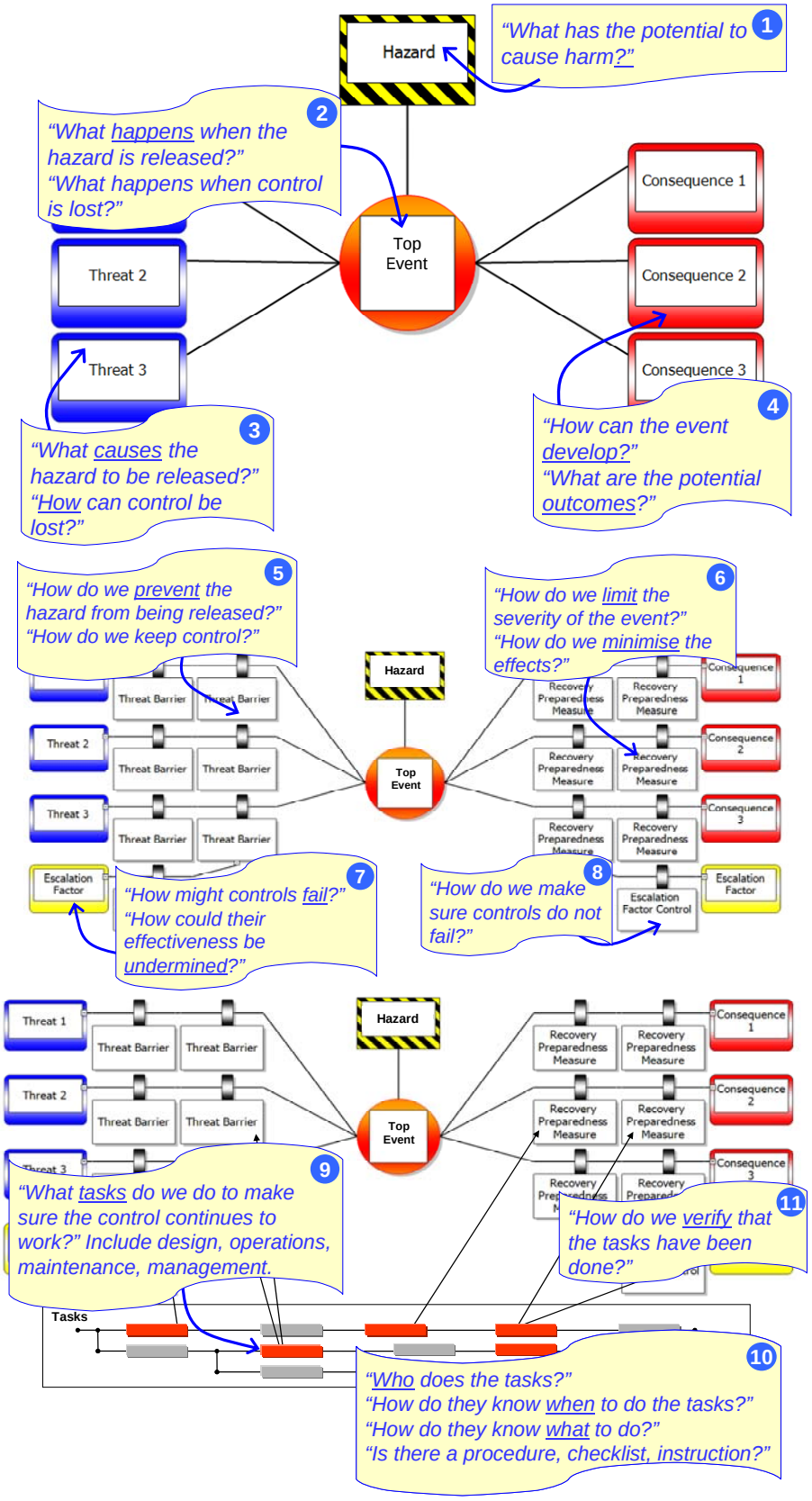


The method for building a bow-tie diagram is well-documented[2,3,13,14,15,16,17], hence it is only covered briefly here.

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 bow-tie 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, other companies have systems and standards for management of commercial, security, business continuity and corporate governance issues[21,22], 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 bow-ties are developed by asking a structured set of questions which build up the diagram step-by-step (Figure 2).

Figure 2 - Building the Bow-tie

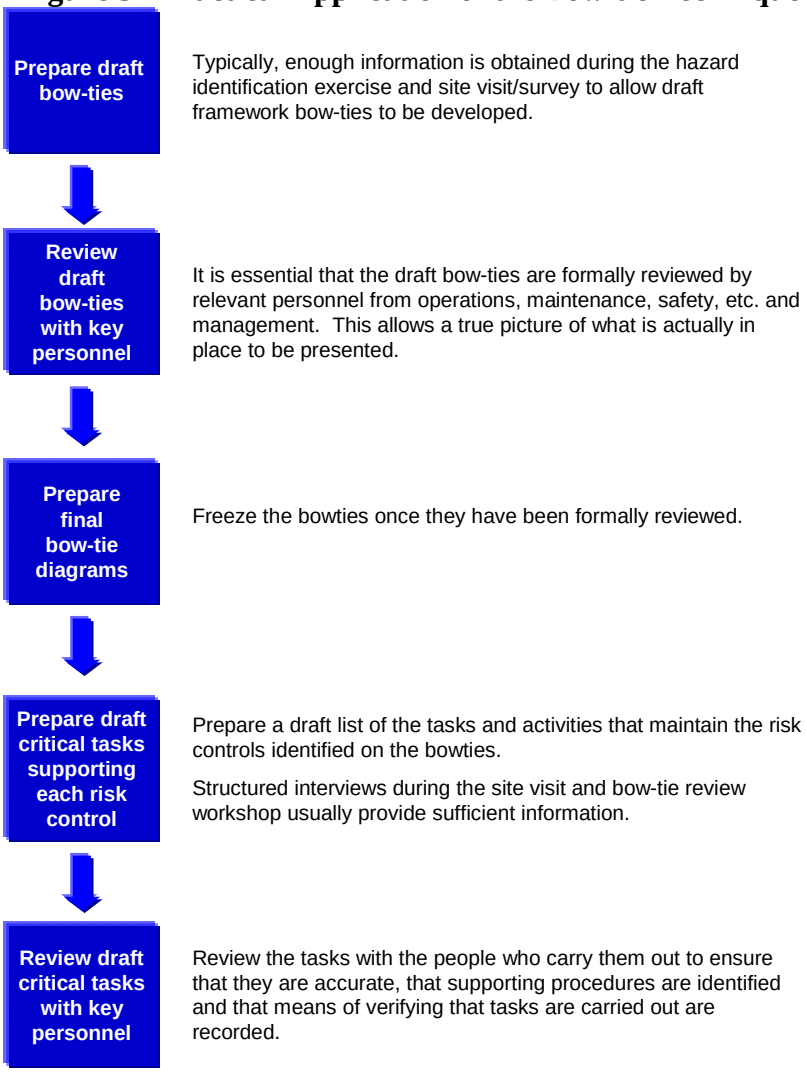


2.1 How to Apply the Technique

Developing the bow-tie diagrams and critical tasks should be carried out in a structured manner in order to obtain quality information and best represent the actual risk control arrangements. Figure 3 summarizes an effective bow-tie 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.

Figure 3 - Practical Application of the Bow-tie Technique



2.2 Practical Uses

The bow-tie technique is incredibly versatile and has proven to be successful in many applications.

2.2.1 Logical Structured Approach

The structured approach of the bow-tie 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.

2.2.2 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 bow-tie method however highlights the direct link between the controls and elements of the management system (Figure 4). As such, it covers far further than HAZOP study, quantitative risk assessment (QRA), etc.

2.2.3 Demonstration

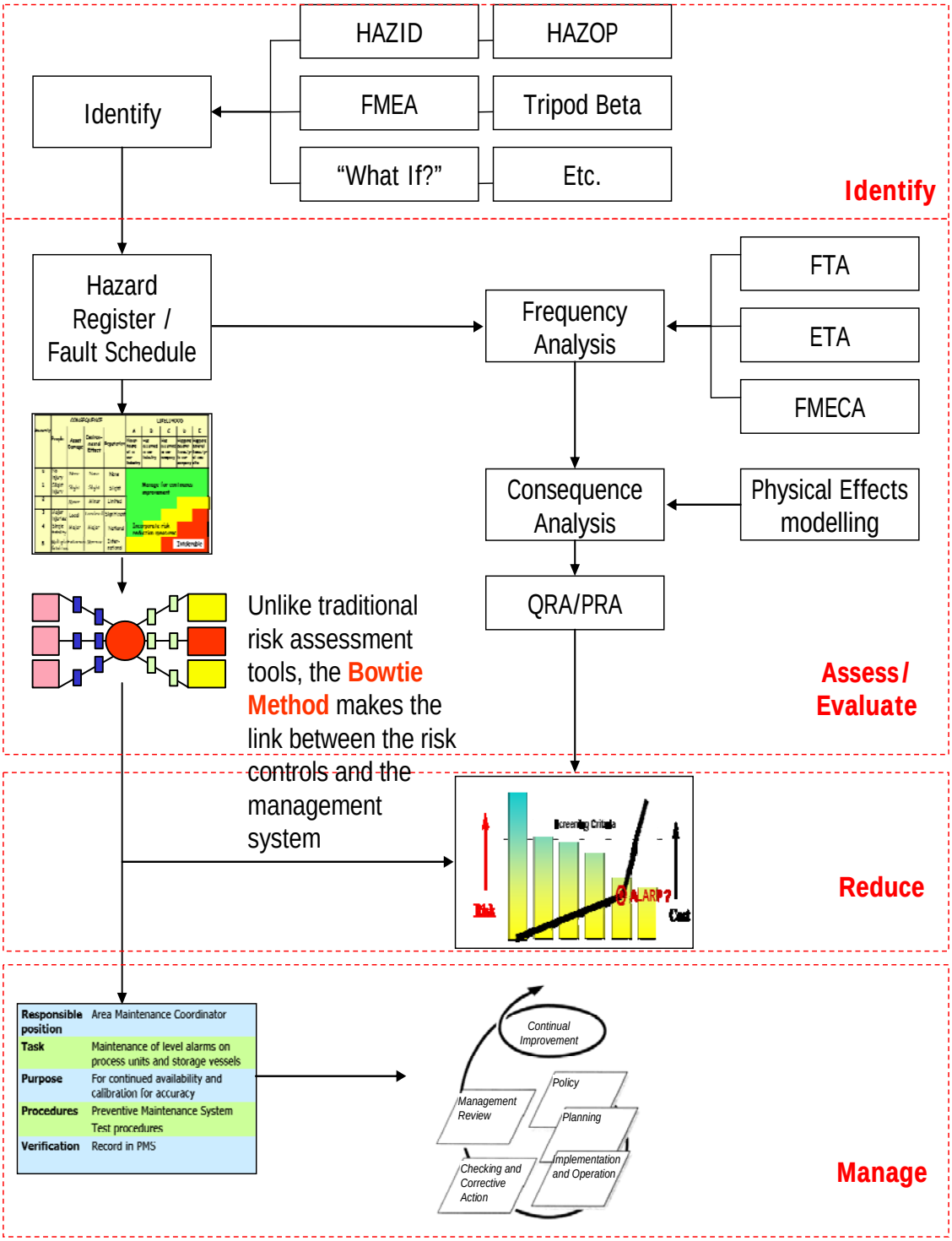
Due to their origin, bow-ties are most commonly used where there is a requirement to demonstrate that hazards are being controlled, and particularly where there is a need to illustrate the direct link between the controls and elements of the management system (Figure 4). For example, bow-ties have been 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 bow-ties 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 bow-tie provides the clearest graphical illustration which is easy to understand.

In Abu Dhabi, the ADNOC HSEMS Guidelines require *"…a demonstrable link between each significant risk and a set of controls or risk reduction measures."*[27] and the associated Code of Practice on Control of Major Accident Hazards (COMAH)[28] outlines the bow-tie methodology as the means to achieve this.

Figure 4 - Link with Management System



2.2.4 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 bow-tie 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 bow-ties being included in web-based HSE 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 bow-tie method. Talking through the components of a particular scenario (causes, consequences, controls, tasks) whilst simultaneously sketching a bow-tie 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.

Bow-ties provide a robust, comprehensive yet simple means of 'rolling out' the main points from a risk assessment exercise or HSE Case. Workshops involving workforce teams can be taken through the bow-ties 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 bow-tie technique, building a bow-tie becomes a viable alternative to traditional hazard assessment tools such as checklists and prompts. The bow-tie structure provides an excellent framework for 'brainstorming' sessions.

2.2.5 Critical Systems

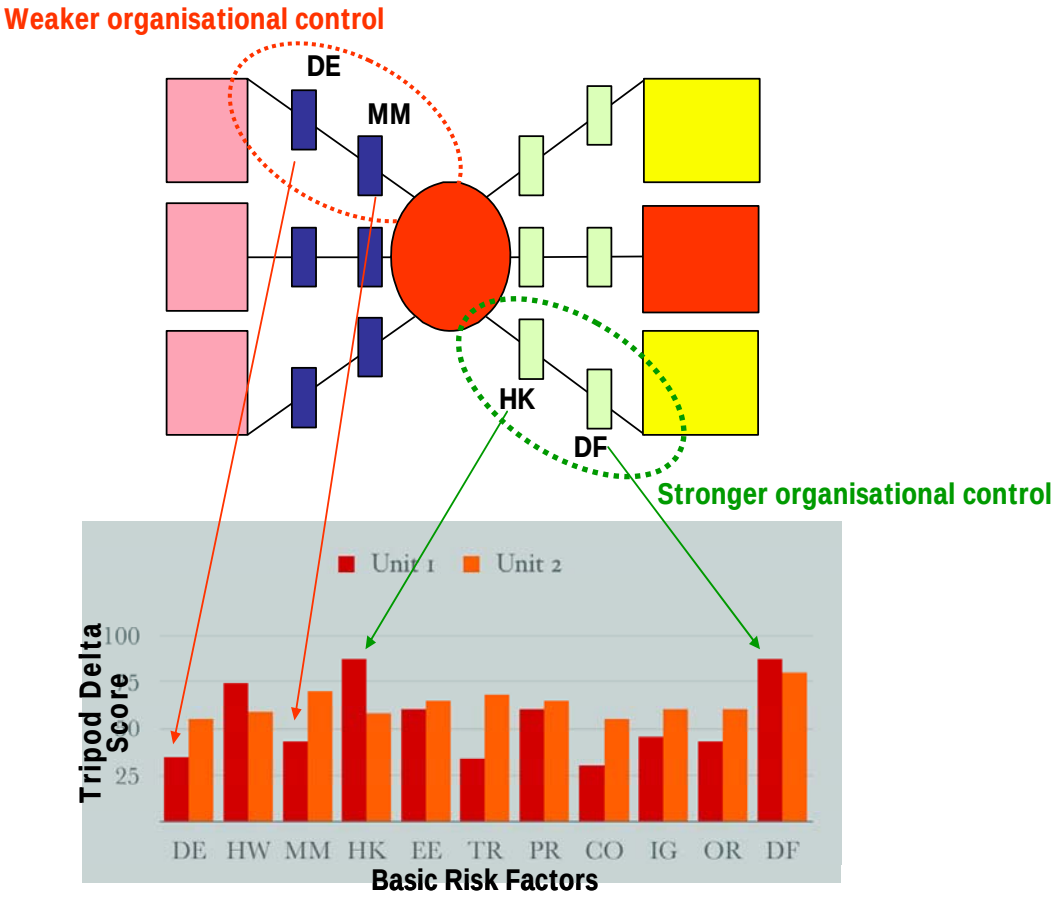
Critical hardware systems can be defined as those which cause, prevent, detect, control or mitigate a hazardous event. The nature of a bow-tie diagram means that these critical systems are clearly illustrated along the threat and consequence branches, providing a ready means of identifying systems which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

2.2.6 Organizational Improvements

It is possible to use bow-ties in conjunction with organizational and cultural survey techniques such as Tripod Delta[29] to highlight the branches of the bow-tie where organizational control is weak, i.e. controls are not effective (Figure 5). Recognition that organizational failures are the main cause of accidents is the principle behind Tripod Delta, which is a questionnaire-based survey used to build a picture of an organization's strengths and weaknesses against eleven basic risk factors. This enables proactive,

sustainable strategies for reducing and managing risk to be focused on weak spots, for example a higher level of inspection or auditing.

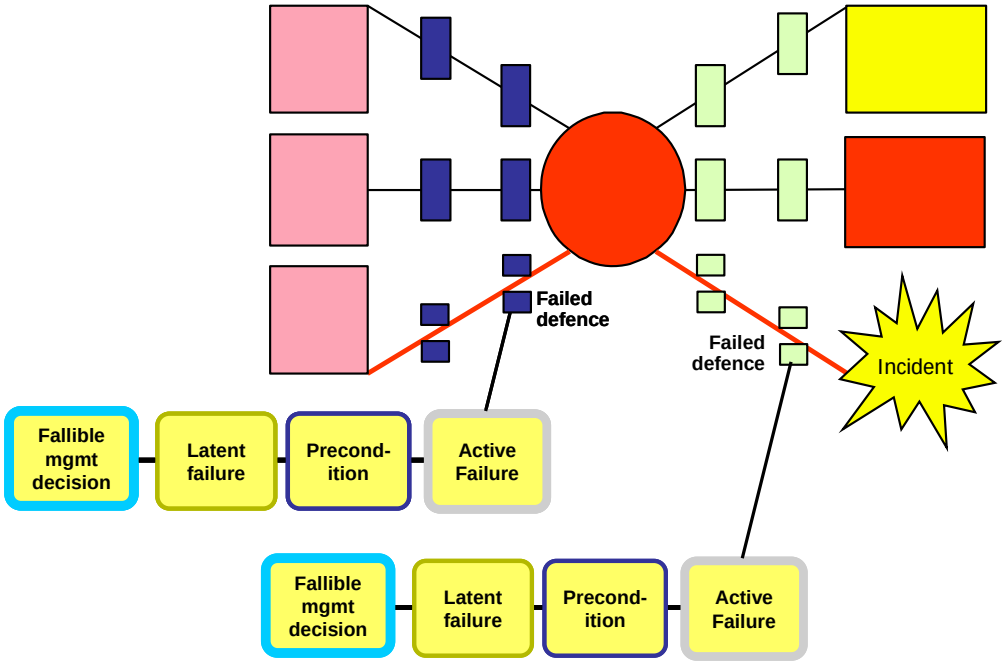
Figure 5 - Link to Basic Risk Factors



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

Also, the bow-tie can be linked to incident investigation techniques such as Tripod Beta[30] which identify the organizational failures that enabled risk controls (defenses) to fail (Figure 6).

Figure 6 - Link to Incident Investigation



2.2.7 Specific Risks

Bow-ties 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.

2.2.8 Procedures and Competence

A completed bow-tie 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 bow-tie 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 bow-tie controls. In this fashion, bow-ties have also been used to manage handover and new-starter responsibilities.

2.2.9 Layer of Protection Analysis

Bow-tie 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[31]. Well-constructed bow-ties, 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 bow-ties 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.

2.3 Benefits

The bow-tie 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 bow-tie can be readily understood at all levels, from senior managers and operations personnel, to regulators and members of the public. Bow-ties 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. Bow-tie 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. Bow-ties 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.
- 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. Bow-ties have been developed for demonstrating management of security, information technology, business interruption and project risks. The possibilities are endless.
- 'Living case for safety' – Comprehensive bow-tie 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..

The bow-tie illustrates not only what controls are in place today, but why they will still be there tomorrow

2.4 Limitations

Of course, bow-ties are not the panacea for all risk management problems. If you want to quantify your level of risk in absolute terms then the bow-tie method will not help directly. If you want to model complex inter-relationships between your risk controls, there are better ways than using bow-ties. 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 bow-ties.

3. Example Case Studies

3.1 Public Meetings

In one oil and gas industry case where onshore sour gas wells are periodically drilled close to third party land, the operating company has pioneered the use of bow-ties to illustrate to the regulator and members of the public that the hazards associated with the operation are recognized, understood and well managed, both from a preventive point of view and for preparedness in the event of an emergency. Simply drawing bow-ties freehand during public meetings helped considerably in putting across the message that the company is in control of the hazards and the risks are minimized.

3.2 Adequacy of Controls

The bow-tie has been used successfully as a means of assessing the adequacy of controls and identifying areas for risk reduction for a rail transport network[11]. A series of stakeholder workshops employed the bow-tie method to test the robustness and number of existing safeguards and identify improvements. For each risk control, critical operating parameters were identified and links were made to rail operating procedures, maintenance systems and international standards. Actions were identified to strengthen particular controls.

3.3 Auditing

As an example of how the technique lends itself to use during audits, bow-tie controls and critical tasks have been used as the basis for pre-start up inspections of land drilling rig activities, to make sure that the drilling contractor personnel were fully aware of their responsibilities in managing hazards and that all controls were in place. The same audit also allowed the contracting oil company to assure itself that the operation was fit to continue.

3.4 Dissemination of Information

Use of bow-ties enables companies to streamline their risk management documentation, as the amount of information which can be included on a single bow-tie diagram would require several pages if presented in text or tabular format. A company operating a number of oil and gas production installations, together with the associated exploration, infrastructure and transport facilities, found that its HSE Case documents, which originally ran to several volumes per asset, could present the information at the same level of detail but in slimline, single volume versions using bow-tie diagrams. Transferral of this information onto the company intranet with electronic links between bow-tie controls and relevant responsibilities, procedures, instructions, etc. allowed online HSE Cases to be readily accessible to all.

Use of web-based bow-ties[32] has enabled one organization to ensure that up-to-date, consistent information on HSE critical roles and responsibilities is managed effectively, aligned with business processes and disseminated to individuals, communities, disciplines and projects. In this way the HSE management system is 'operationalized', enabling it to serve as a dynamic corporate HSE memory.

3.5 Specific Risk Assessment

Bow-ties have been used for risk assessment of a driver-to-signaler train radio communication system on behalf of the rail network management company. The graphical representation enabled easy understanding of the relationships between causes of unwanted events and their controls. The assessment systematically identified procedural controls as well as functional and integrity requirements for engineered measures and established issues for further assessment, information or action where the effectiveness of a control was questioned.

3.6 Periodic Process Safety Review

Many regulatory regimes and corporate standards have a requirement for 'periodic' or 'thorough' review of a safety case to ensure that it remains valid. At first sight, the potentially wide ranging nature of periodic reviews can appear daunting and onerous, with the potential to place a heavy burden on resources. But a well-managed periodic review provides a great opportunity to strengthen the connection between the safety case and the real world – recognizing that the case for safety is based on real plant, processes and, arguably most importantly, people.

A large nuclear site operator took the opportunity to go beyond the traditional desktop study of the safety case documentation by safety personnel. Bow-tie workshops were arranged to involve operational personnel, whose detailed knowledge of the safety case was limited, but who had an excellent first-hand perspective of its practical implementation and direct experience of incidents. The approach improved understanding of both safety and operations personnel, resulting in a safety case that better reflected operations and operations that better reflected safety requirements.

3.7 HSE Critical Systems

A large oil company has chosen to use the bow-tie technique to identify hardware systems and operating and maintenance procedures which are critical to the safeguarding of asset integrity, i.e. those which are 'claimed' as controls on the bow-tie diagrams. These HSE-critical systems and procedures are subject to a transparent inspection, examination and testing program which includes verification by independent third parties.

3.8 Enterprise Wide Risk Management

A major natural resources organization has applied the bow-tie method to map its company-wide corporate risk management strategy, covering all risks including quality, financial, business, political, environmental, information technology, human resources, design and new technology.

At a medium-sized oil company the chief executive uses a 'risk dashboard' which comprises a single bow-tie encompassing all risks, with color-coded controls highlighting priorities for improvement, together with responsibilities for action.

If you want to remove the mystique of risk management, there is no better method than bow-ties

4. Tips for Success

There are several common pitfalls which can be encountered when applying the bow-tie method; the key ones are discussed here together with ways of avoiding them.

- Avoid working in a vacuum - Operational experience or bow-tie experience alone gives sub-standard results; a combination of the two is essential.
- Involve people – Use people in building bow-ties, reviewing tasks and identifying areas for improvement. Whilst a first pass bow-tie can be developed as a desk top study, quality can only be assured by involving competent people who know how activities are in reality carried out in the workplace and have an in-depth understanding of the plant, the operation or design. This ensures that risk controls and supporting tasks accurately reflect actual practice rather than the preconceptions of senior management or the risk department. However, to arrive quickly at a truly representative bow-tie structure and avoid getting stuck in the detail, it is accepted best practice to use independent facilitation to solicit the input from the workforce. The facilitator should have practical experience of building bow-ties. The subjective nature of the method means that different groups of people may produce different bow-ties for the same event. However,

this is of secondary importance; the main point is that the assessment should be complete and the key risk controls and tasks captured.

- Pitch at the correct level of detail - Too high and the bow-tie is meaningless; too low and the exercise is labor intensive.
- Make sure the control responsibilities don't all finish up at the manager level - Care needs to be taken when setting the level of detail. Controls should be independent and self-explanatory. Tasks need to be meaningful and assigned at a level where their completion can be verified. Typically when building bow-ties for assessing major hazards (e.g. multiple fatalities, massive environmental impact, extensive asset loss, international reputation damage), tasks supporting the controls should be pitched at the supervisor or team leader level.
- Balance the information between the bow-ties and the tasks - Depending on the intended use of the bow-ties, it may be appropriate to keep the diagrams simple, with few words, and present any detailed information in the tasks. This approach can be appropriate when using bow-ties to represent the management of major business risks across the company for example. Alternatively, it is sometimes beneficial to keep the detail in the diagram, e.g. where a bow-tie is to be used for training purposes during a pre-job safety meeting.
- Prioritize effort - Don't get carried away. The bow-tie method is a flexible, generic tool that can be applied to any type of risk at any level. It can equally be used for assessing lower consequence 'workplace' hazards (e.g. slips, trips, and falls) as well as for assessing major business risks. It provides useful information for pre-job safety meetings, for example[33,34]. When using the technique at this level, it may be prudent to select representative workplace hazards with care and prioritize resources at those which are most common, are of greatest concern or are unique, otherwise significant resources could be demanded and the method called into question.
- ALARP demonstration - Bow-ties are an appropriate tool for qualitative demonstration that risk is managed to a level which is As Low As Reasonably Practicable (ALARP). However, avoid barrier counting where possible. Instead, in addition to the controls currently in place, the team must ask "what additional, practical controls can we implement?" There is one school of thought that advocates setting numerical risk acceptance criteria for bow-ties, (e.g. there must be at least three independent controls for every threat). The danger with this approach is that the assessment becomes a 'control counting' exercise, with dependent controls artificially represented as separate control measures in order to meet the criteria and with the assessment stopping once the requisite number of controls has been confirmed. It is better to use the cumulative experience of the bow-tie building team to review the completeness of the assessment as a whole and confirm the number, suitability, quality and effectiveness of the controls and supporting critical tasks. The important question must always be asked "is there anything more we can reasonably do?"

- Verify control measures and tasks - Follow-up with an audit. Depending on the make-up of the group who develop the bow-tie and the expertise of the facilitation, there can be a danger that the diagram represents only a single opinion, has serious omissions or does not represent what actually happens in the 'real life' situation. A follow up audit or inspection helps to ensure the credibility of the bow-tie and the completeness of the management arrangements. It verifies that the controls are actually in place and the critical tasks ensuring control effectiveness are being carried out. This is particularly useful when bow-ties have been developed for a new project, when there may be limited information available, when procedures are still to be developed and roles are not yet assigned. The verification audit can be carried out as part of pre-start up activities.
- Software helps but don't get hung up on it - The true benefits from the bow-tie process are largely independent of the means by which the bow-tie is constructed, e.g. by hand or electronically[35]. A number of software tools are available to construct bow-ties and manage the information behind the diagram. It should not be forgotten however that many of the benefits of the approach are associated with the actual implementation of the process and involvement of the workforce, which is often easiest to achieve using hand drawn bow-ties in a brainstorming, workshop setting. Software is ideal for speeding up the reproduction of bow-tie diagrams and organizing the information for future interrogation, retrieval and update.
- Use the method to its full potential - As use of bow-ties has become more widespread, partial assessment has become more common, with the analysis ceasing once the diagram is constructed. While this gives a graphical demonstration of risk control, it provides no more information than other risk assessment tools which illustrate the controls in place at that moment in time, e.g. HAZOP, What-If. In other words the bow-tie diagram on its own is just a 'snap shot' of the current risk control arrangements. What is missing is the direct and visible link between the controls as they are today and the procedures and people responsible for ensuring they will continue to be effective tomorrow. This understanding is only achieved by identifying and documenting the critical tasks and/or critical procedures which are crucial for ongoing functioning of the controls.
- Keep the end objective in mind - It can be easy to get carried away when using the bow-tie method. For example, for an operating plant the key controls are in making sure that the installed equipment keeps working properly, not in assessing the quality control of the design process from many years before. Similarly, there may be little point in reproducing the large number of individual steps taken to control an event if they are already well documented in a work instruction or manual. Reference to the external document is usually sufficient.
- Quantification - use the right tool for the job - The bow-tie is sometimes described as "like a fault-tree on the left hand side with an event-tree on the right". Some risk assessors interpret this as an opportunity to try to quantify the risk level, but the bow-tie is wholly qualitative, without any of the complex logic of fault and

event trees. While a well-constructed bow-tie can be used to support a quantitative LOPA approach, most attempts to quantify the risk tend to miss the main point of the bow-tie, which is to identify how the management system provides assurance that risks will continue to be properly managed in the future.

The method helps to ensure that risks are managed rather than just analyzed

5. Conclusion

This paper presents the lessons learned from application of the bow-tie method across a number of business sectors. 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.

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