The Use of Bow Ties in Process Safety Auditing

Doug Anderson, Technical Director, ERM; Margaret Caulfield, Principal Consultant, ERM; Martyn Ramsden, Technical Fellow, ERM; Glenn Pettitt, Technical Fellow, ERM, 2nd Floor, 33 St Marys Axe, London, EC3A 8AA;
Malcolm G Sarstedt, European Operations Manager Process Safety, Unilever, Lever House, Wood Street Port Sunlight, Wirral, UK CH62 4ZD.

Process safety auditing is a critical tool in identifying potential weakness in technical process systems, and identifying potential improvements and possible measures to manage the risks. Auditing is a key part of an overall safety and environmental management system to assist management in determining how organisations should move forward based on a critical feedback loop as part of the management review.

Bowtie analysis is becoming more prevalent in the petroleum industry (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.

This paper advocates the use of bowtie analysis in process safety auditing.

The paper describes a program of work currently being undertaken by ERM in conjunction with Unilever to review hazards at their sites worldwide. The output of the program is assurance to Unilever that all necessary measures are being applied consistently to reduce the risks associated with their hazardous operations.

Keywords: Assurance, hazard and risk, audits

Introduction

Bowtie analysis is becoming more prevalent in the petroleum industry (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 bowtie analysis in process safety auditing has been established by the authors as an excellent mechanism to help both the auditors and auditees to prioritise audit activities and focus on those aspects of the process design, operation and maintenance that are central to maintaining a good level of safety and ensuring the risk is as low as reasonably (ALARP). Used as an integral part of an audit process, it helps the auditees to understand the relevance of the questions and thereby increases the value of the audit. As a result, the audit is no longer simply a 'compliance' exercise.

As the audit progresses the audit team systematically evaluates the effectiveness of the claimed barriers within the context of the elements of the applicable process safety management framework whether that is driven by regulation or corporate standards.

The bowtie technique provides a good visualisation and communication tool demonstrating to auditees the potential vulnerabilities in their basis of safety, where the focus of their process safety efforts should lie, and to management that the audit process is crucial to maintaining a high level of process safety.

All about Bowties

Introduction

Bowties are diagrams representing the relationship between an unwanted event, its potential causes, its consequences and the controls in place, as shown below in **Figure 1**.

Figure 1: Bowtie schematic

Bowties are thought to have originated in the late 1970s in ICI (Imperial Chemical Industries). However it was not until the early 1990s, that Shell became the first company to incorporate bowties into its operations. Following Shell, the bowtie method started to be widely used throughout the oil and gas industry, as bowties became known as a powerful visual tool to aid risk management *(Lees, 2005)*.

In the last decade the bowtie method has also spread to other industries including aviation, mining, maritime, chemical and healthcare, e.g.*(CAA website, 2015, Kerkhoffs , 2015)*

A typical bowtie diagram is shown below in ***Figure 2***.

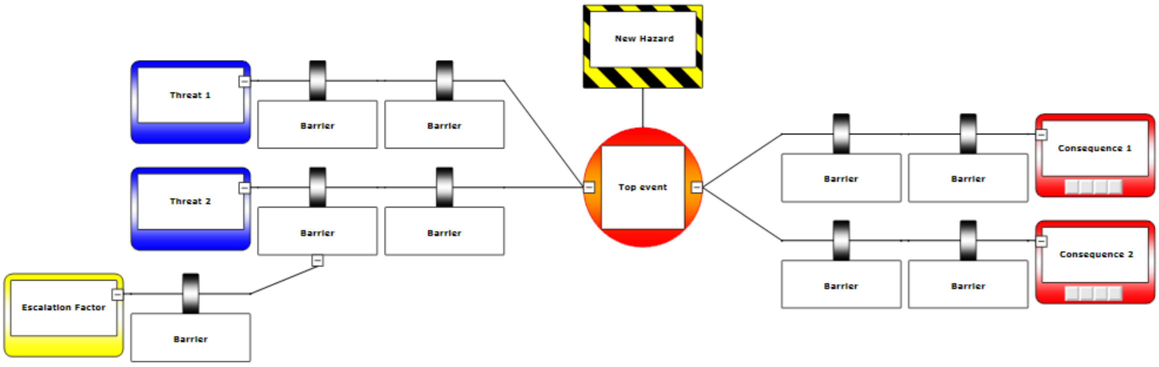

Figure 2: Typical Bowtie Diagram

The "Top Event" is at the centre of the diagram. The "Hazard" is a physical situation that has the potential to cause harm and the potential to lead to the Top Event. The top event is when control of the hazard is lost. The left hand side shows potential threats which, if un-mitigated, could directly lead to the Top Event. In the example of chemical releases on a facility, threats could include "Dropped Objects (mechanical impact)" or "Corrosion", both of which could lead to a release (the "Top Event"). The right hand side shows the potential worst case credible consequences, such as "toxic release leading to fatalities onsite". In between the Threats and the Top Event, the bowtie shows the barriers that reduce the likelihood of the Top Event from occurring. In the example of a chemical release, a typical barrier might be "Maintenance and Inspection of Process Equipment". The right hand side of the diagram shows the mitigating measures that act to reduce the consequences of a Top Event. Again, taking the example of a chemical release, a mitigating measure could be "gas detection and alarm leading to emergency shutdown". Escalation factors can also be incorporated, where an "escalation factor" is a mechanism that could lead to a failure or degradation of a control, for example a floating level indicator on a tank (the barrier being claimed) seizes and does not register a change in level. This could be mitigated by installing an additional instrument to provide level manual checks on the level reading (this would be the barrier on the escalation factor).

Developing Effective Bowties

Although bowties are an increasingly widespread tool for risk management, ERM's experience of reviewing bowtie diagrams suggests that the quality and depth of bowtie diagrams are extremely variable. These problems may stem from a lack of appreciation of the ultimate use to which a bowtie will be put. Problems may also arise from a loose definition of the various component parts of a bowtie. Coupled with insufficient thought given to defining barriers, the result may be an overestimate of the strength and number of safeguards. In particular, bowties often do not contain sufficient consideration of human factors; this is because they are typically developed by technical safety specialists, for example in the oil and gas and chemical industries. Often, human factors is incorporated in the form of procedural barriers such as "Permit to Work" or "Maintenance and Inspection", but with no further consideration of the effectiveness of these barriers. In many cases, the guideword "human error" is used as a standalone threat with barriers such as competency and training; however, this is of little value and does not advance the understanding of the risk management of the process under consideration (*Hamilton 2012*).

As a way of providing guidance, a number of high-hazard organisations have developed internal standards to ensure consistency across bowties developed for the organisation's assets. Some have developed a suite of generic bowties to be used as the starting point for the assessment of common hazards. Many companies and consultancies, however, lack this type of guidance and rely on their own judgement or experience when preparing bowtie diagrams.

In order to bring some consistency to the process of developing qualitative bowties for risk management in major hazard industries, ERM has developed ten 'Golden Rules' , shown in *Figure 3*, to provide practical guidance for developing effective bowties, (*Ramsden 2013*).

Rule 1	Know from the start what you want to achieve with the bowtie since this will affect how you approach the exercise
Rule 2	In general, bowtie diagrams are not quantified and their primary purpose is to represent hazard management arrangements
Rule 3	The 'top event' represents the point at which control of the hazard is lost
Rule 4	Threats are states, conditions or occurrences which could lead directly to a top event
Rule 5	Consequences are discrete worst-case outcomes of the top event with no mitigation

	barriers in place
Rule 6	Barriers must be tangible and must have an effect substantially to prevent or mitigate the top event
Rule 7	Escalation factors should be used sparingly representing only barrier failure modes presenting a major threat
Rule 8	Human error should not be treated generically, but should be included as specific threats to the top event or to barriers
Rule 9	Bowties should be developed and reviewed involving personnel with practical knowledge of the systems being described
Rule 10	Break the rules where necessary to improve risk communication, these rules are intended to provide guidance not a straitjacket

Figure 3: ERM's 'Golden Rules' for Bowties

Advantages of Bowties in Process Safety Management

There are numerous advantages to using bowties as a tool for effective process safety management. These are discussed below:

- **Effective communication:** The simple representation of the safety processes makes them ideal to use in Safety Cases and Reports. The popularity of bowties is due to their ability to simply and effectively communicate how risks associated with Major Accident Hazards are managed on a particular facility or during a particular operation. This is an approach that has gained traction with regulators such as the UK HSE (Health and Safety Executive), and many safety cases and COMAH cases are now developed with bowties at their core.
- **ALARP reviews**: They are an effective and visual way of representing the risk management process and provide a strong starting point for ALARP reviews.
- **Identification of Safety Critical Elements:** Bowties offer a systematic way to identify safety critical elements (SCEs) and activities and then to use this information to develop the SCEs and associated performance standards
- **Workforce engagement:** Bowties are powerful in engaging the workforce. The development and refining of bowties should include the workforce who then take ownership of the bowties. Bowties are a great basis for training and explaining the importance of safety critical equipment/activities
- **Communication with management:** Bowties provide a framework for process safety conversations with senior management whose main focus is an overview rather than detailed analysis of processes. They may also be used as part of the safety induction process for new managers.

Process Safety Auditing

Changes to the basis of process safety for an organisation will inevitably occur over time, (*Hamilton 2014*). The potential for these to lead to a major accident with catastrophic consequences is well documented. These weaknesses typically develop due to ageing of equipment leading to loss of integrity, interruptions in the continuity of operating expertise and inadequate management of change. The absence or infrequency of incidents and accidents and other lagging indicators is not an indication that process safety is being managed successfully.

Process safety auditing is one of the tools that can be used to identify weaknesses and gaps in process safety management systems and potentially latent failures in the basis of safety. It can also be a powerful tool to give assurance to stakeholders that risks are being managed effectively. Process safety auditing needs to be systematic and independent. Auditing should be performed against a particular set of standards or requirements. The output of an audit should include a plan to address deficiencies and a follow-up assurance review.

Using Bow Ties in Process Safety Auditing

ERM has developed a programme of process safety auditing with bowties at its core, and is currently applying this tool with significant benefits to clients in the oil and gas, mining and chemical industries. This approach has been modified and refined in collaboration with Unilever and applied to their manufacturing operations worldwide, as discussed in the next section "Application to Unilever Business".

The work prior to the audit visit commences with the development of pre-populated bowties for several credible top events based on basic process and procedural information supplied by the client in response to a detailed information request. During the audit preparation phase, these pre-populated bowties are used to begin to plan the audit activities and to consider potential threats and consequences. Early in the site phase these bowties are further refined and elaborated during a bowtie workshop involving relevant site stakeholders drawn from process technology, process engineering, operations, maintenance and safety, health & environment (SHE). The final bowties developed during this session, capture the relationships between a set of credible top events, threats and consequences, and the barriers claimed to be in place on that site, and serve as a blueprint to further guide the evidence gathering and interrogation phase of the audit, as described in *Table 2* below. Specifically these activities are tailored to confirm the presence and assess the robustness of the claimed barriers, and in this context it is noted that the approach works well with the assessment of both hard engineered barriers and softer human factors / procedural barriers.

Each of the claimed barriers also clearly relates to one of the normally recognised elements of process safety management. The scope of the audit is based broadly around the elements of the US OSHA Process Safety Management (PSM) Standard (29 CFR 1910.119) and companion EPA Risk Management Planning (RMP) Rule 40 CFR 68 namely:

- Employee Participation
- Process Safety Information
- Process Hazards Analysis
- Operating Procedures
- Training
- Contractors Pre-start up Safety Review
- Mechanical Integrity
- Hot Work Permits 29
- Confined Space Entry
- Process Line Breaking
- Management of Change
- Incident Investigation
- Emergency Planning and Response
- Hazard Assessment
- Compliance Audits
- Management

The approach can however easily be, and typically is, amended to consider the broadly comparable elements of other process safety management systems such as those of the Center for Chemical Process Safety (CCPS) Risk Based Process Safety scheme or of Safety Management Systems as required under Regulation 8 (a) of the Control of Major Accident Hazard (COMAH) Regulations 2015, as indicated in *Table 1*.

COMAH SMS Element	Where it appears in OSHA PSM Standard
Organisation & Personnel - includes: • Leadership • Roles and responsibilities • Training and Competence	Employee Participation
Identification and Evaluation of Major Hazards – includes: • Hazard identification • Assessment of likelihood and severity	Process Safety Information (PSI) Process Hazard Analysis (PHA)
Operational Control – includes • Procedures for safe operation under normal and abnormal conditions, start up and shutdown • Safe operating limits • Emergency shutdown • Maintenance • Permit to Work • Contractor Selection	Pre-start up Safety Review (PSSR) Operational Procedures Hot Work Permits Mechanical Integrity Contractor Management
Management of Change – includes: • Permanent changes – projects • Temporary modifications • Urgent operational changes	Management of Change
Planning for Emergencies – includes: • Identification of foreseeable emergencies • Emergency Planning • Training and Preparedness	Emergency Planning and Response
Monitoring Performance: • Key performance indicators • Incident Investigation • Inspection of Safety Critical Plant	Incident Investigation Mechanical Integrity
Audits	Audit
Review	

Table 1: Correlation between PSM elements under UK COMAH SMS and US OSHA PSM Standard .

Typically the audit normally takes place over one week (5 days) and comprises the activities described in ***Table 2.***

Day 1: Discussion of information from site and process plant visit
The first day on site allows the audit procedure to be described and a general exchange of information with site. The afternoon consists of a walk round of the process areas with appropriate staff to review location, layout of process plant, hazardous material storage, occupied buildings etc.
Day 2: Review of bowties with appropriate site participants
This is a classroom day when the pre-populated bowties are reviewed in detail and modified to reflect the actual equipment and practices on site. There are also discussions with staff on the strength of the barriers claimed.
Day 3 and 4: Review of actions from bowties and review of process safety elements including deep dive discussions as appropriate
These days comprise more traditional "audit activities" where each of the elements are examined through interview, discussion and document / records review and evaluated against applicable regulatory requirements, corporate standards and generally accepted good practice. A particular feature of this phase of the audit is the testing of the presence and strength of the barriers previously claimed in the bowties
Day 5: Presentation of findings and discussion with site.
The findings are presented in easy to read format comprising a closing presentation and a set of recommendations in a spreadsheet against the regulations reviewed.

Table 2: Schedule for Process Safety Auditing incorporating Bowties.

Advantages of the approach are that it has a defined format but is less restrictive and more of a journey with the site staff than a traditional audit against a specific checklist of criteria. An attraction for site itself of the week is the training aspect of the review; this is particularly true for the bowtie review day because the bowties allow an effective systematic overview of the hazardous processes, threats, consequences and barriers in an accessible format. The strength of the barriers themselves can be readily scrutinised during the workshop day, whilst a further benefit is that it helps the participants to understand the relevance of the questions during the audit and thereby increases the value of the audit such that it becomes much more than simply a 'compliance' exercise.

Application to Unilever Business

Unilever is one of the world's leading suppliers of Food, Home and Personal Care products with sales in over 190 countries and reaching 2 billion consumers a day. In the UK, Unilever has been named the most admired company in Britain 2015, according to the largest piece of peer review research of its kind in the UK. (*Management Today, 2015*)

Safety has long been a priority at Unilever, and the company has had much success in driving down its total recordable injury rates globally. However, prompted in part by recent high profile process safety incidents (e.g. Buncefield, UK and BP Macondo, Gulf of Mexico) concerns were raised at Board level about the potential exposure of the business to similar major accident hazard threats.

Although not a chemical company *per se* Unilever has recognised that its operations do include a number of processes where hazardous materials are handled, and if not properly managed, the potential for major accident hazard is present. These hazardous materials are present in detergent manufacturing processes, as aerosol propellants and in refrigeration systems, but are typically not highly visible in the branded products sold by the company.

Typical hazardous materials present on Unilever sites, which have the potential to give rise to major accident events comprise toxic and flammable substances including:

- Ammonia – used in refrigeration plant for ice cream and spreads manufacture and logistics
- Sulphur dioxide, sulphur trioxide and oleum – produced on sulphonation plants, where sulphur trioxide is further reacted with organic feedstocks to produce the anionic detergents linear alkyl benzene sulphonate (LAS) and sodium lauryl ether sulphate (SLES) in used in homecare and personal care products respectively
- LPG (Liquefied Petroleum Gas) – used as an aerosol propellant in personal care products; and.
- Combustible Dusts – e.g. tea drying, flour, milk powders.

Additionally other sites handle materials where process safety management failings and resulting loss of containment have the potential to give rise to serious on site injuries or fatalities or environmental damage.

In order to address these concerns, to provide assurance to the Board and to honour commitments made to stakeholders more generally under the Unilever Sustainable Living Plan (corporate sustainability action plan built around the pillars of improving health & wellbeing, enhancing livelihoods and reducing environmental impacts), Unilever has developed and is implementing a Process Safety Management programme globally. As part of this programme ERM has been working with Unilever over a period of three years to give assurance to the business that the process safety related hazards associated with its sites are being identified and managed effectively.

The programme is underpinned by a company process safety management standard which is based on the CCPS Risk Based Process Safety Guidance (*CCPS, 2007*) and comprises the twenty elements shown in *Figure 4*.

Figure 4: Twenty elements for effective process safety as adopted by Unilever

Unilever has categorised its sites into high, medium and low hazard sites, based on the quantities of hazardous materials being stored and other risk enhancing factors such as age of equipment, history of incidents or near misses and sensitive populations close to the site, and rolled out the PSM programme to all high and medium hazard sites globally. The internal hazard category is generally lower than Seveso and when possible aligned with best practice, e.g., 4.5 tonne threshold for an ammonia refrigeration installation is based on an OSHA PSM level (10000lbs) rather than Seveso threshold of 50 tonnes.

As part of the roll out process site Process Safety Competent persons have been designated and trained for all high and medium hazard sites, and in addition process safety leadership training has been provided to all site directors with responsibility for such sites.

Auditing is a fundamental part of the programme, and the approach described previously has been adopted, although as its function is expanded beyond auditing to include hazard identification, awareness raising and competence building elements; the term PSM Technical Visit is used.

The site technical visit last for five days and follow the format shown in *Figure 5* and discussed earlier in *Table 2*

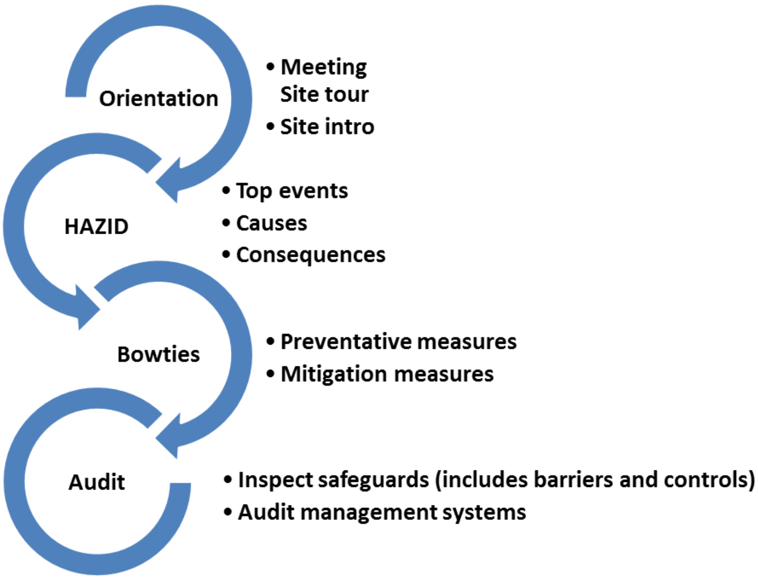

Figure 5: Format for Unilever Site Audits

The output from the Unilever site audits is a spreadsheet covering each of the twenty process safety elements and highlighting commendable practices and deficiencies where these exist. The deficiencies are categorised depending on their severity as shown in ***Figure 6.***

LEVEL I (RED): HIGHEST PRIORITY ACTION REQUIRED: Situations that could result in substantial risk to Unilever in Safety and/or The Environment, the public, employees, stockholders, customers, the Company or its reputation, or in criminal or civil liability for knowing violations.
LEVEL II (ORANGE): PRIORITY ACTION REQUIRED: Does not meet the criteria for Level I but is more than an isolated or occasional situation. Should not continue beyond the short term.
LEVEL III (YELLOW): ACTION REQUIRED: Findings may be administrative in nature or involve an isolated or occasional situation.

Figure 6: Categorisation of findings arising from Unilever site audits

There are many positive aspects to the site visits for the sites themselves and these include:

- A new and timely focus on process safety in a FMCG manufacturing environment where product volume, manufacturing agility and brand are the main drivers;
- Reassurance and recognition of good practice in process safety management;
- Awareness of the drivers of effective process safety; and
- Renewed awareness of the major accident hazards on site and the key control measures

The benefits to Unilever of the programme include

- A single over-arching SHE standard for process safety at Unilever sites worldwide;
- Consistency of audit approach across sites and use of simple visual methods such as bowties and colour coded output;
- Development of in-house knowledge and process safety expertise at Unilever and on individual sites; and
- Assurance of effective management of Unilever’s process safety risks.

A programme is being developed to revisit sites in order to review their progress addressing the findings since the initial visit. These return visits will provide assurance to Unilever that findings have been appropriately addressed.

Conclusion

ERM has developed a methodology for process safety auditing based around bowties and this has been established by the authors as an excellent mechanism to help both the auditors and auditees define the scope of the audit and to focus on those aspects of the process design, operation and maintenance that are central to maintaining a good level of safety and ensuring the risk is ALARP.

The bowtie process provides a good visualisation and communication tool demonstrating to auditees potential vulnerabilities in their basis of safety, where the focus of their process safety efforts should lie, and to management that the audit process is crucial to maintaining a high level of process safety.

ERM has been working with Unilever worldwide using the bowtie process safety audit technique to provide assurance to the Unilever board that process safety risks are being managed effectively.

References

https://www.caa.co.uk/bowtie

Hamilton, W I. 2012. Human Error: in the loop. The Chemical Engineer, Issue 854 August 2012

Hamilton, W I., & Turner, C. 2014. Building a culture of effective process safety management. Society of Petroleum Engineers (SPE) Annual Caspian Technical Conference and Exhibition SPE-172323-MS

Kerckhoffs, M.C., Van Der Suijs, A.F. ,Dongelmans, D.A., 0871 - IMPROVING PATIENT SAFETY IN THE ICU USING THE BOW-TIE PROSPECTIVE RISK ANALYSIS MODEL, European Society Of Intensive Care Medicine, 2011.

Lees, Frank P, Loss Prevention in the Process Industries, 3rd Edition, 2005, ISBN: 0-7506-7555-1

Management Today 2015, http://www.managementtoday.co.uk/go/bmac/

Ramsden, M., Taylor, M., Steer, R., & Bennet, R. 2013. Ten golden rules for developing robust bowties. Society of Petroleum Engineers (SPE) European HSE Conference. SPE 164956-MS.