Bow Ties in Risk Management; using the new CCPS-EI book to avoid pitfalls

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CCPS and The Energy Institute have collaborated to produce a new concept book, 'Bow Ties in Risk Management'. The Bow Tie method today is often conducted too loosely with poor analysis, no generally accepted methodology and, only proprietary company or software guides being available. The purpose of the book is to provide the basis for the chemical and process industries to move towards consistency in the approach adopted and terminology used when developing and using bowties. The book also provides the link between bow ties and typical process safety management systems.

1. This paper and presentation will highlight pitfalls in the construction and use of bowties and the key recommendations, assumptions and as supported by the book including:
2. No common usage of terminology leading to confusion between those creating and those using bowties
    - Degradation factors: barriers may fail, or degrade for various reasons. Previously these factors were called escalation factors, due the escalation of the risk due to the barrier failing.
    - Degradation controls has been chosen for the element that prevents the degradation factor from impacting the barrier within the main pathway on the bowtie.
3. No rule set for barriers resulting in too many barriers giving operations and management a false sense of security
    - Barriers must be 'effective, independent and auditable' i.e. they must have the capacity to completely stop the threat from leading to the top event and must be independent of the threat and other barriers linked to a particular threat
    - Incomplete Barriers through users wanting to include barrier elements such as an Emergency Shut Down valve (ESDV) whereas the complete barrier includes the three elements of Detect, Decide and Act. In this case the ESDV would include for example a pressure sensor, a logic controller and also the ESDV.
4. Management system elements included as barriers.
    - There is a desire that everything is included on the bow tie such as training, competence, MOC, audit, inspection and maintenance programme, contractor management. These influence many or all of the barriers, but they are not barriers in themselves.
    - Some can be included as Degradation controls but would 'clutter' the bowtie if applied to every barrier. A Safety / Operational Management System is required in addition to bow ties.
    - Use of tank overfill example to show how degradation factors impacting critical barriers all sit within the process safety management system.
5. Complicated scoring systems
    - There is a temptation to assign scoring systems to barriers with eventually a 'pass or fail' criteria. Some companies used numerical scoring but moved away from this, others have successfully used a simple colour coding and this is proposed in the book.
6. 5 key questions to ask when your barriers are degraded in an operational system
7. Real time dashboard using bowties……the holy grail but take care
8. Other Frequent pitfalls of bowties
    - Not pre-defining the target audience in sufficient detail. Bow ties may be used in all phases of a project lifetime but have a different focus and audience if used in the design phase, operational phase for risk management or only for general awareness of barriers.
    - Bowties not used to manage the risk

- The bow tie is a means to an end….'risk management'. There is a danger to spending all your time on finessing the bow tie, the 'BowTieXP' or - 'THESIS', 'jockeys' who love to make ever more complex bow tie models.
    - Producing too many bow ties, too soon

Keywords: bow ties, risk management, process safety, threat, hazard, consequence, barrier, degradation factor, CCPS, EI

1 Introduction – Background to Bow ties and the CCPS/EI Book

CCPS and The Energy Institute (EI) have collaborated to produce a new concept book, 'Bow Ties in Risk Management'. The Bow Tie method today is often conducted too loosely with poor analysis, no generally accepted methodology and, only proprietary company or software guides being available. The purpose of the book is to provide the basis for the chemical and process industries to move towards consistency in the approach adopted and terminology used when developing and using bowties. The book also provides the link between bow ties and typical process safety management systems. Bowties are also used in other industries (e.g. aviation, mining, business risk) and the rules in the book may also be applied for these industries but the examples in the book focus on process industry applications.

Poor quality bow ties are unfortunately frequently produced. This paper highlights common pitfalls observed in these bowties and summarises the guidance in the construction and use of bowties and some key recommendations, assumptions which are described in detail in the book.

2 Terminology and elements of bow ties

There is no common usage of terminology leading to confusion between those creating and those using bowties. The proposed terminology was presented in Hazards 27 and a detailed definition of each of the bow tie elements is given in that paper, (Manton, 2017a). This paper should be read in conjunction with that paper, 'HAZ27_033 Standardisation of Bow Tie Methodology and Terminology via a CCPS/EI Book'. Following peer review of the book is was decided to use the term Degradation Control for those elements that can mitigate a Degradation factor. When reading the paper HAZ27_033, the term 'Safeguard' should be replaced with 'Degradation control'. Most of the terms below will be familiar to bow tie users with the exception of 'Degradation factor' for elements that cause a barrier to fail, or degrade. Previously these factors were called escalation factors, due the escalation of the risk due to the barrier failing, but 'Degradation factor' was felt to be a better term.

The bow tie diagram is shown in Figure 1 with the following elements:

1. **Hazard**, the bowtie starts with the hazard
2. **Top Event** being the loss of control of the hazard
3. **Consequences** of loss of control of the hazard are depicted on the left side (customarily the mitigation side) of the bow tie diagram.
4. **Threats** are depicted on the left side (customarily the prevention side) of the bow tie diagram.
5. **Prevention Barriers** on the left side of the diagram represent prevention barriers, which stop threats from resulting in the top event.
6. **Mitigation Barriers** shown to the right of the top event represent mitigation barriers, which mitigate the top event (i.e. reduce the scale of and possibly stop undesired consequences).
7. **Degradation factors** can be applied to both prevention and mitigation barriers, which are the holes in the cheese slices that represent barrier deficiencies (i.e., reductions in effectiveness or reliability).
8. **Degradation controls** act to mitigate the Degradation factors, helping maintain the main pathway barrier at its intended function. Degradation controls can, but do not necessarily satisfy the criteria of effective, independent, and auditable.

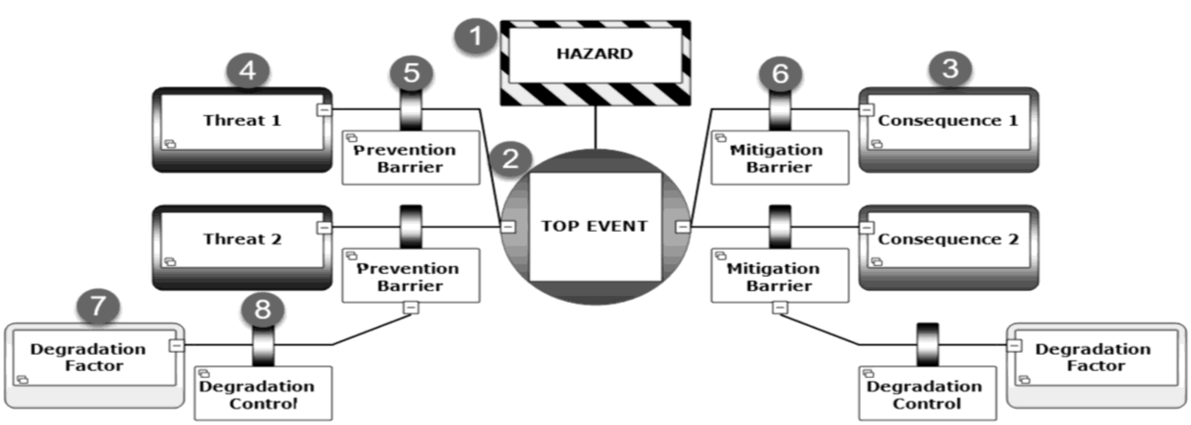

Figure 1: Standard terms for bow ties

3 Rule set for barriers

Bow ties have been produced with 20 or 30 (supposed) barriers. The example given in Figure 2 from a drilling contractor to model well control included 20 prevention and 32 mitigation barriers. The bow tie has included everything connected with the top event but this does not help the understanding of barriers or risk management. Most critically having a supposed large number of barriers can give management and operations personnel a false sense of security believing that an incident cannot occur because so many barriers exist. Purposefully, Figure 2 does not enable readers to read the 'barriers'.

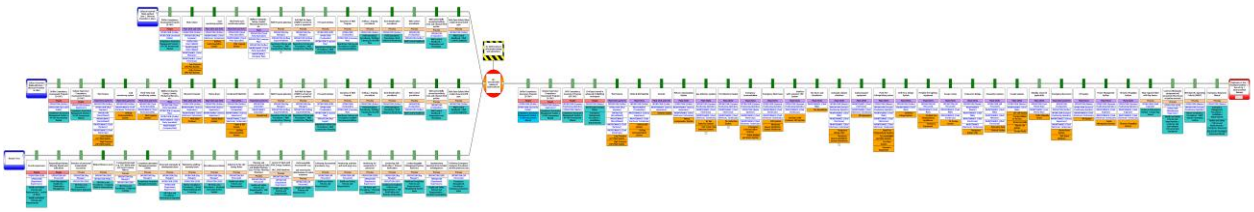

Figure 2: Poor bow tie example created with no rule set for barriers

The application of the rule that barriers must be 'effective, independent and auditable' will typically lead result in the number of barriers on the bow tie between one to five barriers on each threat pathway. Consequence pathways often have more barriers than prevention pathways. The barrier is the complete system, for prevention barriers blocking the threat from progressing to the top event.

Figure 3 shows the most common threat leg from a 'loss of primary containment' bowtie for a process system. Only 4 barriers are shown, if careful rules are followed to demonstrate independence of the process control system from the alarm, such as independent instrumentation loops, then these can be considered two separate barriers, giving a total of 5 barriers.

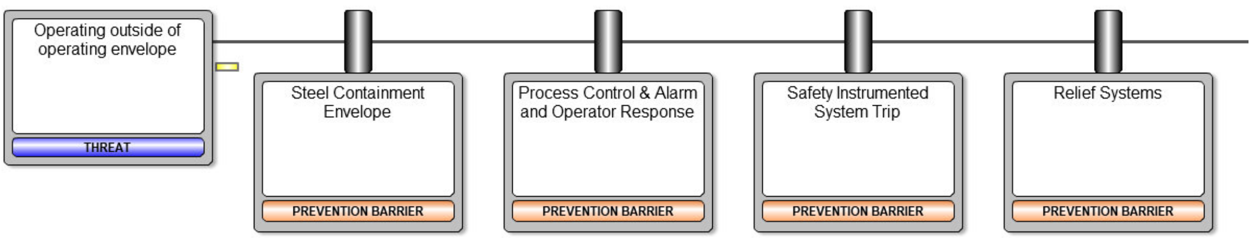

Figure 3: Overpressure threat leg containing only 4 barriers

Frequently a single equipment item is listed as a barrier for example; a fire pump or an Emergency Shutdown valve (ESD). These individual equipment items on their own cannot stop a top event leading to a consequence. Using the rule that Active barriers must have separate elements of 'detect-decide-act', avoids this problem. Figure 4 provides two examples of the detect, decide, act components within a barrier; 'detect' a change in condition or what is going wrong, 'decide' what action is required to rectify the change and 'act' to stop the threat from progressing further. These three terms are sometimes called 'sensor', 'logic solver', and 'actuator' by some bow tie users, relating the terms to common elements of an instrumented control loop.

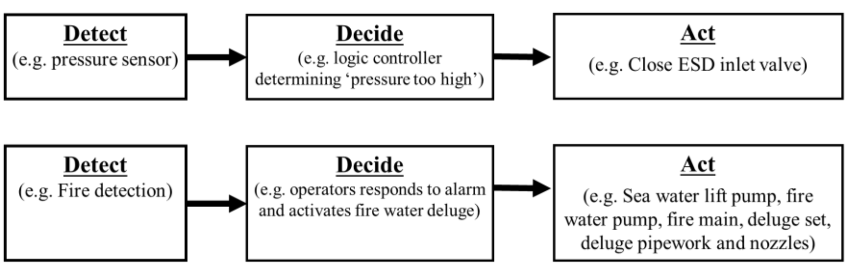

Figure 4: Detect-decide-act model for Active barriers

4 Management system elements not barriers but degradation factors.

4.1 Not pre-defining the target audience in sufficient detail.

There is a desire that everything is included on the bow tie such as training, competence, MOC, audit, inspection and maintenance programme, contractor management. These influence many or all of the barriers, but they are not barriers in themselves. The application of the barrier rule set differentiates a well-constructed bow tie from a Swiss cheese model. Figure 5 gives an example of a Swiss cheese model from the Texas City explosion showing 17 management system and hardware issues but these are not all barriers that failed.

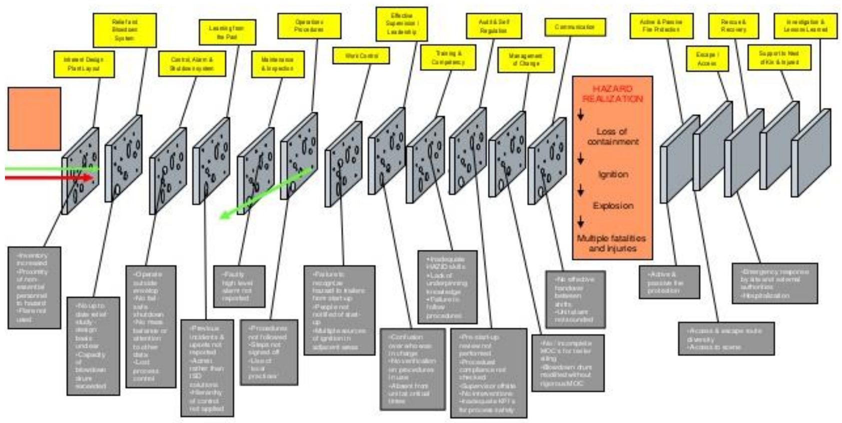

Figure 5: Swiss cheese model including management system elements

Management systems elements can be included as Degradation controls but would 'clutter' the bowtie if applied to every barrier. There are exceptions to this rule where specific management systems are particularly relevant. An example would be to include competence management as a degradation control of an operator controlling of an exothermic reaction as it affects a critical barrier (competence being the accurate implementation of training and experience). Competence on its own it cannot prevent the top event 'loss of control of reactor' and so is not a barrier but a control to ensure the barrier works as intended.

Since competence management applies to most human actions this should be covered under the management system, similarly for MOC, audit, inspection and maintenance programmes etc. The management system and assurance and auditing of this system works in parallel with a bow tie, where the bowtie is primarily focussed upon the hardware. Figure 6 shows how the management system and bowtie interact.

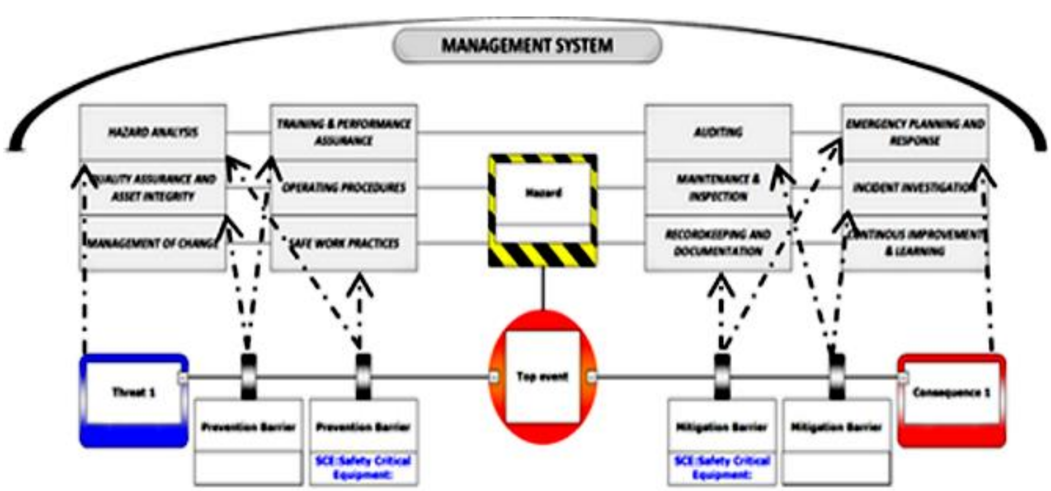

Figure 6: Bow tie connections to management system elements

4.2 Degradation factors upon degradation factors, Multi-level bowties.

Degradation controls including management system elements such as competence management can be explored using bowties. The book proposes using multi-level bow ties to link this or alternatively separate standalone bowties be generated. When this is done it should be noted that this will show 'competence' as a degradation control in the 'main barrier' position with degradation factors to the degradation factor then shown.

Multi-level and incorporation of human factors is a more advanced use of bowties that is covered in chapter 4 of the book. It is also covered by the IChemE Hazards 27 conference paper 'HAZ27_034 Representing Human Factors in Bow Ties as per the new CCPS/EI Book' (Manton, 2017b) and the Chartered Institute of Ergonomics and Human Factors' (CIEHF) "Human Factors in Barrier Management" White Paper (CIEHF, 2016). There was overlap in membership of the CCPS/EI and CIEHF committees so both arrived at comparable outcomes.

4.3 Tank overfill example of degradation factors as part of the management system.

The following example of tank overfill shows the use of degradation factors linked to management system elements. One of the key barriers is the high-high level alarm and automatic trips to shut off the flow. The degradation factors that would prevent this barrier from functioning as desired are all managed by controls that sit within the process safety management system.

With the tank overfill example, one of the key barriers is the high-high level alarm and automatic trips to shut off the flow. The degradation factors that would prevent this barrier from functioning as desired are all managed by controls that sit within the process safety management system. The barrier could fail if:

1. The need for the trip function had not been identified – a fully functioning Hazard Identification and Risk Assessment program would prevent this
2. The trip functions are not inspected or checked under a preventative maintenance plan – part of Management of Safety Critical Devices or Inspection and Maintenance
3. The maintenance activity led to the trip being incorrectly returned to service – avoided via an employee competency management system together with complete Operating Procedures (covering the method for checking the trip)
4. Incidents leading to loss of containment from errors with removing the equipment are voided using a functioning permit to Work system.
5. Suitable KPIs and management overview via the Audit, Assurance and Management Review elements of the management system.

5 Why we do not score barriers

The first issue is to differentiate between the condition of a barrier and its inherent strength, as these differ. Inherent strength is the effectiveness of the barrier in its 'as designed' condition or condition when the barrier fully meets its acceptance criteria. Inherent strength can be thought of as the number of holes in a slice of Swiss cheese, whereas condition would be the size of these holes which are expanding over time as the barrier degrades. Condition is the state of the barrier at a specific time.

5.1 Assessing the condition of barriers and displaying this on a bow tie

There is no agreed way to display condition – this can be as colour codes or as text beneath the barrier or even as special symbols. If software is used to model the bowties multiple, user configured options are available to represent the condition of the barrier. With that caveat, one system used successfully by a major oil and gas company is shown in Table 1.

The color-coding can be applied as shown in the table above, and different software tools display these in different manners (e.g. as a note under the barrier symbol or by colouring the barrier bar). Some other companies use the sequence of symbols +, 0, -, placed beside the barrier to indicate barrier condition, but the same symbols are also used for barrier effectiveness (inherent) strength, which is a different characteristic that addresses effectiveness.

Table 1: Suggested format to display barrier condition

Condition (simple)	Condition (detailed)	Color code
Effective	In place, available and effective	Green
Partially effective	In place and available, but operating below its intended functionality	Yellow
Not effective	Not in place, not available	Red
No data	No operational information is currently available	White
Deactivated. Optional expansion of category 'Not Effective'	Not in place, turned-off, deactivated #.	Black

Can also be used to differentiate a local system not having this barrier from corporate standards.

5.2 Complicated scoring systems

There is a temptation to assign scoring systems to barriers with eventually a 'pass or fail' criteria. Some companies used numerical scoring but moved away from this. The scoring system can become highly complex with decisions as to which elements to include, for example for active barriers are all the 'detect, decide act' components included and then what weighting is applied. Similarly, what reduction factor is applied when a barrier component is degraded. Considerable time and resources can be required to develop the system and then to score the barriers with potential 'gaming' of the system. The focus of the barrier review should be to answer the five key questions from the next section in this paper and not just to develop a 'barrier score'. Companies have successfully used a simple colour coding and this approach is proposed in the book.

6 Five key questions to ask when your barriers are degraded in an operational system

The aim of ongoing bow tie-based risk review meetings should not be to 'rubber stamp' the continued operation, but rather to be truly inquisitive, to challenge each barrier with a view to discovering the 'holes in the cheese' before devising improvements. A multi discipline team of operations, maintenance and engineers should support the risk review meeting and have engagement and support from management.

The key questions for a bow tie risk review meeting of an operational plant are given in Table 2

Within a single risk review meeting there is typically insufficient time to fully explore in depth, the current condition of all barriers and associated degradations controls. All risk review meetings should cover known, significant barrier or degradation control condition concerns with the in-depth review of specific barriers and associated degradation controls conducted on a rotation basis e.g. after 12 months of meetings all the barriers have been explored in depth.

. Asking these five questions is a powerful use of the bow tie to guide action in managing the risk. Just assessment of the risk and updating the bow tie is not risk management, only though taking action (e.g., stopping the operation, repairing barriers, adding temporary additional barriers) will the risk be reduced.

Table 2: Critical questions when using bow ties for risk management

1	Considering the threats - are there any changes in the context or demand under which the barriers operate (e.g. new threats, changes in the throughput or the environment)?
2	What is the current barrier condition?
	• Are all the existing barriers functioning as intended? What is the status of the barrier against the design intent or performance standard?
	• Are any barriers unavailable or deactivated on a temporary or long-term basis?

3	Is it safe to continue operations or should the operation be shut down?
4	Are immediate measures required to strengthen barriers or should temporary additional barriers be added to allow continued operation?
5	How are the longer-term actions being prioritized in order to restore barrier condition back to the design intent, or to meet the performance standard? By exception, additional barriers might be proposed.

Within a single risk review meeting there is typically insufficient time to fully explore in depth, the current condition of all barriers and associated degradations controls. All risk review meetings should cover known, significant barrier or degradation control condition concerns with the in-depth review of specific barriers and associated degradation controls conducted on a rotation basis e.g. after 12 months of meetings all the barriers have been explored in depth.

Risk review meetings using bowties can be very powerful in the following ways

- Providing a cumulative picture of risk management through the visualization of the number and types of barriers and degradation controls and their condition (e.g. highlighting in a visual way that multiple barriers on a single threat leg of the bowtie are not functioning as intended).
- Assist in decision making for operations and activities when barriers are known to be degraded, or their status is unknown due to overdue maintenance or inspection backlog;

Further uses of bowties include:

- Bow ties show how individual barriers or degradation controls can address multiple Major Accident Events (MAE), and help with change management to ensure that a change focused on one MAE does not adversely affect other MAEs; and
- Enhance incident investigations, and improve sharing of lessons learned, by tracking all barrier failures – as virtually all incidents involve some barrier failures.

7 Real time dashboard using bowties……the holy grail but take care

Dashboards are a means to display the status of safety barriers an indicator of overall facility safety. The status of the barriers is typically presented in terms of dials or traffic light colours of green, yellow or red (functioning, degraded or failed / missing) but can be user customized. Other systems can be connected to automatically update the status of the barrier on the dashboard. While this is referred to as ‘real time’, the dashboard only shows the status from the time of the last update.

Dashboards require a considerable effort to set up and maintain, it is important to be clear on the purpose, target audience, and whether they supplement or replace parts of the existing barrier management program. Several companies are presently working on tools to monitor the health and status of safety barriers and have developed their own version of dashboards. Scottish Power (Gray & Fenelon, 2013) has published a well-known example that uses a bow tie based dashboard system.

Benefits of bow tie-based dashboards include:

- An ‘at a glance’ assessment of leading and lagging indicators for facility condition;
- Assurance that barriers are being maintained and monitored;
- Prompts for actions to restore degraded / failed barriers;
- Supports immediate decision making using ‘at-the-moment’ information (e.g. barrier condition as an input to maintenance prioritization)
- Decision support at all levels in an organization from frontline all the way up to senior executives; and
- Wide sharing of information to prevent repeat incidents.

Although ‘real time’ bow tie dashboards bring benefits there are also are difficulties:

- Many barriers do not lend themselves to online monitoring
    - e.g. wall thickness measurement to assess corrosion or flow measurement from a fire pump;

- The health indication of the barrier is only as good as the level of detail that supports the 'online' assessment;
    - Barriers that conform to effective and independent rules with inherent 'detect, decide act' components are comprised of many elements. Therefore, it may be difficult to determine which of these should be included or weighted in the barrier health score
- Some barrier status indicators can be outdated and do not truly capture current conditions
    - a false impression may be given that a barrier shown as healthy is currently healthy because the system is 'online' whereas in fact it shows the status from the last time data was entered in the system being months or years previously
- The online system can remove or reduce the human input and analysis of barrier condition
    - The parameters providing input to the on-line score and weighting of these can be hidden or unknown to those viewing the dashboard
    - If colour coding is used it is not visible to the user if a barrier is just on the boundary of being for example 'red', significantly degraded
- The dashboard may not normally differentiate which degraded barriers are critical, and therefore which should receive priority.

Methods for dashboards are still under development. Given the diversity of industries, safety management systems, and decision-making needs, no single approach is likely to emerge as industry consensus.

8 Other frequent pitfalls of bowties

Bowties are used extensively in some industries and gaining popularity is many areas. The new CCPS/EI book, 'Bow Ties in Risk Management' provides a strong structure for how to create and use bowties more effectively. Further pitfalls in the creation and use of bowties include not pre-defining the target audience in sufficient detail and bowties being created but then not used to manage the risk.

8.1 Not pre-defining the target audience in sufficient detail.

Bow ties may be used in all phases of a project lifetime but if the goal and intent of producing the bow tie are not made clear, limited value will be gained from the bow tie. Examples are given below of different applications of bowties illustrating the different needs and outcome of how the bowtie will look.

Design Phase: During the design process if the bow tie is used to help design and assesses the sufficiency of barriers it will typically be far more complex and detailed. The audience for bow ties is then the design team but will need to link closely with other Process Hazard Analysis (PHA) methods employed such as HAZOP and LOPA.

Bow ties in Safety Case: Bow ties have been used to support the development and submission of Safety Case. The audience is then the regulator to gain approval but from a practical perspective it is also essential to define the users of the Safety Case once in the operational phase and what they need and how they will use the bowties.

Bow tie use in the operations phase: During operations phase the target audience are typically operators and maintenance technicians where the drive is to generate participation in the process of risk management. The bowtie can be used at the highest level to assist awareness of how their work interfaces with risk e.g. a maintenance person understanding that inspection of Ex classified equipment is part of the ignition control barrier. At a more detailed level bow ties can be used at regular risk review meetings to help guide the conversation as to identification of new threats then degradation upon barriers and degradation controls . The bow tie can then form an extremely important task of linking input from the front line, to engineers and managers who make decisions such as continue or cease operations and allocation of resources to repair / reinstate the strength of barriers and degradation controls.

8.2 Bowties not used to manage the risk

The bow tie is a means to an end….'risk management'. There is a danger to spending considerable amounts of time on finessing the bow tie, the 'BowTieXP' or - 'THESIS', 'jockeys' who love to make ever more complex bow tie models. Similarly, subject matter experts can forever finesse 'their' bowtie. The benefit of the bow ties will be lost if the bow tie keeps changing and remains with the subject matter expert. The cautions are similar about use of scoring systems and the amount of time that can be taken to develop and then assign scores.

8.3 Producing too many bow ties, too soon

If the organization has no experience of bow ties, then piloting perhaps two to three (2-3) bow ties will likely might prove more efficient as there is normally much iteration in both the design of the bow ties and how they are used in the organization. More bow ties can be generated after experience is gained in their creation, but even more importantly, incorporating lessons from their regular use as part of the risk management system.

Some early experience suggested that around 10 bow ties might be sufficient for a major refinery or chemical plant activity. However, twenty to thirty (20-30) bow ties are likely required to address a wide range of processing, storage, and transportation issues or to provide differentiation of barriers for particular processing units. Experience shows that too many bow ties cause confusion to staff and detract from the objective of effective communication of risks and barrier management.

9 Summary

Bowties can be very powerful tools to support risk management but there are many pitfalls and problems. The CCPS-EI book Bow ties in risk management is the assembled knowledge of many of the world's leading developers and users of bowties with support from both operating companies, consultancies and developers of bow tie software. The book received extensive peer review providing improvements to the book but also *de facto* endorsement with the direction and proposed philosophies and approaches contained within the book.

It is hoped that the proposed terminology will become widespread and the first choice when bow ties are produced and used. This will enable a common language and understanding to develop.

The rule set for barriers being 'effective, independent and auditable' gives typically between one to three, and an absolute maximum of five, barriers on the mitigation side. Most critically this avoids management and operations personnel gaining a false sense of security believing that an incident cannot occur because many barriers exist.

The color-coding to score barriers has been successfully used and allows the conversation from risk review meetings supported by bow ties to quickly move onto 'what to do about the degraded barriers and new threats'. Complicated barrier scoring systems are discouraged.

Real time dashboards are the holy grail for risk managing using bowties but take considerable resources to develop and maintain. The results and output from real time dashboards needs considerable care in its interpretation and great care should be applied prior to commissioning real time dashboards to understand and address the concerns highlighted in this paper.

The objective is not to produce some target number of bow ties and then to file them. It is to use them to help manage the barriers identified in an ongoing and effective manner.

The purpose of developing bowties is to support risk management. The bowtie and assessment of new threats and barrier condition does not manage or reduce the risk, it only highlights deficiencies and areas where the risk can be managed and reduced. In the operational phase, risk reviews using bowties give focus to the five questions in section 6 support the management of the risks associated with operating the facility. It is only when the barrier condition has been increased, a temporary additional barrier installed or, by exception, a new barrier installed and functioning that the risk is reduced.

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Manton, M., Johnson, M., Pitlado, R., et al, 2017b, HAZ27_034 Representing Human Factors in Bow Ties as per the new CCPS/EI Book IChemE Hazards 27 conference paper.

Publishers of the new CCPS-EI book, *Bow Ties in Risk Management*

CCPS and The Energy Institute have collaborated to produce a new concept book, 'Bow Ties in Risk Management'. The book is sponsored by these organisations with authors from DNV GL and CGE Risk Management Solutions. The production has been supported by Bow Ties in Risk Management Subcommittee some of who are the authors of this paper.

It is planned to publish the book in 2Q 2018 and will be available via Wiley publishers,

The Chemical Center for Process Safety (CCPS) issues books that have become the de facto best practise for process safety management globally. For example, the CCPS issued the original LOPA book in 2001 and has just published the 2nd edition of Siting and Layout of Facilities.

The Energy Institute (EI) is the professional body for the energy industry, developing and sharing knowledge, skills and good practice towards a safe, secure and sustainable energy system. The EI has published many guidance documents on Process Safety, including the Energy Institute Process Safety Framework, and Human and Organizational Factors.