Presentation by Mark Boult and Paul McCulloch
Hi

- Paul McCulloch
- CGE

- Mark Boult
- DNV GL
What we will cover today

- Summarise the book’s key messages – Mark Boult
  - Why it was decided to write a book, and what it covers
  - Terminology
  - Recommended process for constructing a bow tie
  - Rules for barriers
  - Barriers vs degradation controls
  - Human errors in bow ties
  - Effectiveness vs condition
  - Uses of bow ties

- Implementing the key messages of the book in BowTieXP – Paul McCulloch
Why it was decided to write a book, and what it covers
Why a “Bow Tie” book?

- Confusion about who (and what) bow ties are for
- No generally accepted methodology and terminology
- Some typical problems with existing bow ties:
  - Structural errors: e.g. degradation controls shown as barriers
  - Lack of rigour in constructing bow tie elements:
    - Hazard or Top Event description vague, or confused with Consequence
    - Incomplete barriers: barrier elements listed as ‘the barrier’
    - Management System elements included as ‘barriers’
  - ‘Human and Organisational Factors’ confused and ineffective
  - Unfair criticism that bow ties over-simplify incident causation

“Well constructed bow ties, which are clear and enable easy communication, can give the impression that they are easy to create. This is not the case. Too often bow ties are created with structural or other errors which can significantly degrade their value.”
CCPS / Energy Institute Concept Book

- CCPS decided to develop a Concept Book to capture best practice and define a methodology for bow ties.
- Energy Institute joined the project with a special emphasis on human factors

“Bow Ties in Risk Management: A Concept Book for Process Safety”
- Proposes standardized bow tie terminology and definitions
- Explains how to:
  - Construct bow ties of high practical value, avoiding common pitfalls
  - Treat human and organizational factors in a sound and practical manner
  - Apply bow tie can be used to create high value organizational learning from incidents and audits
  - Practical application and value of bow ties in plant management and active risk management, from the control room to the board room
- Based on current best barrier management knowledge and approaches
- Draws on a wealth of industry experience from well-known experts

180 Pages. Planned publication October 2018
Terminology and recommended process for constructing a bow tie
Stepping through bow tie construction process (with terminology)

Hazard

Top Event

Threat

Barrier

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Barrier
DEGRADATION FACTORS: a situation, condition, defect or error that compromises the functionality of a barrier.

DEGRADATION CONTROL: A risk management measure in place to prevent the failure of an identified barrier; not a barrier in its own right.

Stepping through the risk assessment process:

- Threat
- Barrier
- Top Event
- Consequence
- Degradation factor
- Degradation Control
Examples and useful rules for quality in bow ties

- **Hazard** is an operational, activity or materials with the potential to cause harm
  - “What you are trying to control”
- Hazards should
  - Be specific
  - For the hazard in its controlled state
  - Can also include:
    - Situational context
    - Indication of scale
- Not always possible to define all in the box

![Diagram](Too general)

![Diagram](Better)
Examples and useful rules for quality in bow ties

- **Top event** is the moment when control over the hazard is lost releasing harmful potential.

- Top event
  - Describe how / what control is lost
  - Can give an indication of scale (e.g. leak vs rupture)

- Do not define as:
  - A threat (corrosion of the tank)
  - A consequence (e.g. tank overflow and major dike fire)

- A barrier failure is not a top event
Examples and useful rules for quality in bow ties

- **Consequences** direct outcome of an accident sequence that results in harm ...
- Recommend defining before “threats” – this can help ensure that threats defined are those that lead to the significant consequences
- Should be defined as:
  - “Damage” due to “Event”, e.g. environmental damage due to liquid spill
  - Do not be too specific in defining the consequences (e.g. differentiating injury outcomes from fatality outcomes) as the barriers are likely to be the same and the number of branches is increased

![Diagram showing examples of consequences](image)
Examples and useful rules for quality in bow ties

- **Threats** initiating event that can potentially release a hazard and produce the top event
- Should be sufficient to lead to the top event by itself – be a *specific direct* cause
- Should be credible
- Should NOT be a barrier failure

<table>
<thead>
<tr>
<th>Threats</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level gauge out of maintenance cycle</td>
<td>✓ Level gauge out of preventive maintenance cycle</td>
</tr>
<tr>
<td>Excessive flow into tank</td>
<td>❌ Excessive flow into tank</td>
</tr>
<tr>
<td>Loss of containment</td>
<td>Good</td>
</tr>
</tbody>
</table>
Rules for barriers

No rules can lead to image of many barriers and perception of great risk control:

Rules help present more realistic image:
Barrier types

Passive

Active

Human
Barrier types - Examples

Passive
- Passive Hardware

Active
- Active Hardware
- Active Hardware + Human

Human
- Active Human
- Continuous Hardware

Fire Wall
Safety instrumented system
Operator activated EDS
Visual fire detection and evacuation
Cathodic protection system
Active barrier elements deliver: detect, decide and act

- Passive
  - Passive Hardware

- Active
  - Active Hardware
  - Active Hardware + Human
  - Active Human
  - Continuous Hardware

- Detect
- Decide
- Act
Barrier properties

**Effective**
- Prevention barrier is effective if it is capable on its own of preventing a threat developing into the top event
- Mitigation barrier is effective if it is capable of completely mitigating the consequences or reducing its severity

**Independent**
- A barrier is independent if it is has no common failure modes with other barriers

**Auditable**
- A barrier is auditable if there is a means to check that it works / delivers its functionality on demand
- Barriers can have performance standards for their functionality
Barriers vs degradation controls
Degradation Controls (vs barriers)

- Degradation Controls are on degradation pathway (NOT on the main pathway)
- Degradation Control types as for barriers
- Degradation Controls may not meet the full requirements of barrier validity
Where human errors fit in a bow tie
Do not use the words “human error” in your bow ties

- Human error is not a threat leading to a top event, but rather something that could defeat a barrier that is protecting against that top event.
- Whenever someone is inclined to put ‘human error’ as a threat, they should challenge themselves by asking:
  - “What is the barrier (or degradation control) that this error would defeat”? 
Do not use the words “human error” in your bow ties

- A non-specific degradation factor leads to a non-specific degradation control

- Unlikely the human error is the same for failure of 2 different barriers

- Ask: “What is the actual error and why did it occur”?
Model for including human error in a bow tie

- Threat / cause
- New Hazard
- Event
- Degradation factor (cause of a failure in the human task(s) - failure to control the work)
- 1st level degradation control (control of work)
- Barrier (requiring human task(s) to deliver its function)
- Degradation factor (no / failed system to control work)
- 2nd level degradation control (corporate management systems)
- Degradation factor (failure / deficiency in system or its implementation)
- 3rd level degradation control (leadership, initiatives to improve systems and their application, e.g. a safety culture programme to improve compliance)
Example using model for including human error in a bow tie

- Fill volume exceeds tank ullage
- Tank level alarm and operator response (to stop filling)
- Gasoline in atmospheric storage tank
- Tank overfill

- Rostering supervisor does not consult HR competence system before assigning operators
- Operator does not recognise, understand or know how to respond to the level alarm
- Rostering - Only personnel with the relevant experience and capability assigned as operators on the tank storage facility
- Rostering and competence management systems and processes
- Leading by example - Leaders always working in accordance with the corporate systems and processes
- Rostering supervisor does not recognise the importance of following systems and processes
Effectiveness vs condition
Effectiveness vs condition

- The guidance clearly explains the difference between effectiveness vs condition

Effectiveness
- The initial effectiveness of the barrier – “how well each barrier performs”
- Design intent / performance standards set required effectiveness:
  - Functionality
  - Reliability, availability and survivability
- Some barriers will be naturally more effective than others

Condition / state
- How well is the barrier performing vs its required performance (i.e. its design intent / performance standards)?
- Degradation affects the barrier condition

Barrier A
- Very effective PS
- Slightly degraded

Barrier B
- Moderately effective PS
- Working as intended

Barrier C
- Very effective PS
- Moderately degraded

Barrier D
- Effective PS
- Currently out of use
Communicating barrier effectiveness

- Possible colour coding for barrier “effectiveness” (design or current / at a moment in time)

<table>
<thead>
<tr>
<th>Effectiveness name</th>
<th>Effectiveness name (design or current – must define which)</th>
<th>Colour code</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Barrier to prevent event or prevent or mitigate the consequence &gt;99.9% (on demand / in operation)</td>
<td>Dark blue</td>
</tr>
<tr>
<td>B</td>
<td>Barrier to prevent event or prevent or mitigate the consequence &gt;99% on demand (on demand / in operation)</td>
<td>Blue</td>
</tr>
<tr>
<td>C</td>
<td>Barrier to prevent event or prevent or mitigate the consequence &gt;90% on demand</td>
<td>Light blue</td>
</tr>
<tr>
<td>D</td>
<td>Barrier to prevent event or prevent or mitigate the consequence &lt;90% on demand</td>
<td>Very light blue</td>
</tr>
<tr>
<td>Unknown</td>
<td>Unknown</td>
<td>White</td>
</tr>
</tbody>
</table>
Communicating barrier condition

- CCPS suggested colour coding for barrier “condition” (current / at a moment in time)

<table>
<thead>
<tr>
<th>Condition name</th>
<th>Condition description</th>
<th>Colour code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good / excellent</td>
<td>Condition assessed to be such that the barrier is performing at / above it’s design (PS) effectiveness</td>
<td>Green</td>
</tr>
<tr>
<td>Slightly degraded</td>
<td>Condition assessed to be such that the barrier is performing slightly below design (PS) effectiveness</td>
<td>Yellow</td>
</tr>
<tr>
<td>Moderately degraded</td>
<td>Condition assessed to be such that the barrier is performing well below design (PS) effectiveness</td>
<td>Red</td>
</tr>
<tr>
<td>Out of service (significantly degraded)</td>
<td>Condition assessment finds the barrier is not in place, turned-off, deactivated or fully degraded</td>
<td>Black</td>
</tr>
<tr>
<td>No data</td>
<td>Unknown</td>
<td>White</td>
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</tbody>
</table>

PS = Performance standard
Design PS (initial?) effectiveness

- Operating outside design envelope (pressure higher than design pressure)
- Steel containment envelope
  - P-HW Passive hardware
  - A-HW Active hardware + human
- Process controls and alarms and operator response
  - A-HW + A-HW Active hardware
- Safety instrumented system trip
  - A-HW Active hardware
- Pressure safety valve (PSV)
  - A-HW Active hardware

- External corrosion
  - Point
    - P-HW Passive hardware
    - C-HW Continuous hardware
  - Anodic protection
    - A-HW Active hardware
  - External inspection and maintenance of process equipment
    - A-Hu Active human

- Internal corrosion
  - Chemical injection system (corrosion suppression)
    - C-HW Continuous hardware
  - Anodic protection
    - C-HW Continuous hardware
  - Internal inspection and maintenance of process equipment
    - A-Hu Active human

- Breaking containment (e.g., for maintenance)
  - Isolation and removal of process fluids from isolated section prior to and during breaking containment
    - A-Hu Active human
  - Reinstate containment prior to re-introduction of process fluids
    - A-Hu Active human

- External impact
  - Control of vehicles (on site roads at low speeds), and lifting equipment (managed with permits)
    - A-Hu Active human
  - Barriers along site road sides
    - P-HW Passive hardware

- Loss of primary containment

- Hydrocarbon in process equipment
Initial (ideal / expected) state condition

Barrier condition is dynamic
Current understanding of condition

Barrier condition is dynamic
Current effectiveness (design PS effectiveness adjusted to reflect the current condition)
Uses of bow ties
Uses of bow ties

▪ Allow the communication of accident scenarios and the understanding of the importance of barriers and degradation controls

▪ Uses of bow ties discussed includes:
  – Linking bow ties to the risk management system (e.g. development and verification of design and as part of risk management in operations)
  – Communicating accident scenarios and all important barriers and degradation controls (including for different audiences)
  – Sharing barrier metadata
  – Accountability and engagement
  – Assessment of risk treatment
  – Identification of safety and environmental critical information
  – Supporting ALARP demonstration
  – Supporting organisational learning through corporate bow ties for major accidents
  – Supporting investigations
  – Real time dashboards
  – …
Applying the rules of the book in BowTieXP
Setting up BowtieXP

With BowtieXP Advanced

With BowtieXP Standard

- Download the CCPS template
Setup with BowtieXP Advance

- Only ‘element’ name to change is Escalation, which is renamed to Degradation to match the guidelines.
- Change columns:
  - Custom Description
  - Custom plural description
  - Custom abbreviation
Add the Barrier Types (in Std or Adv)

- CCPS guidance suggested the following five types
  - Passive Hardware
  - Active Hardware
  - Active Hardware + Human
  - Active Human
  - Continuous Hardware

- Short titles might also be used
  - Passive
  - Active (covering Active Hardware)
  - Human (covering Active Hardware + Human and Active Human)
  - Continuous Hardware (special category not frequently used)
Add the Effectiveness (in Std or Adv)

- CCPS guidance suggested the following types

<table>
<thead>
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<th>Effectiveness (design or current – must define which)</th>
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</thead>
<tbody>
<tr>
<td>A</td>
<td>Barrier to prevent event or prevent or mitigate the consequence &gt;99.9% (on demand / in operation)</td>
</tr>
<tr>
<td>B</td>
<td>Barrier to prevent event or prevent or mitigate the consequence &gt;99% on demand (on demand / in operation)</td>
</tr>
<tr>
<td>C</td>
<td>Barrier to prevent event or prevent or mitigate the consequence &gt;90% on demand</td>
</tr>
<tr>
<td>D</td>
<td>Barrier to prevent event or prevent or mitigate the consequence &lt;90% on demand</td>
</tr>
<tr>
<td>Unknown</td>
<td>Unknown</td>
</tr>
</tbody>
</table>

![Effectivenesses Tree Diagram]

- A Category A
- B Category B
- C Category C
- D Category D
- Unknown Category Unknown
Add the Condition (in Std (BRF Code) or Adv)

- CCPS guidance suggested the following five types

<table>
<thead>
<tr>
<th>Condition name</th>
<th>Condition description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good / excellent</td>
<td>Condition assessed to be such that the barrier is performing at / above its design (PS) effectiveness</td>
</tr>
<tr>
<td>Slightly degraded</td>
<td>Condition assessed to be such that the barrier is performing slightly below design (PS) effectiveness</td>
</tr>
<tr>
<td>Moderately degraded</td>
<td>Condition assessed to be such that the barrier is performing well below design (PS) effectiveness</td>
</tr>
<tr>
<td>Out of service (significantly degraded)</td>
<td>Condition assessment finds the barrier is not in place, turned-off, deactivated or fully degraded</td>
</tr>
<tr>
<td>No data</td>
<td>Unknown</td>
</tr>
</tbody>
</table>

![Diagram showing the condition hierarchy: GE Good / Excellent, SD Slightly degraded, MD Moderately degraded, OoS Out of service, ND No Data]
New book: Bow Ties in Risk Management

In collaboration with the Energy Institute

Project Team Chair: Kiran Krishna, Shell
Co-Chair: Mark Scanlon, Energy Institute
Vice-Chair: Tim McGrath, Genentech (ex Chevron)
CCPS Staff Consultant: Charles Cowley
Principal author: Robin Pitblado, DNV GL
Sub-contractor to DNV GL: CGE Risk
(Ben Keetlaer, Paul Haydock)

Project Team members: CCPS
Martin Johnson BP
Mark Manton ABS
Ron McLeod Independent Consultant
Darrin Miletello Lyondellbasell
Americo Neto Braskem
Sid Phakey Linde
Keith Serre Nexen
Ryan Supple ConocoPhillips
TV Venkateswaran Reliance Industries India
Stephanie Warde Husky Energy
Danny White BHP Billiton

Project Team members: Energy Institute
Dennis Evers Centrica
Peter Jeffries Phillips66
Rob Miles Hu-Tech
Rob Saunders Shell
Donald Smith ENI

Project Team members: EC JRC MAHB
Zsuzsanna Gyenes EC JRC MAHB
Maureen Wood EC JRC MAHB

Also in collaboration
European Commission Joint Research Centre
- Major Accident Hazards Bureau

Peer Review group
Some of the peer review participants, in addition to companies of the working group.

UKPIA Major Hazards Working Group
UK Health & Safety Executive (HSL)
API RP 75 revision
COMAH, Environment Agency England
Process Safety & Reliability Group
ExxonMobil
Patrick Hudson Independent Consultant
ex Professor, Delft University
John Sherban, Systematic Risk Mgt.
Introduction to the CCPS / Energy Institute Process Safety book:
“Bow Ties in Risk Management”
Presentation by Mark Boult and Paul McCulloch

Mark Boult, Director
mark.boult@dnvgl.com
+44 203 816 4273 or +44 777 165 2882

Paul McCulloch, Process Safety & Implementation Consultant
p.mcculloch@cgerisk.com
++44 749 515 2747

www.dnvgl.com
www.cgerisk.com

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