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Analysing and managing flammable atmosphere risks using bowties

The potential harm and asset damage from a flammable atmosphere explosion have been known for many centuries. A wide variety of materials that are explosive in dispersed forms exist in many industries, however knowing about an issue is not the same as properly understanding and adequately addressing the challenges.

A traditional tabular hazard analysis format is often applied to flammable atmosphere risk assessments which may have the following weaknesses:

1. Controls wrongly assigned to causes/threats/ignition sources
2. Controls missing from appropriate causes/threats/ignition sources
3. Failure to distinguish between prevention and mitigation/recovery measures
4. Failure to identify and evaluate connections between nodes/equipment where smouldering particles can ignite connected (up/downstream) atmospheres

Few (if any) duty-holders (Owner/Operators) allow their facilities to run knowing that they are unprotected, therefore incidents are likely (inevitable) when there is an assumption (misbelief) that the protection is present (fit for service) and performing (fit for purpose) when it is neither available nor reliable.

Risk assessments are predictive based on current knowledge and informed judgements, however even regularly conducted reviews can quickly become out of date as protection measures degrade often without fully appreciating their impact on risk.

Opportunity

A 'bowtie' is a diagram that visualises the risk you are dealing with in just one, easy to understand picture. The diagram is shaped like a bowtie, creating a clear differentiation between proactive and reactive risk management. The power of this type of diagram is that it gives you an overview of multiple plausible scenarios, in a single picture. In short, it provides a simple, visual explanation of a risk that would be much more difficult to explain otherwise.

Bowtie diagrams are now commonplace in understanding and managing process safety risks, particularly associated with major accidents. Historically they have been applied most frequently in the chemical, petrochemical and oil & gas industries but are equally applicable in all industries, e.g., transport, mining, energy, finance or healthcare and can be used to manage all risks (effect of uncertainty on objectives) including safety, environmental impact, asset damage or loss of reputation.

Bowties demonstrate how hazards are controlled and illustrate the links between controls (barriers) and the relevant components of the safety or risk management system. They are read from left to right as shown in Figure 1, where the Top Event (Loss of Control or Containment) can lead to one or more significant negative Effects (Consequences) due to one or more credible Causes (Threats).

Losing Control is prevented by one or more Controls (Barriers) between each Threat and the Top Event. The scale/severity and/or likelihood of potential effects are mitigated by one or more barriers between the Top Event and each Consequence.

Visualising barriers and providing them with context on the bowtie helps those not involved in the risk assessment fully appreciate the contributions, criticality and vulnerability of the measures. This can be particularly helpful in facilities or countries where English and/or Risk are not the primary language or familiar terminology.

Scenarios

The potential effects from the uncontrolled ignition of a flammable atmosphere include flames & hot gases, thermal radiation, pressure waves & flying debris and release of hazardous materials. All of these can cause serious harm to adjacent/exposed personnel, significant damage to plant, equipment or structures and can lead to secondary explosions.

Understanding how ignition can be prevented and how the effects can be mitigated should provide a more robust asset & safety management system.

Chaining bowties together, e.g. the consequence of ignition in one location is the secondary ignition in another location, provides a more holistic view of the issues associated with connected or adjacent equipment or environments.

Ignition sources & controls

Sources of ignition can be classified into several types (as shown in Clause 5 of BS EN 1127-1). Each has one or more risk reduction measures or controls (from Clause

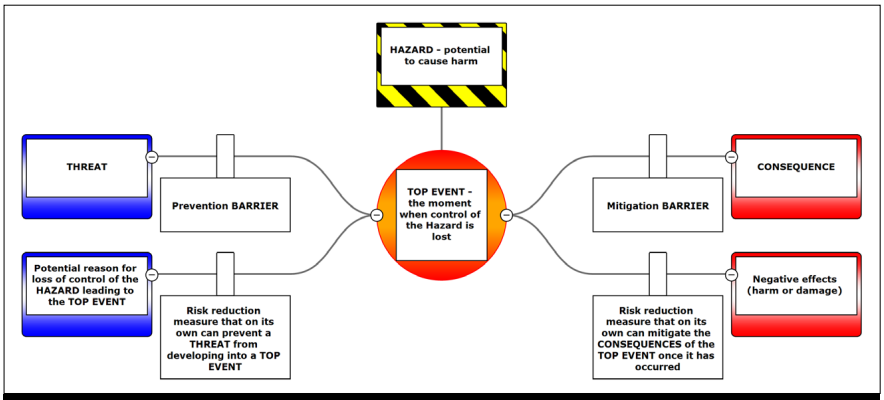

Figure 1

6 of BS EN 1127-1) which can be visualised in bowtie format as shown in Figure 2. This provides context & criticality e.g. where a specific threat has fewer (or no) barriers thus highlighting a potential vulnerability (depending on how likely or credible that threat may be).

Ignition potential & control effectiveness

Threats (ignition sources) can be coloured/coded according to their likelihood e.g. when they are expected to occur and prevention barriers (ignition controls) can be coloured/coded according to their effectiveness (ideally as current as practical to provide the most representative status of the protection portfolio). A bowtie which is predominantly red (for example) provides an immediate sense of vulnerability because either the Threats are likely and/or the Barriers are ineffective (see Figure 3).

Mitigation effectiveness & consequence risks

Consequences can be similarly coloured/coded according to their severity and fire/explosion mitigation measures (like ignition controls) can be coloured/coded according to their effectiveness.

Using the Threat (ignition source) likelihood, the Consequence severity and the prevention & mitigation barrier effectiveness, judgements can be made on the risks associated with each outcome. These risks can be evaluated qualitatively (using a matrix) or quantitatively (using LOPA: Layer of Protection Analysis).

Objective barrier effectiveness

The effectiveness of prevention and mitigation measures should be justified based on a number of factors:

- Capability of people
  - o The Mental (Competence & Workload) & Physical (Fitness &

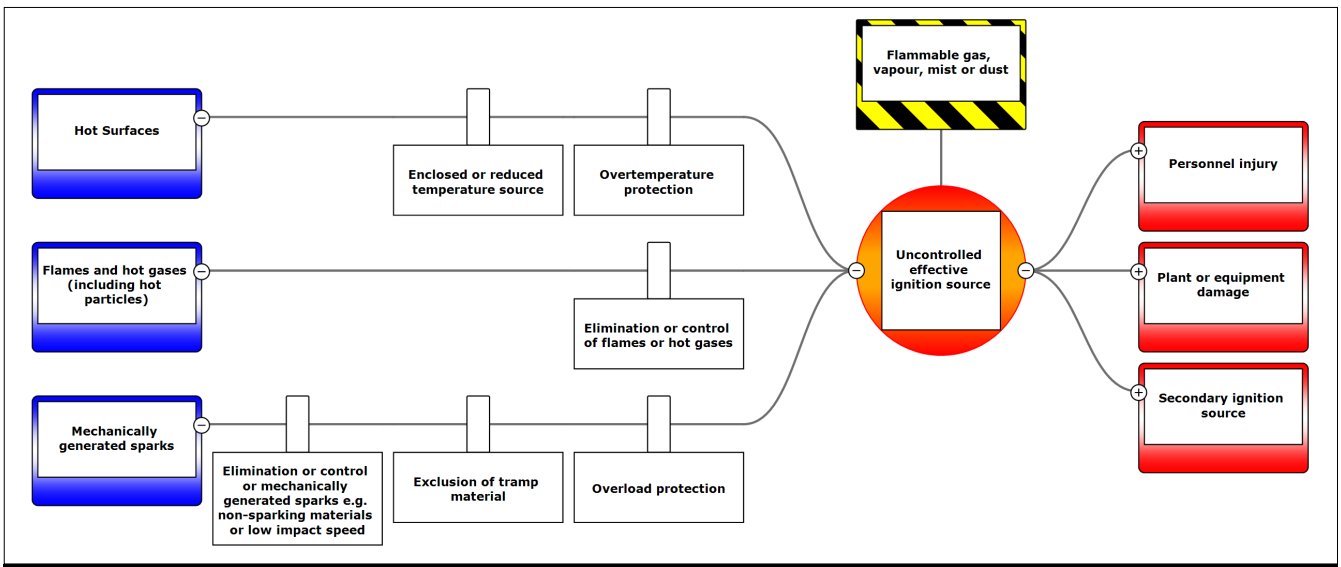

Figure 2

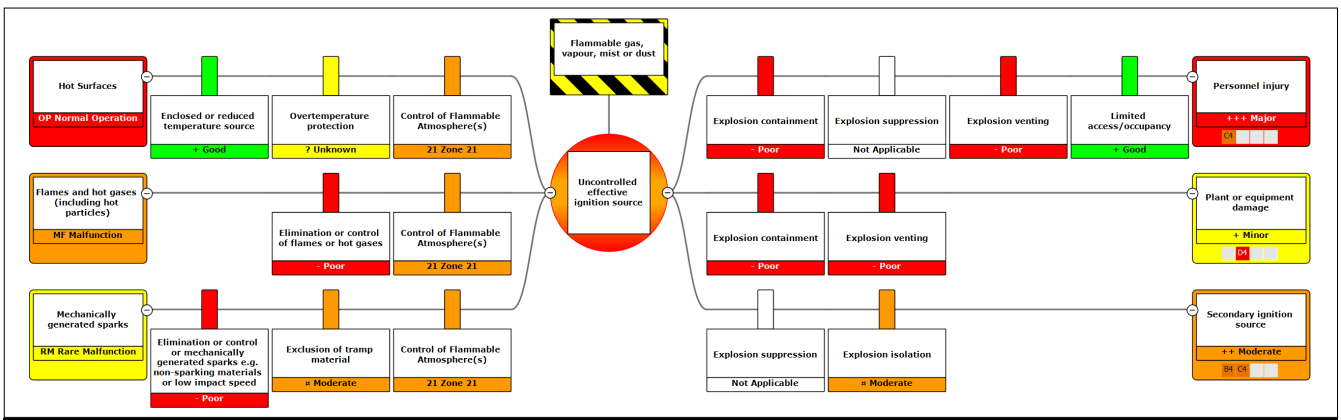

Figure 3

Health) capacity of those who are responsible for Sustaining (Operating or Maintaining) the barrier.
- Documentation of process
  - The Validity (Fit for Purpose) & Currency (Up to Date) of documentation (Drawings, Procedures, Standards etc) that support the Operation, Maintenance & Modification of the barrier.
- Maintenance of plant
  - Frequency (How Often) & Effectiveness (How Well) of barrier maintenance & testing including resolution of defects & failures.

Barrier classification

Classification of barriers, either by type or owner, allows dependencies or common mode vulnerabilities to be evaluated and addressed. A common mode failure occurs when a single event causes multiple barriers to fail (either within the same bowtie or across multiple bowties) and therefore barriers should be independent of the threat that they prevent and of other barriers on the same threat to top event or top event to consequence pathway.

Barrier management

In between routine/regular reviews, duty-holders can ask themselves if they are still "safe" by considering the following challenges:

- Estimation
  - Assumed frequencies, effectiveness values, potential for flammable atmospheres are too generic to represent site/process specific conditions.
- Degradation
  - Barriers (Human & Hardware) are operated outside capabilities or are not regularly or properly maintained/ tested (incl. ventilation) .
  - Occupancy or exposure higher than assumed.
- Modification
  - Barriers are permanently Deleted.
  - Barriers are temporarily Defeated.

Identification of barrier criticality and ownership makes Management of Change (MoC) more robust since the potential impact of defeating, degrading or deleting barriers within a single or across multiple scenarios (bowties) is more apparent.

Suitable bowtie software with a barrier database can be filtered/sorted to focus on the deployment of barriers. This allows proper addressing in all scenarios where an affected barrier or barriers is/ are implemented. Because barriers can be hardware, human or a combination of both, technical and organisational changes can be evaluated to ensure that the risk reduction is not unduly compromised.

Conclusions

The aim is not just to make existing assessments more engaging i.e. to involve all stakeholders, but also to provide a life-long dynamic framework where threats (competent ignition sources) and barriers (control measures) are monitored, evaluated and actions taken to ensure that protection is sustained and risk targets are maintained. Visualisation enables duty-holders not only to analyse their hazards but also to communicate the analyses to front line personnel to ensure that they understand the risks they are responsible for managing and sustain the protection measures for which they are accountable.

Bowties are not a static snapshot of assumed/planned controls but a live asset/ risk management platform that can be updated (manually or automatically) to show the current state of health (presence and performance) of controls and the current risk exposure. Barriers degrade over time and their performance must be monitored, measured and sustained at the required level to achieve the necessary risk reduction.

They can be used to operationalise scenarios and demonstrate that duty-holders are and remain in control through ongoing barrier maintenance and robust change management.

An initial step for duty-holders would be to migrate their existing tabular (worksheet) assessments into bowties to expose and address weaknesses. This approach is designed to be different (evolution rather than revolution) with a format where existing information is not lost but knowledge is gained.

Remember – you can't manage what you don't understand, and analysis/assessment is not the same as ongoing assurance. ■

References

[1] *AIChE CCPS "Bow Ties in Risk Management: A Concept Book for Process Safety" (https://www.aiche.org/ccps/resources/publications/books/bow-ties-risk-management-concept-book-process-safety)*

[2] *British Standard "Explosive atmospheres - Classification of areas. Explosive gas atmospheres": BS EN 60079-10-1*

[3] *British Standard "Explosive atmospheres - Classification of areas. Explosive dust atmospheres": BS EN 60079-10-2*

[4] *British Standard "Explosive atmospheres. Explosion prevention and protection - Basic concepts and methodology": BS EN 1127-1*

[5] *AIChE CCPS "Layer of Protection Analysis: Simplified Process Risk Assessment" (https://www.aiche.org/resources/publications/books/layer-protection-analysis-simplified-process-risk-assessment)*

About the author

David Hatch, Process Hazard Analyst at Process Safety Integrity, holds a BSc in Chemical and Process Engineering from the University of Strathclyde and has over 35 years of experience working with major accident hazard facilities and design, and operating and consulting roles in highly regulated industries. He is an IChemE fellow, an IChemE Professional Process Safety Engineer, and a certified functional safety specialist with a focus on bowties and visual risk management methods.