Safety Risk Management Methodologies (SRM)

Bowtie - guidelines

This document was developed by the Safety Management Panel (SMP). It is intended to support safety experts in the application of risk management methodologies. Any comments to this material should be forwarded to safetymanagement@icao.int.

Version 1.0 – June 2022

CONTENTS

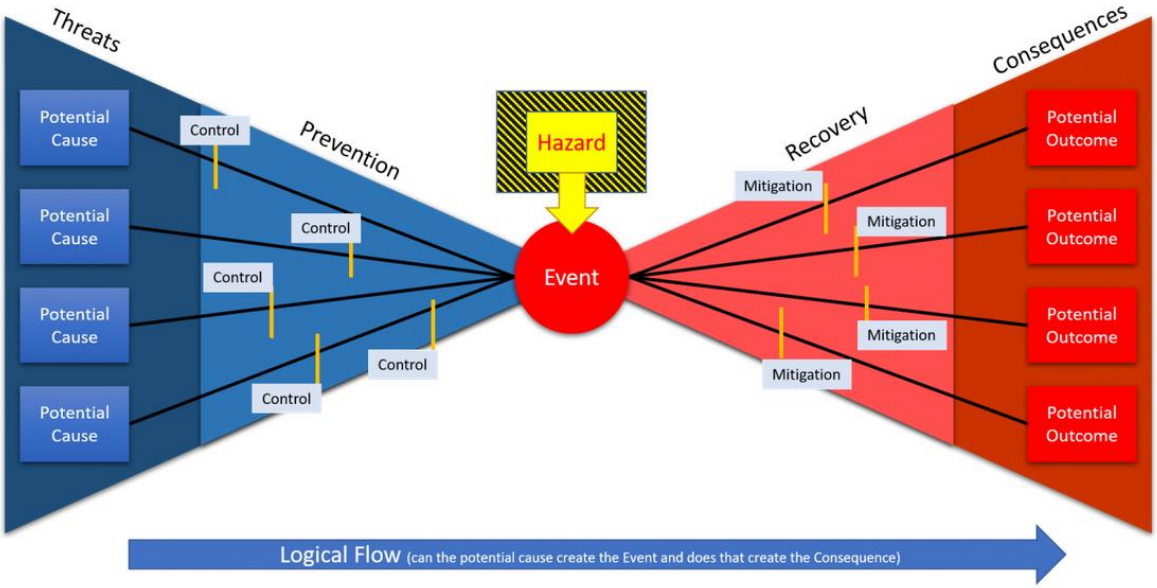
1. DESCRIPTION

1.a) Purpose of the methodology

The Bowtie model organizes the risk and event factors to better understand the risk situation. It is a visual representation of how threats and hazards interact to produce consequences and the barriers and mitigations that could prevent an event or reduce its impact.

When looking at the Bowtie from left to right, you should first see a logical flow from the threats/causes to the outcomes (i.e., it can be reasonably understood how threats could trigger the event and lead to outcomes). Safety barriers are placed both left and right of the event at the centre, depending on whether they participate in the efforts to prevent, recover, and/or reduce the impact from that event.

Figure 1 - Bowtie overview



Credit: https://www.manycaps.com/blog/8-steps-to-bow-tie-analysis.html

1.b) Theoretical basis

The Bowtie draws elements from other methods or concepts that preceded it to combine them into a graphical presentation of the many factors and barriers that are likely to play a role in a specific occurrence (a.k.a. the top event). Bowties combine:

- Fault Tree Analysis (FTA): as suggested by the analogy with trees and their roots in particular, FTA constructs failure paths leading towards a critical breakdown of a system. Scenarios are quantified whenever possible;
- Event Tree Analysis (ETA): in contrast with FTA, ETA starts from a single event to explore and ideally quantify possible scenarios in its aftermath;
- Cause Consequence Diagrams (CCD): graphically combine FTA and ETA that share the same 'critical event', but in a vertical orientation;

- Barrier thinking: back when accidents were seen as an undesirable release of energy (1950s), barrier management was thought to help prevent, control, or mitigate such undesired events (and particularly the multiplication of barriers through the concept of 'defence in depth').

To summarize, Bowties reorient a CCD horizontally and complement it with the barriers that are relevant to the critical event (or top event) under consideration. Several approaches to bowties exist. Qualitative and/or quantitative bowties are the most common. It became relatively popular in high hazard industries such as oil & gas, mining, and aviation between the 1990s and 2010s.

1.c) Risk acceptance method and criteria

Bowtie does not have a standardized risk acceptance method but can interface with other models.

1.d) Key terms and definitions

While there is no set taxonomy for Bowtie, the below represents the key components of the model. Also note that, for instance, there is no formal, commonly agreed definition of what makes a good top event. Any event can be taken, and the quality of the analysis will depend on the expertise of the analysis team(s) in the risk or topic that is considered.

Where multiple terms are used to describe the same concept, they are listed together.

Table 2 - Bowtie key terms and definitions

Term	Definition
Hazard	A condition or object with the potential to cause harm.
Top Event	An event that can cause a deviation of or loss of control over the hazard. A Top event is caused by a *threat* and results in a *consequence*.
Threat / Causes*	Factors that can cause a top event to be realized.
Consequence	Possible outcome resulting from the realization of a Top Event.
Control / Barrier	Specific mitigating actions to modify risk. Can be **preventive** - measures put in place to prevent a threat resulting in the realization of a Top Event or **recovery** – measures that prevent escalation of a Top Event into an undesirable consequence.
Escalation Factor	A condition that leads to increased risk by defeating or reducing the effectiveness of a control/barrier.

***Note:** the term threat is not defined in the ICAO SARPs or guidance material. Hence the dictionary definition "an indication of something impending" (Merriam Webster) should apply. It is important to note that in this context, the term threat does not extend to the usage in security risk assessment.

1.e) Data/Information Inputs

The inputs for bowtie will depend on the use case (i.e., hypothetical risk analysis versus incident management). In most cases a combination of qualitative and quantitative data can be used.

Some examples:
Hazard – may come from existing hazard register, brainstorming
Consequence – may come from historical accident/incident reports, brainstorming, etc.

Inputs for Bowtie's should be an ongoing process as more hazards/threats are identified and new barriers are introduced or removed.

1.f) Tools available

Although this model can grow quite large and complex it can be accomplished through any visual means, such as whiteboard, post-its, Visio, PowerPoint, etc.

More sophisticated software for the creation and management of Bowties does exist. The most common and well known is BowtieXP developed by CGE.

2. User Factors

2.a) Applications

The Bowtie model can be said to have a general application. It can effectively be used in safety risk management practice and applied in aviation sectors (both industry and regulators).

However, since it takes its roots in linear risk assessment methods such as FTA and ETA that were originally developed for very real, physical systems (e.g., Minuteman missiles, nuclear powerplants), the model is more suited for the engineering or investigation of technical systems and industrial processes. It cannot model reality in an exhaustive way.

2.b) Users

Bowtie is not commonly used in the general workforce but they more likely will encounter it as a participant in the creation of models. Bowties are often created through collaborative sessions with Subject Matter Experts lead by someone knowledgeable in the methodology. They are most used by safety analysts and those involved in SMS. Management may also use completed Bowties to see the potential costs of hazards, and it is often used at the planning level.

Being a graphical tool built on a linear and rather simple concept of causality, it can also be used as an educational tool, provided the Bowtie is not too extensive.

Some examples of uses cases include:

- Risk scenario analysis
- Communication tool of risks/costs for management
- Teach what risk management is
- Safety incident management
- Risk control and root cause analysis

2.c) Evaluation of Complexity

Bowtie risk methodology can be scaled up or down depending on need. The complexity lies in having a firm understanding of what each component means so as not to stumble into common pitfalls such as confusing a "top event" for an "outcome".

Regardless of whether it is being used for a simple purpose or something more elaborate, the completed Bowtie should flow logically from the left-hand side "threats" leading to the middle "top event" and ending with the right-hand side "consequences".

2.d) Availability of training

There is a wide variety of free information online to learn more about Bowtie. It is also taught as part of the ICAO Safety Management for Practioners (SMxP) and the Health Safety Protocols for Practitioners (HSPxP) courses. CGE also offers training on the use of the BowtieXP product.

3. Quality and Consistency

3.a) Consistency/Differences from SMM Concepts, Terms and Definitions

The leftmost entity in the bow tie diagram reflects the source of risk, the conditions that could foreseeably cause an event with potentially injurious or damaging consequences. One commonly used bow-tie tool (Bow-Tie XP) uses the term, "threats," to depict this entity. This term is not used in the SMM. Other depictions of the bow tie depict this entity as, "hazards," (for example, Hale and Heijer in *Resilience Engineering*, Hollnagel, Woods, and Leveson, eds.). The definition of threats, however, is reasonably aligned with that of hazards in the SMM in terms of being the source of risk.

Further, both the Hale and Heijer and Bow-Tie XP versions depict the central entity as an undesirable event ("top event" in XP). The SMM, while not depicted in a model or diagram, refers to an "immediate outcome." While not identical, both refer to a central initiating event, with bow tie referring to the event and the SMM referring to its outcome. For example, certain airport and operational conditions could cause crew errors, resulting in a runway incursion, an immediate outcome of operations in the presence of hazards.

The final entity in the bow-tie model is referred to as a "consequence", although usually depicted in terms of several possible consequences. The SMM refers to an "ultimate consequence," which corresponds well with bow-tie terminology. In the previous example, this represents the potential that, given a runway incursion, the likelihood of a runway collision.

While there can be differences in terminology, the structure and flow of the bow-tie model corresponds favourably with that described in the SMM. Therefore, if attention is paid to translation of terms, the bow-tie model does not appear to conflict with the SMM's formulation of safety risk and safety risk analysis.

3.b) Validity and reliability of outputs

As with most things, the quality of the outputs is greatly determined by the inputs. Often there is not enough data to create a complete Bowtie, thus users are relying mainly on expert opinion. This means that different users may end up with different results.

Reliability depends on the maintenance of the Bowtie. This speaks to the evolutionary nature of Bowtie, which should be reviewed and updated regularly, allowing a more comprehensive risk picture to be developed over time.

3.c) Overall pros and cons, strengths and limitations

Pros & strengths	Cons & limitations
• Can potentially provide both qualitative and quantitative results • Accessible to anyone with expert knowledge of the component or system to be analysed • Organizes thinking • Clearly illustrates both preventative and recovery barriers • Applicable at all stages of planning, design, delivery, review, and investigation • If kept simple (trade-offs will be inevitable), can be used with a wide audience as a risk communication tool • Relatively easy to monitor once complete • Size and complexity of Bowtie is flexible (simple on a white board to large, compounded Bowties) • Most valuable for risk assessments of hardware or simple systems and subsystems (with little or no software or human element)	• Built on a linear model of accident causation, at odds with current systems thinking • The graphical end-product is not an analysis method per se, and first requires both knowledge and usage of FTA and ETA models • There is no set taxonomy • Resource-intensive • Finding reliable data to calculate probabilities can be difficult and complex • It is not a complete SRM tool on its own • Easy to get too far in the details • Due to the resource issue, users typically create a limited number of bowties that do not cover their entire operations, systems, and interfaces (e.g., mostly low-probability, high-consequence accidents) • Focuses on one top event at a time • In complex Bowties, the failure or absence of controls may be difficult to identify • Significant risk of oversimplification, particularly of highly automated systems • Mitigating the experts' biases can be difficult

3.d) Team assessment of usability

Bowtie allows for visual communication of risk. It is usable as part of a risk analysis, but lacks a risk acceptance component.

The level of detail may be customized to the audience or purpose of the Bowtie. This makes it a tool suitable for a variety of uses and can be created through simple methods. However, when constructing large, complicated Bowties, it becomes difficult to share the model without the appropriate software.

4. Examples

SMI WEBSITE – EXAMPLES AVAILABLE:

9.4 Component 2: Safety risk management

6. Lithium Batteries in Cargo Aircraft Bowtie Analysis

The Bowtie was developed for the carriage of lithium batteries onboard cargo aircraft (e.g. freighters). The model effectively depicts risk providing an opportunity to identify and assess the key safety barriers either in place or lacking between a safety event and an unsafe outcome. The left side of the model shows the preventative measures which should eliminate the threat entirely or prevent it from causing the top event recovery. The right side shows measures to reduce the likelihood of the consequence owing to the top event being "live" or mitigate the severity of the consequence. The model seeks to be comprehensive, so the elements on either side may not be presented within a specific operation. Further, the operator needs to evaluate the strength of each element based on their own knowledge and experience of their operation and the external factors affecting it.

Note: This example complements the Guidance for Safe Operations Involving Aeroplane Cargo Compartments (Doc 10102)

The example Bowtie Analysis - Lithium Batteries in Cargo Aircraft can be found on the SMI website (www.icao.int/smi)

Source: UK Civil Aviation Authority

COVID-19 SRM WEBPAGE - EXAMPLES AVAILABLE:

Bow-tie for risk assessment of COVID-19 impacts - https://acsa.cocesna.org/en/analisis-de-riesgo-bowtie/

ACSA has prepared a set of Bow-Tie diagrams and reports with the objective of providing assistance and support to the member States of COCESNA. The Bow-Tie analyses determine possible threats, consequences, and existing and proactive barriers due to the COVID-19 Pandemic in relation to Aircraft Operations, Civil Aviation Authorities and Airport Operators.

2.1 Air operation (EN & SP)

2.2 Degradation of the capacity in the functions and responsibilities of the CAA (EN&SP)

2.3 Airport Operations (EN & SP)

Source: Central American Aviation Safety Agency (ACSA)

Note: These bow-ties are only examples and do not capture all 'safety events' or precursors to the Top Event e.g. infection of critical flight operations personnel to support safe flight operations. Users should aim to use this as a starting point and tailor the approach for the specific operational environment.

5. Additional information

5.a) Abbreviations

Abbreviations	Meaning	Notes
SRM	Safety Risk Management	
SRA	Safety Risk Assessment	
SMM	Safety Management Manual	ICAO document 9859

Abbreviations	**Meaning**	**Notes**
SRM	Safety Risk Management	
SRA	Safety Risk Assessment	
SMM	Safety Management Manual	ICAO document 9859

5.a) Literature, references

ICAO Safety Management Manual (SMM) (Doc 9859)

Dallat, C.; Salmon, P.; Goode, N. (2019). Risky systems versus risky people: To what extent do risk assessment methods consider the systems approach to accident causation? A review of the literature. Safety Science. Volume 119.

de Ruijter, A; Guldenmund, F. (2016). The bowtie method: A review. Safety Science. Volume 88.
Ericson, C. A. (1999). Fault Tree Analysis. https://cs.ucf.edu/~hlugo/cop4331/ericson-fta-tutorial.pdf

Hale, A.; Heijer, T. (2006). Defining Resilience. In Hollnagel, E.; Woods, D.; Leveson, N. (Eds) Resilience Engineering: Concepts and precepts. Ashgate.

Leveson, N. (2019). Shortcomings of the Bow Tie and other safety tools based on linear causality. Massachusetts Institute of Technology. https://psas.scripts.mit.edu/home/nancys-white-papers/