# Bowtie Diagrams, a Tool to Improve Risk Assessment

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**Abstract.** Risk assessment in the lift and escalator industry is usually conducted following the guidelines of BS EN ISO 14798: 2009. The method defined in this standard works well.

Bowtie diagrams are a graphic representation of a hazard and the mitigations that either reduce the probability of occurrence of a hazardous event or reduce the harm caused by the event.

Bowties help the team who is conducting a risk assessment by allowing them to visualize the issues involved. Bowties also help the personnel who are at risk to better understand the hazard and how they can reduce their risks. Bowties and how to employ them are then explained.

## 1 BACKGROUND

### 1.1 Safety, Hazards, Risk, and Harm

Safety is freedom from unacceptable risk [1].

Hazards are potential sources of harm.

Risk is a combination of the probability of occurrence of harm and the severity of that harm.

Risk assessment is a methodology used to identify the risk of harm resulting from hazards.

Safety is achieved by risk assessment followed by risk reduction.

## 2 RISK ASSESSMENT AND RISK REDUCTION

Risk assessment and reduction are usually performed using the methodology defined in BS EN ISO 14798: 2009 [1].

This process starts with identifying a hazard.

When one thinks of harm, one often thinks only about harm to people. However, one must also consider harm to property and the environment when one considers hazards.

An example of a hazard might be an escalator truss full of oil-soaked flammable debris. If the debris catches fire, passengers could be harmed, the building (property) might be harmed, and smoke could harm the environment.

Next, a scenario is developed where a hazardous situation will exist. A hazardous situation is a circumstance in which people, property or the environment are exposed to one or more hazards.

A harmful event occurs when a hazardous situation actually harms a person, property, or the environment.

The identified harmful event is then assessed using two criteria as follows:

1. What is the probability of this event occurring?
2. What is the severity of the harm this event will cause?

The assessment uses Table 1 to quantify the Probability of Occurrence and Table 2 to quantify the Severity of Harm.

**Table 1 Probability of Occurrence**

| Identify level of probability | Description |
|---|---|
| **A — Highly probable** | Likely to occur frequently in the life cycle |
| **B — Probable** | Likely to occur several times in the life cycle |
| **C — Occasional** | Likely to occur at least once in the life cycle |
| **D — Remote** | Unlikely, but may possibly occur in the life cycle |
| **E — Improbable** | Very unlikely to occur in the life cycle |
| **F — Highly improbable** | Probability cannot be distinguished from zero |

**Table 2 Severity of Harm**

| Identify level of severity | Description |
|---|---|
| **1 — High** | Death, system loss, or severe environmental damage |
| **2 — Medium** | Severe injury, severe occupational illness, or major system or environmental damage |
| **3 — Low** | Minor injury, minor occupational illness, or minor system or damage |
| **4 — Negligible** | Does not result in injury, occupational illness, or system or environmental damage |

Once the levels of probability and severity are established, their combined value is determined using Table 3.

**Table 3 Combined Value of the Levels of Probability and Severity**

| Level of probability | Level of severity | | | |
|---|---|---|---|---|
| | 1 — High | 2 — Medium | 3 — Low | 4 — Negligible |
| A — Highly probable | 1A | 2A | 3A | 4A |
| B — Probable | 1B | 2B | 3B | 4B |
| C — Occasional | 1C | 2C | 3C | 4C |
| D — Remote | 1D | 2D | 3D | 4D |
| E — Improbable | 1E | 2E | 3E | 4E |
| F — Highly improbable | 1F | 2F | 3F | 4F |

Table 4 defines the *Measure to be taken* for the combined risk level.

**Table 4 Measure to Be Taken**

| Risk group | Risk levels | Measure to be taken |
|---|---|---|
| I | 1A, 1B, 1C, 1D, 2A, 2B, 2C, 3A, 3B | Protective measures required to reduce the risks |
| II | 1E 2D, 2E 3C, 3D 4A, 4B | Review is required to determine whether any further protective measure is appropriate, taking into account the practicability of the solution and societal values [a] |
| III | 1F 2F 3E, 3F 4C, 4D, 4E, 4F | No action required |

[a] Society will not tolerate some specific risks. Further measures can make use, service, etc. of the lift impractical or impossible.

Figure 1 is a Risk Assessment Template from BS EN ISO 14798: 2009.

**Risk assessment template**

**Purpose [a] and subject:** ____________ **Moderator [a]:** ____________ **Date:** ____________

| Case number | Scenario | | | Estimation of risk elements | | Protective measures (risk reduction measure) | After protective measures | | Residual risk |
|---|---|---|---|---|---|---|---|---|---|
| | Hazardous situation | Harmful event | | S [b] | P [c] | | S [b] | P [c] | |
| | | Cause | Effect | | | | | | |
| | | | | | | | | | |
| | Comments | | | | | | | | |
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| | Comments | | | | | | | | |

[a] Purpose, team moderator and members may be recorded in a separate document.

[b] S — Levels of severity of the harm (see 4.5.3):
1 — High 2 — Medium 3 — Low 4 — Negligible

[c] P — Level of probability of occurrence of harm (see 4.5.4):
A — Highly probable B — Probable C — Occasional D — Remote E — Improbable F — Highly improbable

**Figure 1 Risk Assessment Template**

Figure 2 below is a risk assessment of an escalator fire.

Purpose and subject: Fire on an escalator Moderator : Rory Date: June 23, 2024

| Case number | Scenario | | | Estimation of risk elements | | Protective measures (risk reduction measure) | After protective measures | | Residual risk |
|---|---|---|---|---|---|---|---|---|---|
| | Hazardous situation | Harmful event | | S [b] | P [c] | | S [b] | P [c] | |
| | | Cause | Effect | | | | | | |
| E 1 | Fire | Accumulation of flammable material in truss. | Death, environmental damage, property damage | 1 | C | Regular cleaning | 1 | D | |
| | Comments: | | | | | | | | |
| E 2 | Fire | Accumulation of flammable material in truss. | Death, environmental damage, property damage | 1 | C | Regular Cleaning & Installation of fire suppression system | 1 | F | |
| | Comments: The best solution is regular cleaning and a fire suppression system | | | | | | | | |
| | | | | | | | | | |
| | Comments | | | | | | | | |
| | | | | | | | | | |
| | Comments | | | | | | | | |

[a] Purpose, team moderator and members may be recorded in a separate document.

[b] S — Levels of severity of the harm (see 4.5.3):
1 — High 2 — Medium 3 — Low 4 — Negligible

[c] P — Level of probability of occurrence of harm (see 4.5.4):
A — Highly probable B — Probable C — Occasional D — Remote E — Improbable F — Highly improbable

**Figure 2 Risk Assessment of an Escalator Fire**

Case Number E 1 in Figure 2 has an initial risk estimation of 1C. After a risk reduction measure was applied, the risk level was reduced to 1D. 1D requires additional risk reduction measures.

In Case Number E 2, a Fire Suppression System was added and the risk estimation is now 1F. 1F is an acceptable risk level.

This risk assessment methodology is defined in BS EN ISO 14798: 2009 and is *quantitative*. The methodology is quantitative because the results are an ordinal value for both severity of harm and probability of occurrence.

## 3 BOWTIE DIAGRAMS

Bowtie Diagrams are a graphic tool for displaying the events that lead to a harmful event, known as a Top Event. They also display the consequences of that Top Event [2].

Royal Dutch Shell was the first major company to successfully integrate bow-tie diagrams into their business practices [3]. Bowtie diagrams based on this system are referred to as *Shell Bowties*. Shell Bowties are qualitative [2].

Bowtie diagrams are qualitative because they are graphic representations of the risk.

### 3.1 Bowtie layout

The typical layout and components of a bowtie diagram are shown in Figure 3 [4].

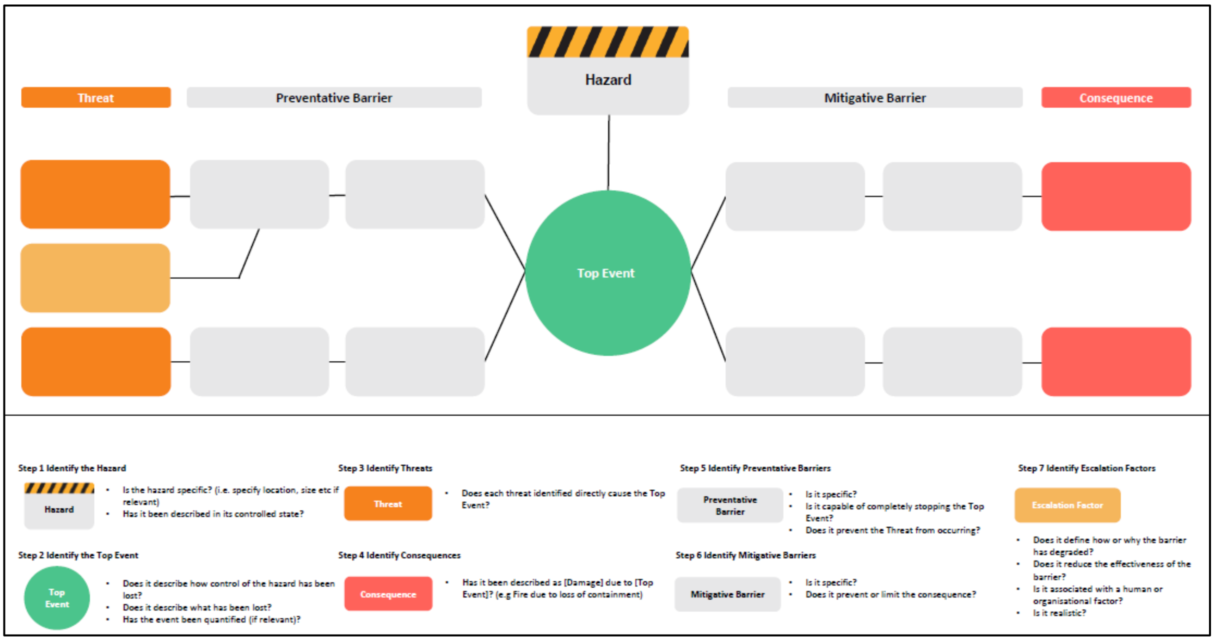


**Figure 3 Typical Layout and Components of a Bowtie Diagram**

The green circle in the centre of the diagram represents the harmful event.

The dark orange boxes on the left side represent the threats that might, if no preventative barrier exists, cause a harmful event.

The light orange boxes are known as *Escalation Factors*. These factors reduce the effectiveness of a preventative barrier.

The grey boxes to the left of the green circle represent the barriers that might prevent a threat from progressing to a hazardous event.

The red boxes on the extreme right side of the diagram represent the consequences that can result from a harmful event if no mitigative barriers are employed.

The grey boxes on the right side of the green Top Event represent barriers of the harmful event that can mitigate the harm and reduce the harmful consequences of the event.

Figure 4 is a bowtie diagram developed by the author as a graphic tool to *qualitatively* explain the risk assessment of the escalator fire depicted in Figure 2.

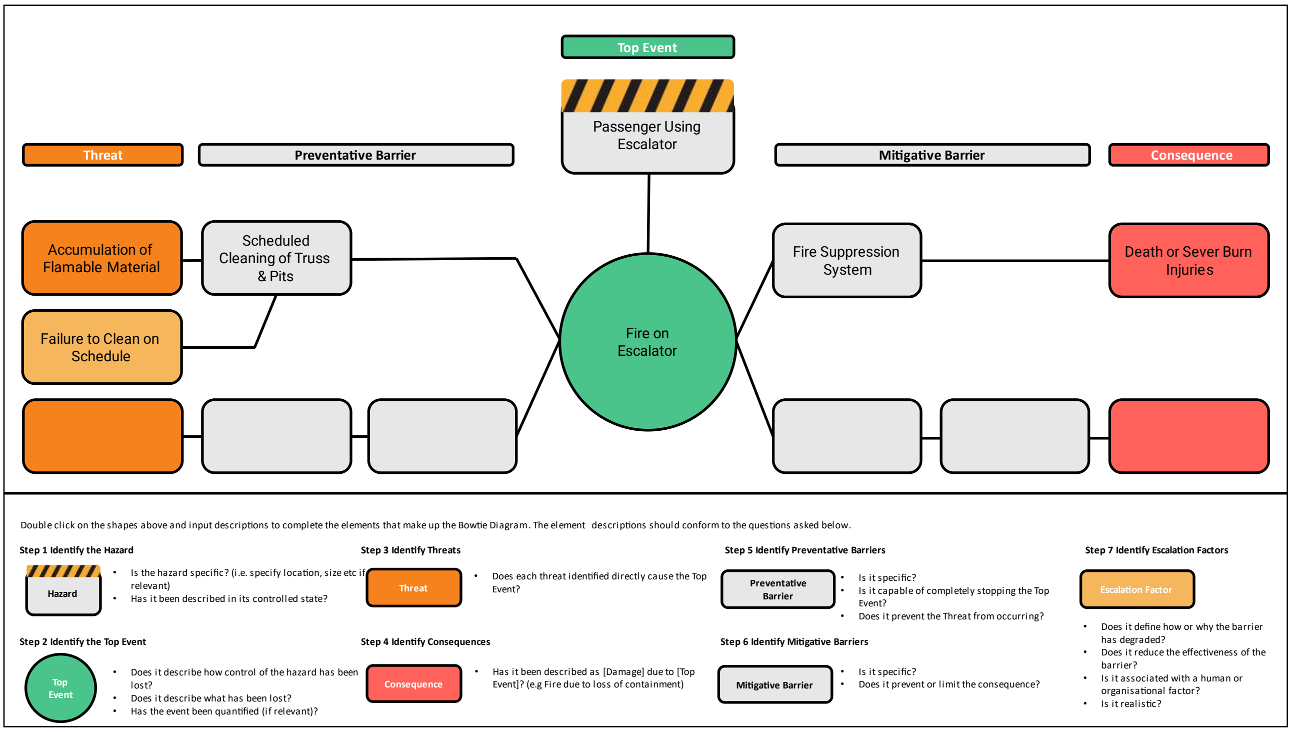


**Figure 4 Bowtie Diagram of the Escalator Fire Depicted in Figure 2**

## 3.2 Explanation of Figure 4

The threat that can, if not prevented, cause harm, is the accumulation of flammable debris.

The scheduled cleaning of the truss and pits is a preventative barrier. However, failure to clean the truss and pits is an *escalation* factor that degrades the preventative barrier.

Even with the preventative barrier, the debris can still catch fire, although the probability of occurrence should be less than if the preventative barrier did not exist.

Without a mitigative barrier, the consequences of this Top Event could be death or severe injuries to passengers using the escalator. With a mitigative barrier, such as the fire suppression system, the consequences of a fire can be substantially mitigated.

# 4 CONCLUSIONS

BS EN ISO 14798: 2009 is a proven method of conducting risk assessments on lifts and escalators. This method is quantitative.

Bowtie Diagrams are a qualitative graphic tool that can augment quantitative risk assessments.

Bowties are not a replacement for quantitative risk assessments. They can help teams that are conducting risk assessments to better understand how preventive and mitigative barriers can produce a safer product.

Additionally, bowtie diagrams can help people working in hazardous conditions to understand the risks they face and better appreciate the role barriers play in their safety.

## REFERENCES

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[3] Bow-tie diagram available from: https://en.wikipedia.org/wiki/Bow-tie_diagram Last accessed 22 June 2024.

[4] Bowtie Master. (2024, February 15). The ultimate risk overview. Retrieved from https://bowtiemaster.com/

## BIOGRAPHICAL DETAILS

Rory Smith is a Visiting Professor in Engineering/Lift Engineering at the University of Northampton and a Consultant at Peters Research Ltd. He has over 55 years of lift industry experience during which he held positions in research and development, manufacturing, installation, service, modernization, and sales. His areas of special interest are Machine Learning, Traffic Analysis, dispatching algorithms, and ride quality. Numerous patents have been awarded for his work.