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Overview of Bowtie Methodology of Risk Analysis and its Application for Steel Industry

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ABSTRACT:

Risk assessment lies at the heart of risk management and one of the most powerful and increasingly popular risk assessment techniques is the bow-tie method. Its strength is that it goes beyond the usual risk assessment 'snapshot' and highlights the links between risk controls and the underlying management system. It is an excellent demonstration tool, but is also well-suited to communicating risk issues to non-specialists. While highlighting the step by step approach / methodology involved in Bowtie Risk Analysis, the paper also include a case study of use of this methodology in Steel Making which is intrinsically hazardous in nature.

Key Words: Bowtie, risk, barrier,

1.0 Introduction:

1.1 History and rise to popularity

It is said that the first 'real' bowtie diagrams appeared in the Imperial Chemistry Industry (ICI) course notes of a lecture on Hazard Analysis (HAZAN), given at the University of Queensland, Australia in 1979, but how and when the method found its exact origin is not completely clear. The catastrophic incident on the Piper Alpha platform in 1988 shook the oil & gas industry. After the report of Lord Cullen, who concluded that there was far too little understanding of hazards and their accompanying operational risks, the urge rose to gain more insight in the causality of seemingly independent events and conditions and to develop a systematic way of assuring control over these hazards.

In the early nineties the Royal Dutch / Shell Group adopted the bowtie method as part of the companies' HEMP standard for analysing and managing risks (Zuijderduijn, 1999). Shell facilitated extensive research in the application of the bowtie method and developed a strict rule set for the definition of all items, based on their ideas of best practice. The primary motivation of Shell was the need for assurance that appropriate risk controls are consistently in place throughout all worldwide operations.

Following Shell, the bowtie method rapidly gained support throughout the industry because bowtie diagrams appeared to be a suitable visual tool to keep an overview of risk management practices, rather than replacing any of the commonly used systems. In the last decade the bowtie method also spread to industries outside of the oil & gas industry: aviation, mining, maritime, chemical, financial, judicial and health care to name a few.

The Bowtie method takes its name from the shape of the diagram that is created, which looks like a men's bowtie. Bowties today are mainly used to make a decision whether the current level of control is sufficient. This can be done to satisfy an organisation internally or an external regulator or customer. There are many methods that do this, so what are some additional reasons why bowties are used? First, the bowtie has a helpful structure to brainstorm with a team on risks. Second, it contains operational hardware barriers, behavioural barriers and organisational management systems, which makes it an ideal place to holistically look at where investing resources would have the greatest impact. But perhaps the best reason for choosing the bowtie method is that it creates an easy picture to understand and communicate on multiple levels of the organisation. A complete bowtie diagram, linked to the management system, is like a graphical table of contents – a map, showing everything an organization does to controls its major risks.

1.2 Related methods

While the origin of the bowtie method itself is unclear, there were other methods and ideas at the root of bowtie thinking. So we do have some idea about what logically preceded the bowtie. There are three main methods which have relations to the bowtie methodology:

1. The first method is fault tree analysis which, in simplified form, corresponds to the left side of the bowtie. It shows how different scenarios can cause a company to lose control over its processes or hazards.

2. The second method is event tree analysis which, again in simplified form, corresponds to the right side of the bowtie. This side of the diagram shows what the consequences can be once control over a process or hazard is lost.

3. Barrier-based thinking. The fault and event trees have been simplified largely by adding the barrier concept. The best way to explain this concept is perhaps with the famous Swiss cheese model by James Reason, which originated in the early nineties. This metaphor of thinking about safety systems is not new – it has existed for a long time since before the bowtie model, such as for example in the nuclear industry's defence in depth philosophy or Haddon's 10 strategies for controlling energy.

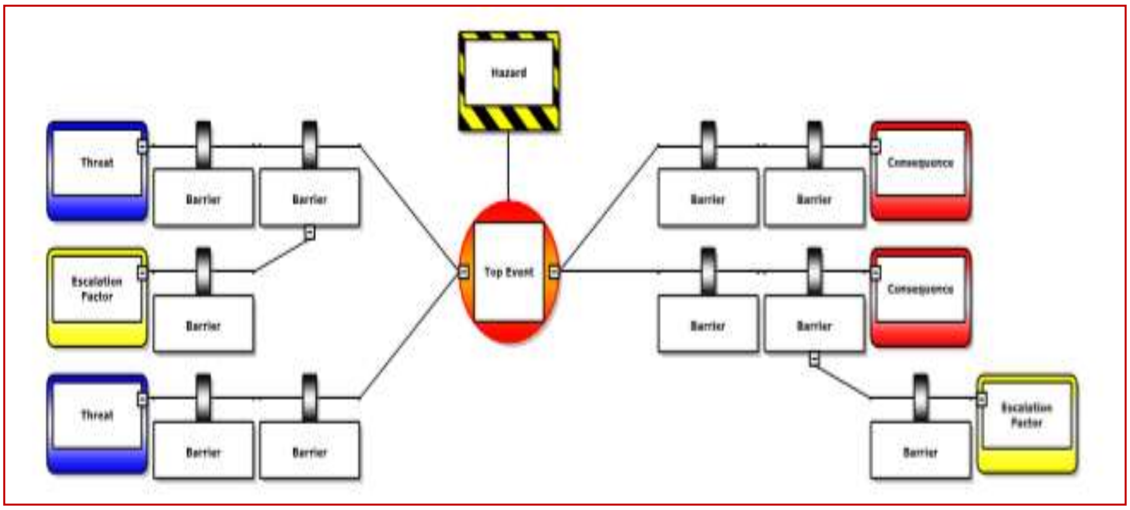
2.0 Methodology:

8 Steps in Bowtie diagram

The method for building a bow-tie diagram is well-documented, and involves asking a structured set of questions in a logical sequence to build up the diagram step by step (Table 1). The completed bow-tie illustrates the hazard, its causes and consequences, and the controls in place to minimise the risk. Facilitated workshops involving people who are regularly confronted with the hazards have proven to be the most effective way of identifying real controls and capturing current practice.

Sl. No	Step	Description
1.	Identify hazard	The first step in managing risks is to identify what their sources are.
2.	Identify top event	When we know what is potentially hazardous, we need to know how we could lose control over it.
3.	Identify threats	Next we need to consider the scenarios or events which could directly cause the occurrence of the top event.
4.	Evaluate consequences	After the top event occurs, subsequent scenarios or events are now possible. These consequences can lead to losses and damage. 5
5.	Identify preventive barriers	The next step is to identify the barriers which should prevent the threats from reaching or causing the top event. These are preventative barriers
6.	Identify recovery barriers	Barriers on the right side try to recover from the occurrence of the top event. These barriers should prevent or mitigate the consequences and/or the resulting losses and damage
7.	Identify escalation factors	The next step is to identify the specific situations or conditions under which the barriers are less or not effective
8.	Identify escalation factor barriers	The last step is to look at what barriers you have to prevent or manage these escalation factors.

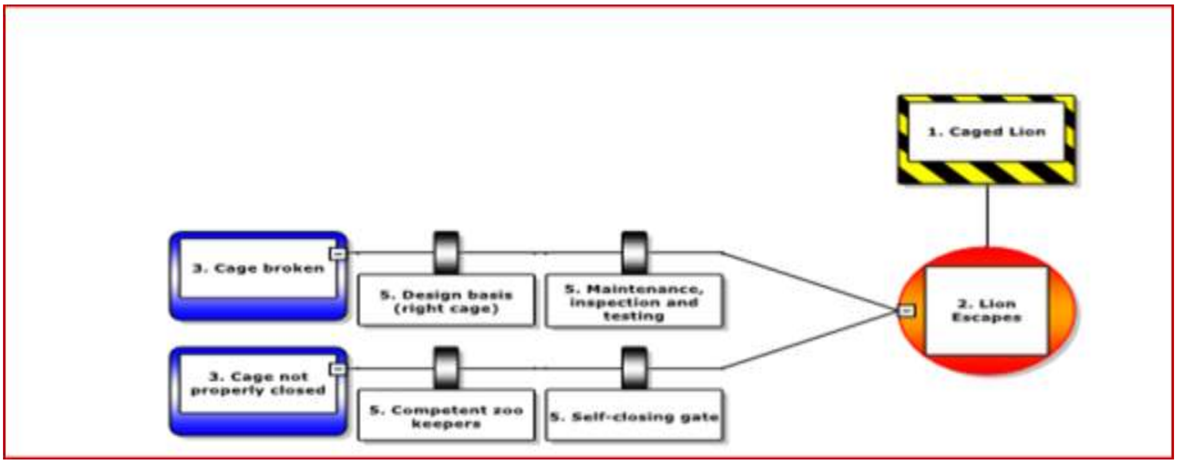
A bowtie diagram showing all elements is shown below.

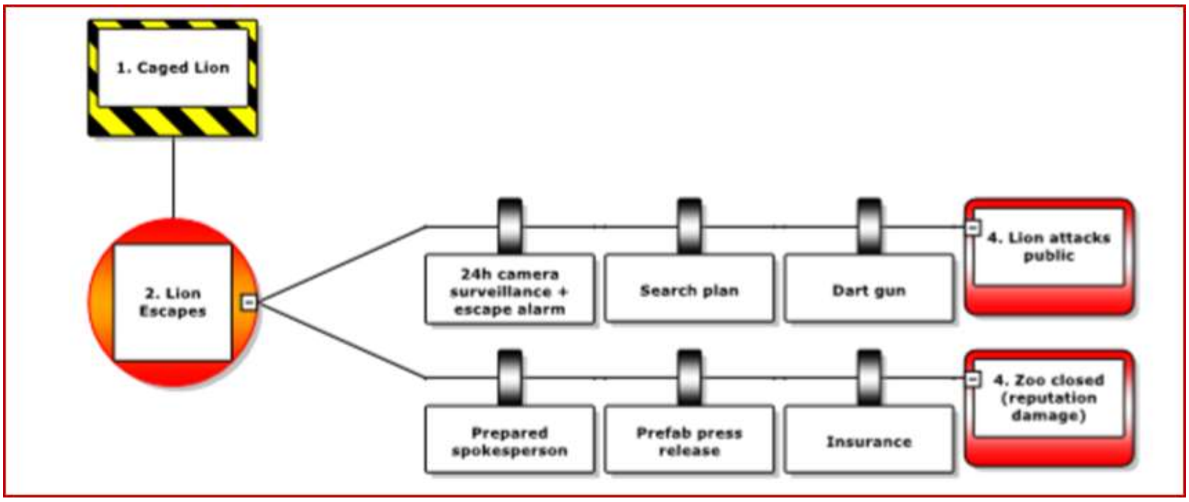


An example of lion in a cage is taken to illustrate the above 8 elements /steps . Say you are the general director of a zoo. Your zoo is an organization that earns its existence by exhibiting animals to the public. Like every organisation, your zoo is subject to certain risks that originate from your business

Sl. No	Step	Description
1.	Identify hazard	One of the obvious sources of risk is that we have dangerous wild animals in our zoo. They are a part of normal business, without them we would not have a zoo, and as long as they are controlled, we are fine.
2.	Identify top event	We could lose control over these animals – they might get out the cage. If our lion escapes, we can face potential consequences

3.	Identify threats	How could our lion escape? On the one hand, the cage itself might fail – allowing the lion to escape. But maybe a mistake was made and the cage was left open/unlocked
4.	Evaluate consequences	If the lion gets out, we can face a multitude of consequences – the lion might attack and injure the public. At the very least we will get a lot of negative press, leading to a bad reputation and loss of revenue; we might even need to close.
5.	Identify preventive barriers	There are two threats in our example and we can think of barriers for both. The first threat is a broken cage. To prevent this we can make sure the initial design is correct to ensure a minimum level of quality. If the initial design is up to our standards, we also have periodic maintenance and inspection and a testing schedule. The second threat is not properly closing the cage door. To prevent the cage being improperly closed, we ensure we have competent zoo keepers, and we have self-closing gates.
6.	Identify recovery barriers	There are also two consequences in our example that should have barriers. First, we want to know how to prevent or mitigate the lion attacking the public after it has escaped. To do that we have camera surveillance and escape alarms. We also have a search plan and dart gun to find the lion as soon as possible and get it back into the cage. To prevent reputation damage possibly leading to closing of the zoo, we have a prepared spokesperson to address the press along with a prepared press release. We also have insurance to cover any losses (up to a point).
7.	Identify escalation factors	Our self-closing gate is reliant on mains power – if the power fails, our self-closing gate will not work.
8.	Identify escalation factor barriers	if the power does fail, provision of an emergency generator will ensure our safety systems keep working.



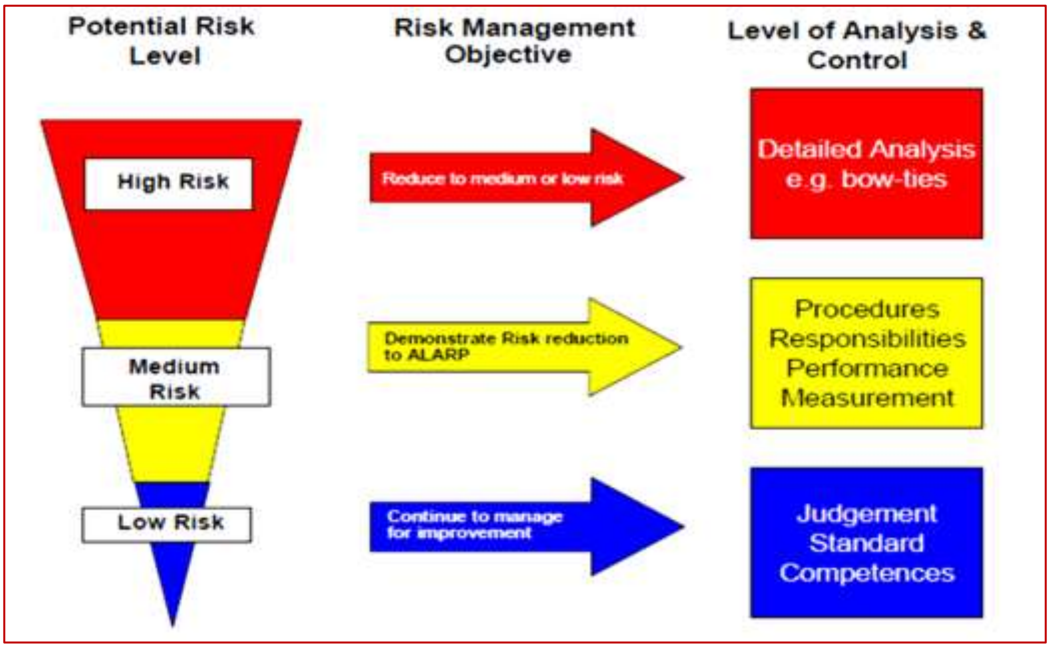


3.0 Application of Bowtie in Steel Industry

Steel industry is a hazardous process industry as per Factories Act,1948. Section 7A (c) of FA requires every Occupier of a factory to ensure, so far as is reasonably practicable, the health, safety and welfare of all workers while they are at work in the factory. Some of the inherent hazards that can be found during the steelmaking process are-

1. Molten metal inside the Electric Arc Furnace (EAF)
2. Molten metal inside the Basic Oxygen Furnace (BOF)
3. Molten metal in ladle
4. Molten metal in vacuum degasser
5. Molten metal in casting, including moulds
6. Molten metal in tundish
7. Molten metal in torpedo ladle
8. Oil (high pressure and flammable [consider flash point])
9. Accumulated Direct Reduced Iron fine/dust (flammable)
10. Carbon monoxide from the EAF
11. Inert gases (argon/nitrogen)
12. Water steam from vacuum degasser
13. CO gas inside the BOF system (vessel - cooling and gas cleaning system)
14. Magnesium (hot metal desulpharisation)
15. Calcium carbide (hot metal desulpharisation)
16. Radioactive sources

As compliance to above statutory provision as well as in conformance to ISO- 45000 requirements, steel plants have mandatorily carried out preliminary Hazard identification & Risk assessment. Some of units/installations like Oxygen Plant, Propane Plant, Coal chemicals department, Gas holder, LPG installation, etc. are deemed as Major Accident Hazard units in view of storage of hazardous chemicals in excess of threshold quantity than stipulated. They are required to submit Safety Reports as per schedule VIII, Rule-10 of the MSIHC Rules to the concerned regulatory authority for approval. The safety report requires the risk analysis to be carried out for hazardous chemicals to find the effect of accidental release of material on human, property and environment. For this purpose, Bow tie method of risk analysis is used for this purpose.



3.1 Steps involved:

a) *Listing of all dangerous chemicals in use*

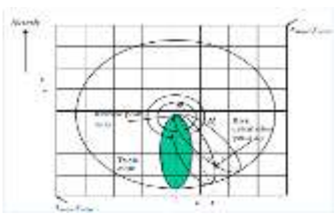
Sl. No.	**Name of the chemical**	**Location**
1.	Ammonia Anhydrous	CCD
2.	Carbon disulphide	CCD
3.	Carbon monoxide	BF & COG network
4.	Chlorine	WTP
5.	Hydrogen Chloride Anhydrous	CCD
6.	Hydrogen Sulphide	CCD
7.	Sulphur Dioxide	CCD
8.	Sulphur trioxide	CCD
9.	Acetone	Mills
10.	Benzene	CCD
11.	Butane	CCS- LPG Cylinder
12.	Calcium Carbide	SMS
13.	Carbon disulphide	CCD
14.	Coal powder	RMHP
15.	Hydrazine	PBS
16.	Hydrogen	CCD & COG Network
17.	Methane	COG Network
18.	Sulphuric acid	CCD
19.	Morpholine	PBS
20.	Propane	Propane storage
21.	Toluene	CCD
22.	Xylene	CCD
23.	LD Gas	SMS Gas holder
24.	PCM	EMD
25.	Furnace Oil	EMD

b) *Calculation of severity through DOW-F&E INDEX & short listing based upon severity*

The criteria for selecting HHP (High hazardous process) is based upon Toxicity & Dow Fire & Explosion Index as mentioned below

Hazard	**Parameter**	**Selection criteria**
Toxicity	Toxicity Index	40 & above
Flammability	Material Factor Dow Fire & Explosion Index	16 & above 96 & above

c) Based on above, 20 chemicals were shortlisted for consequence analysis for fire, explosion & toxic release using ALOHA Software.



Hole Diameter		**Leak Frequency (per vessel year)**	
Range	**Nominal**	**Storage Vessels**	**Small Containers**
1-3 mm	2 mm	2.3×10^{-5}	4.4×10^{-7}
3-10 mm	5 mm	1.2×10^{-5}	4.6×10^{-7}
10–50 mm	25 mm	7.1×10^{-6}	
50-150 mm	100 mm*	4.3×10^{-6}	
>150 mm	Catastrophic	4.7×10^{-7}	1.0×10^{-7}
TOTAL		4.7×10^{-5}	1.0×10^{-6}

Table 1: Risk matrix

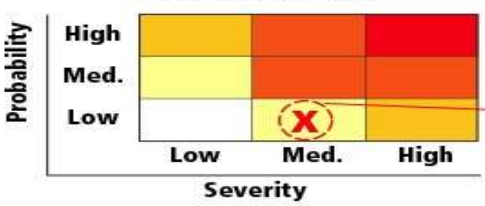


Table 2: Risk Ratings

Description	**Colour Code**
Immediately Dangerous	
High Risk	
Medium Risk	
Low Risk	
Very Low Risk	

d) For high risk jobs, controls / barriers were decided through brainstorming session involving a team from operations, mechanical , electrical, instrumentation & safety personnel in the workshop wherein both preventative & mitigative barriers as well as escalation factors & their controls were decided . These were represented in a user friendly & graphical form.

e) For all identified barriers responsibility is defined for its current and future state. Usually a job title / position title is linked to a barrier but it could also be a person's actual name. Depending on the purpose of the bowtie (for operational use or for risk assessment) one of the two is chosen.

f) There are different ways to classify these systems. In this example we use five different categories:, *Active hardware, Continuous hardware , Passive hardware, Active hardware Human & Active Human*. These barrier works on Detect- Decide- Act model. If any of the detect decide act elements is missing from an active barrier, the barrier will not be able to stop the threat.

A sample bow tie for identified significant hazard namely 'LD gas in gas holder of SMS' with top event as 'Loss of containment of LD gas' is shown below. LD (Convertor gas) is produced during the process of steel making, is stored in wet type gas holder of 40,000 m 3 capacity, three boosters of 10,000 m3/ hr each are provided to draw the gas from gas holder & pump it into CO gas network whenever the yield from CO Batteries fluctuates. In addition, this also helps in controlling atmospheric pollution. As LD gas contains high CO & CO_2 gas (around 65-70 & 15-20 % respectively) which is highly toxic & flammable, any uncontrolled release would result affecting the surrounding persons in the downwind side. Likely cause that will lead to top event (loss of containment of LD gas) and likely consequences (fire & toxic release) in the event of failure of associated barriers is given at **Annexure-1** with types of barrier & responsibility for its maintenance.

Conclusions:

Bowties are a proven method in a wide variety of high-hazard/-risk industries that are used to visualize the integrity of the business from equipment all the way up to the enterprise. Bowties complement and supplement existing hazard identification and risk-analysis tools to create a framework for ongoing risk management. They offer user-friendly engagement and empowerment from the board room to the control room and can provide a live source of knowledge and understanding that underpins all critical decisions. Bowties assist with audits, inspections, and assessment to confirm actual vs. assumed barrier presence and performance, threat frequency, and consequence severity. Finally, they support incident investigations by indicating what the barriers should have done and what they actually did (or did not) do.

References:

a) Process safety Management- Scenario development using bowtie diagrams by World Steel Association

b) Bowtie methodology manual

c) Lessons Learned from the Real World Application of the Bow-tie Method- RISKworld issue 6 autumn 2004 pg 2-3

d) Barrier-Focused Approaches to Risk Analysis -Introduction to Bow Tie Analysis by WorkSafeBC Risk Analysis Unit

e) Practical HSE Risk Management –An Introduction to the Bow-tie Method