

Visual HAZOP - Exploiting the power of Bowties to improve study efficiency and enhance engagement

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A bowtie methodology that meets the expectations of HAZOP standards & best practice and offers a robust framework from which risks can be assessed & managed without further interpretation or manipulation. An evergreen process safety reference supports effective management of change (since the impact on threats or barriers is more obvious) and facilitates a more empowered relationship with Operations & Maintenance personnel.

Representing hazard scenarios in graphical rather than written format enables participants to maintain focus as they are not burdened by masses of text, yet they can be confident that their contributions are recognised and recorded

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Introduction

Hazard and Operability (HAZOP) is a well understood, respected and employed technique in the process (and other) industries. It offers systematic rigour in challenging the design & operating intent of a new, modified or established facility and provides a foundation for further analysis and risk assessment.

The principles have changed very little since the method was conceived in the 1960's by ICI and published by H. G. Lawley in 1974 ^[1]. A typical approach is documented in an international standard ^[2] and more practical guidance is available from the IChemE ^[3] and the CCPS ^[4].

Current practice utilises software to record the HAZOP study as it happens and to display the worksheet on a screen to ensure all participants have the opportunity to view their contribution and, if necessary, correct or expand the notes.

The output from HAZOP studies either stand alone or are developed in risk assessments such as Layer of Protection Analysis (LOPA) to qualify or quantify the risks associated with the identified hazards and although integrated HAZOP & LOPA applications exist they are however limited by the quality and quantity of information or knowledge they can impart to those who were not present during the studies. It is also often the case that participants may become disengaged from a method that is wholly textual (particularly those unfamiliar with the technique).

Challenges

Whilst the technique has proven to be an invaluable hazard identification tool, it does have its limitations which have been documented (but not necessarily well publicised or acknowledged) in several industry journals & books.

Strictness

The esteemed Trevor Kletz, in his book HAZOP and HAZAN ^[5], noted that:

“Although Hazop is a valuable technique, no-one jumps out of bed on a Monday morning shouting, ‘Hooray! I’ve got a Hazop today!’. The need to consider every deviation on every line can become tedious. Beware of making it more so by bureaucratic procedures such as insisting on excessive recording or discussing everything twice (or three times) – in the Hazop meeting and afterwards with the boss or the project team. There is a net loss if in our eagerness to document it and explain it to everybody we discover less information worth documenting. If Hazop and similar systems are not acceptable to creative minds, they will never succeed.”

Team burn out is a well-known phenomenon which must be managed with due consideration to project timescales, budgets and participant continuity.

Safeguards

The standard ^[2] format for a HAZOP worksheet (which is typically replicated in commercial HAZOP/PHA software tools) only includes a single column for Safeguards (or Existing Controls according to the current version)

STUDY TITLE: PROCESS EXAMPLE								SHEET: 1 of 4	
Drawing No.:			REV. No.:			DATE: December 17, 1998			
TEAM COMPOSITION:			LB, DH, EK, NE, MG, JK			MEETING DATE: December 15, 1998			
PART CONSIDERED:			Transfer line from supply tank A to reactor						
DESIGN INTENT:			Material: A		Activity: Transfer continuously at a rate greater than B				
			Source: Tank for A		Destination: Reactor				
No.	Guide word	Element	Deviation	Possible causes	Consequences	Safeguards	Comments	Actions required	Action allocated to
1	NO	Material A	No Material A	Supply Tank A is empty	No flow of A into reactor Explosion	None shown	Situation not acceptable	Consider installation on tank A of a low-level alarm plus a low/low-level trip to stop pump B	MG
2	NO	Transfer A (at a rate >B)	No transfer of A takes place	Pump A stopped, line blocked	Explosion	None shown	Situation not acceptable	Measurement of flow rate for material A plus a low flow alarm and a low flow which trips pump B	JK
3	MORE	Material A	More material A: supply tank over full	Filling of tank from tanker when insufficient capacity exists	Tank will overflow into bounded area	None shown	Remark: This would have been identified during examination of the tank	Consider high-level alarm if not previously identified	EK

Figure 1 Example HAZOP Worksheet (from IEC 61882 [2] Annex B)

With only a single field to document all the prevention & mitigation measures for the Cause-Consequence scenario, it is difficult to fully appreciate the balance of Safeguards and their role in reducing risk by their presence and/or performance before or after the hazardous event.

Jones [6] covered this and other pitfalls in the technique by noting that the HAZOP team can often give unwarranted credit to Safeguards or conversely offer too little or no credit for Safeguards where it may be due – potentially as their role was not apparent. Without a comprehensive appreciation of the relative and absolute contributions made by Safeguards, their criticality and therefore the maintenance, monitoring and management attention they merit is often subjective resulting in resources being deployed in the wrong areas.

Singularity

The linear, tabular nature of recording tends to focus on a single Cause leading to one or more Consequences and often where a separate Cause is identified as leading to the same Consequence e.g. in a subsequent Guideword/Deviation discussion, then it is all too easy to simply record “As above” or “See above” without fully appreciating the common elements and subtle differences in such scenarios.

The UK Health & Safety Executive recognised this as a weakness in the technique. One document [7] notes that “HAZOP is also weak in handling multiple cause events. Teams find difficulty in holding together and tracing through the implications of a number of failures at once”. Another report [8] notes this more strongly as a distinct disadvantage as HAZOP “Focuses on one-event causes of deviation only. Only the hazards associated with single deviations can be studied. Hazards that are caused by two or more separate deviations cannot be identified by the technique.”

Proposal

In order to address the disadvantages of HAZOP noted above but ensure that suitably proportionate rigour is applied to confirm known issues and identify unknown problems, a technique (provisionally referred to as Visual HAZOP) is proposed which applies the Guideword/Deviation approach of HAZOP with the clarity of Bowtie analysis.

Bowtie (like HAZOP) originated in ICI in the 1960's and first appeared in the public domain via the University of Queensland in 1979 (although its exact origin is unclear). It came to prominence after the Piper Alpha incident in 1988 when the Cullen Report [9] concluded that there was far too little understanding of hazards and their accompanying risks that are part of operations, and the urge rose to gain more insight in the causality of seemingly independent events and conditions and to develop a systematic/systemic way of assuring barrier over these hazards.

The technique is graphically summarised in the diagram below:

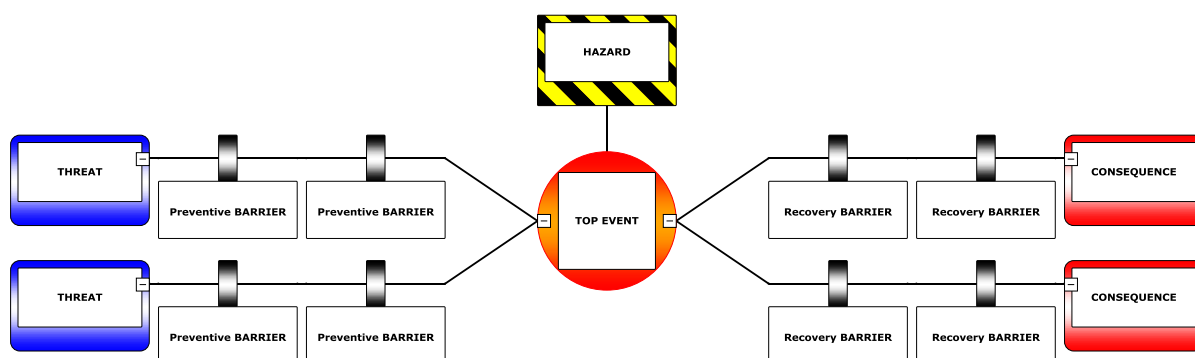


Figure 2 Example Bowtie diagram

This is read from left to right and is centred about a Hazard (something with the potential to cause harm) and the Top Event where that Hazard is realised or released. The Top Event may be caused by a number of Threats which are prevented from escalating by risk controls in the form of Barriers (technical or organisational measures) and the effects of the Top Event can be mitigated by risk reduction measures before the Consequences occur.

It is therefore easy to simply change the terminology used to be consistent with HAZOP as shown below.

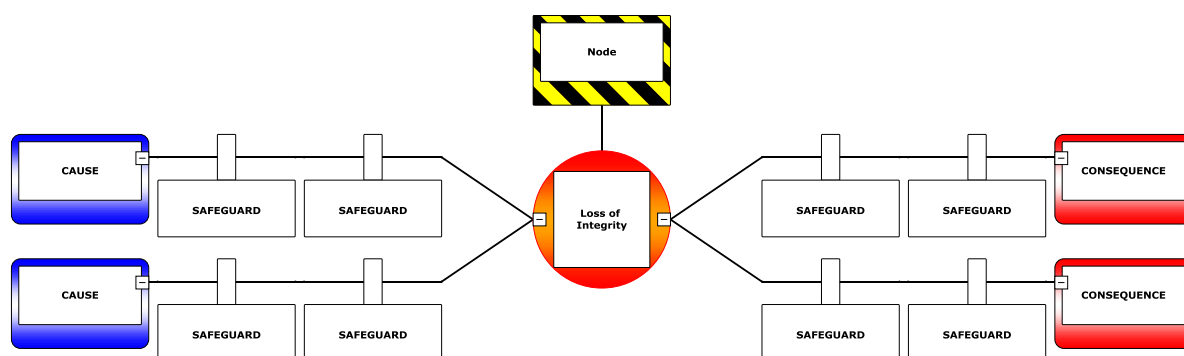


Figure 3 Simple Bowtie representation of a HAZOP

The visual intuitive nature of bowties allows the risks associated with the Cause/Threat-Consequence scenarios to be universally understood, promptly addressed, and successfully managed. This clarity helps study participants quickly develop hazard scenarios in a collaborative environment and also assists in recalling discussions several days or weeks after the study sessions have passed.

There are however a number of issues in simply swapping the terms over;

1. It is not clear what Deviations the Cause(s) and Consequence(s) relate to.
2. It is not obvious which Cause(s) lead to which Consequence(s).
3. A HAZOP node may have several different hazards associated with it.

To overcome these challenges, suitable software and an efficient HAZOP scribe are required, however since the industry should be moving towards appropriate tools and better use of limited resources, neither of these are considered to be insurmountable tasks. Arguably Microsoft® Office (either as Excel or Word) is the most common HAZOP recording tool however it does not offer the reporting, analysis & action management power of commercially available PHA tools (of which there are numerous on the market). Similarly, Bowties can be developed using conventional drawing, drafting or presentation tools, but again these formats offer little or no analytical features and there are Bowtie tools available which are much better suited to ongoing barrier-based risk management.

HAZOP guidewords, 'No Flow' etc can be offered to the team for consideration and possible Causes are documented as Bowtie Threats. For each Cause/Threat appropriate Safeguards that would prevent a Loss of Integrity (e.g. Containment or Control) are documented as Barriers. Thereafter Consequence(s) associated with that Cause/Threat are discussed & documented with appropriate recovery measures following the Loss of Integrity – again these are displayed as Barriers.

The 'conventional' HAZOP process continues with each Guideword/Deviation discussed and added to the Bowtie diagram. Where the same Cause arises during discussions of another Guideword/Deviation then it is recorded as the same Threat but can be annotated with another Deviation e.g. a closed valve can lead to No Flow and also More Pressure (upstream) or Less Pressure (downstream).

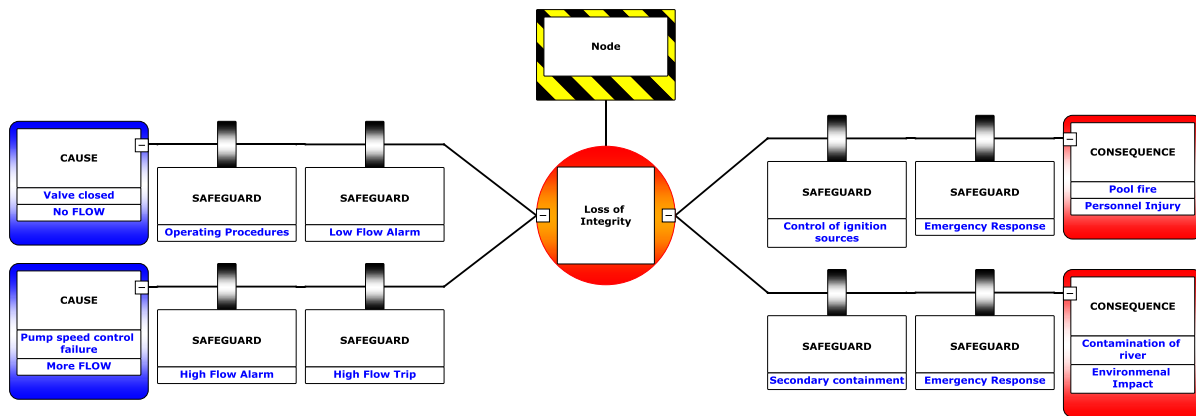


Figure 4 Developed Bowtie representation of a HAZOP

Where Deviations or not applicable, Causes are not credible, or Consequences are not significant, these can be recorded as such to provide full recording.

As the Bowtie develops, the relationships between the components are captured (by the Scribe whilst the discussion continues) and these can be used for analysis inside or outside the review meeting.

Although it is possible to convert HAZOP worksheets into Bowties (these are most effective when Safeguards are separated into Prevention & Mitigation measures) arguably any discrepancies e.g. missing or misplaced Safeguards need to be revisited by returning to the HAZOP and resuming the discussions. By developing the Bowtie as the discussions evolve (hence the need for an effective Scribe) such rework is avoided.

An enhanced HAZOP methodology approach is therefore suggested which exploits the immediate efficiency of scenario development plus the long-term knowledge retention that a simple but effective graphical representation offers. Bowties and worksheets can be easily interchanged to assist in the transition between primitive worksheets and a more advanced representation

Example

Consider the transfer of acid from vessels A to B, the HAZOP worksheet might look like this:

Deviation	Cause	Consequence	Safeguards
1. No FLOW	1. Pump stopped	1. Loss of production	1. Low flow alarm
	2. Line blocked - possibly due to sticky liquid	1. Maintenance call out will be needed	1. Low flow alarm 2. Flushing
	3. CV closed by Operator	1. Loss of production	1. Low flow alarm
	4. Tank empty (see previous node)	1. Loss of production	1. Operational 2. Low flow alarm
2. Less FLOW	1. Line clogged	1. Loss of production	1. Low flow alarm 2. Flushing
3. More FLOW	1. CV open too far	1. Loss of quality in tank	1. Operational
4. Reverse FLOW	1. Pump stops, CV open & pressure in B greater than A	1. Gas forces into tank A and escapes to atmosphere	1. CV closed by Operator before pump stops
	2. CV leakage when pump stopped	1. Gas forces into tank A and escapes to atmosphere	
5. Less TEMPERATURE	1. Loss of steam supply	1. High viscosity, pump cannot deliver. Risk of clogging pipes	1. Operational 2. Low temperature alarm
	2. Instrument fails	1. High viscosity, pump cannot deliver. Risk of clogging pipes	1. Operational
6. More TEMPERATURE	1. Temperature control fault on steam jacket	1. Excessive vapour from the acid. Environmental pollution	1. High temperature alarm
		2. Acute toxic risk to persons	2. Extended vent stack
		3. High rate of corrosion	3. Rubber-lined tanks & vent stack
7. Less LEVEL	1. No supply	1. No transfer	1. Operational
	2. Outflow exceeds inflow	1. Pump damage	1. Operational
8. More LEVEL	1. Uncontrolled input (inflow exceeds outflow)	1. Overflow to effluent drains	1. Operational
		2. Acid spills	2. High level alarm
9. Less COMPOSITION	1. Uncontrolled input	1. Reduced yield in Tank B	1. Operational
10. More COMPOSITION	1. Upstream mixture error	1. Pump drive overload. Pump overheats - moderate risk of fire in pump	1. Electrical overload switch fitted
	2. Low temperature (see above)		

Figure 4 Example HAZOP worksheet

However, representing this in a bowtie (consequences are colour coded to represent the impact type) shows a potential imbalance between prevention & mitigation safeguards as shown in the following diagram:

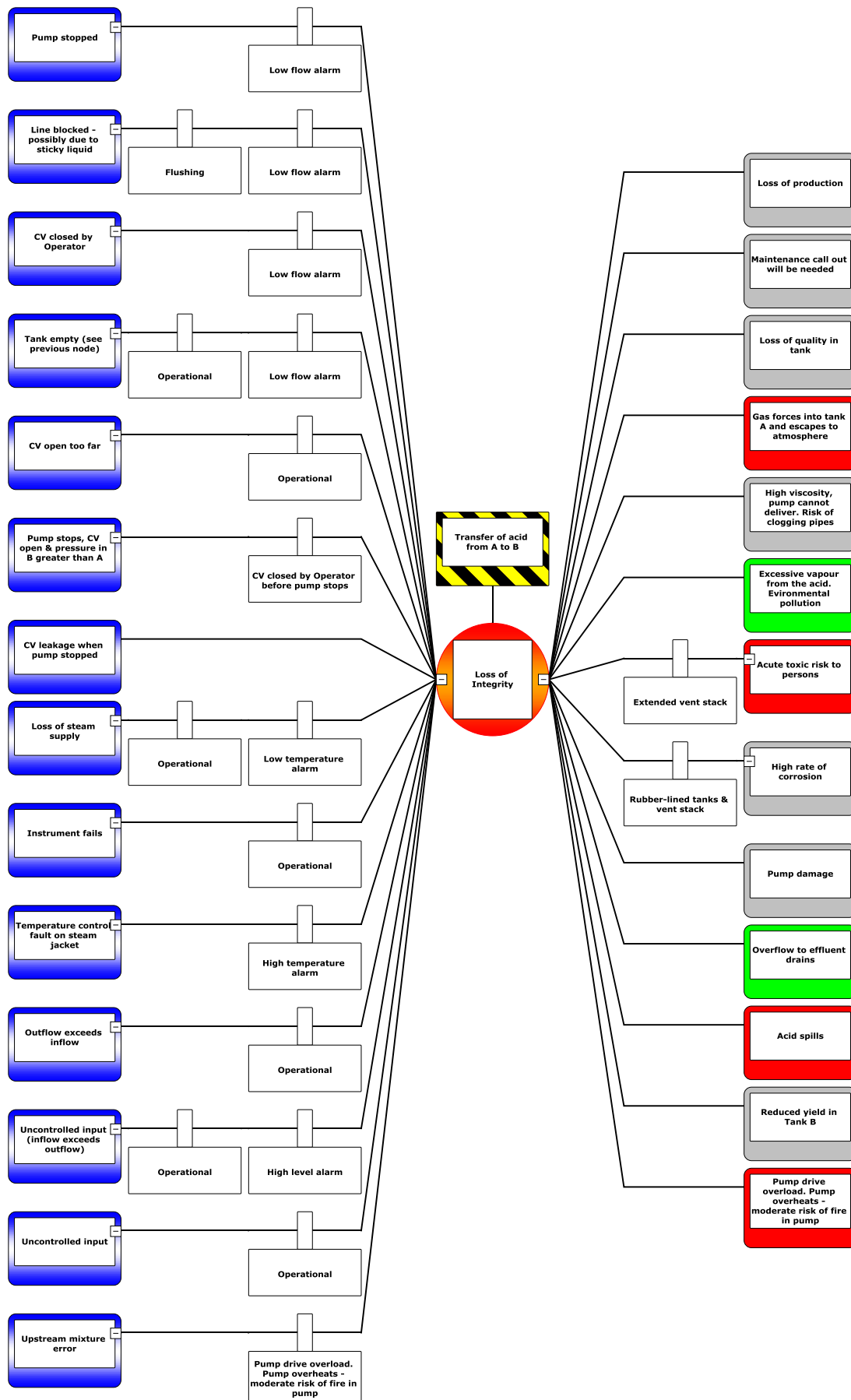


Figure 5 Example HAZOP bowtie

As mentioned earlier, this imbalance might be identified if the HAZOP worksheet was converted to a bowtie after the study, and whilst it is never too late to address issues unless & until the incident actually occurs, it is more efficient to spot such discrepancies while the knowledge is still in the room – hence the proposal to record the discussion in real-time using the bowtie format.

Benefits

Representing hazard scenarios in graphical rather than written format enables participants to maintain focus as they are not burdened by masses of text, yet they can be confident that their contributions are recognised and recorded.

Showing Safeguards as Barriers on their respective side of the Top Event ensures that the complete protection portfolio is represented and encourages the team to discuss and document each scenario all the way to its conclusion and not just stop at the hazard without considering what recovery measures may be available or what resilience is necessary.

A single view of a node presents oversight of the number of Threats to, Consequences from and the associated Barriers protecting an asset.

Conversely, viewers can focus in on areas of interest e.g. Cause-Consequence relationships or Barriers which are deployed in multiple locations which may be susceptible to common cause failure by the nature of their type, technology employed or requirement for manual interaction.

Challenges

HAZOP has proven its worth for several decades and it is acknowledged that attempts to change it may be perceived as compromising its effectiveness. This is addressed simply by clarifying that the HAZOP method remains unchanged, it is simply how studies are captured & communicated that offers advantages within and beyond the meeting room.

Conclusions

The well-established HAZOP procedure can be applied in a more effective format using Bowties rather than worksheets without compromising the systematic rigour offered by the technique.

Visual representation maintains participant engagement and encourages discussion on scenarios that are not apparent from tabular recording. The graphical illustration of the Threats (Causes), Barriers (Safeguards) and Consequences make it easier to share the outcome from the HAZOP to those who are responsible for sustaining the protection measures but were either not present or some time has passed since the study was conducted and the results published.

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