Process Safety Index - An objective, consistent method for evaluating the balance between Threats and Protection

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A consistent approach based on established industry principles to objectively evaluate the balance between threats and protection to assist duty holders to determine if they have adequate protection. A good set of performance indicators may indicate that operations are 'safe' but are they safe enough?

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Introduction

The quote (attributed to either W. Edwards Deming or Peter Drucker depending on your source) that "*If you can't measure it, you can't manage it*" is often used within the Process Industry to encourage companies to employ Process Safety Performance Indicators (PSPI) as an effective tool for monitoring and analysing the success of risk control measures both in terms of Leading (to provide advance warning of potential events) and Lagging (to record & evaluate these events when they occur).

High Reliability Organisations (HRO) utilise these indicators to improve performance and increase engagement, however with so many indicators to choose from, it is likely that different sites, companies, countries and industries will have different sets of indicators and it is therefore more challenging to identify and analyse wider trends in similar applications to maximise shared knowledge.

Furthermore, a good set of performance indicators may indicate that operations are 'safe' but are they safe enough?

This paper proposes a standard approach (called the **Process Safety Index**) which is based on established industry principles to objectively and consistently evaluate the fine balance between threats and protection in order to assist duty holders to determine if they have sufficient (or indeed excessive) protection in a way that can be anonymously compared across businesses without revealing sensitive process information.

In simple terms, the Process Safety Index is an arithmetic evaluation of the overall Protection against the Threat(s) being addressed.

Threats

Threats are determined by two factors, the Properties of the chemicals and their Processing conditions & location.

Properties (Chemicals)

These are evaluated using a variation of the Dow Fire & Explosion Index where chemical hazards are scored according to their material factors, general & special process hazards. A simplified approach is proposed which is initially based on the 4 categories within the NFPA 704 "Fire Diamond" which are:

- Health Hazards (blue square/quadrant at nine o'clock position in the diamond)
- Flammability Hazards (red square/quadrant at twelve o'clock position in the diamond
- Instability Hazards (yellow square/quadrant at three o'clock position in the diamond)
- Special Hazards (white square/quadrant at six o'clock position in the diamond)

The 3 principal categories of Health, Flammability & Instability hazards are assigned a degree of severity by a numerical (integer) rating ranging from 0 (indicating minimal hazard) to 4 (indicating severe hazard).

Special hazards relate to water reactivity and oxidising properties of the materials that may require specialist fire-fighting techniques and these are represented as follows:

- ~~W~~ Materials that react violently or explosively with water
- OX Materials with oxidising properties
- SA Simple Asphyxiants including Nitrogen, Helium, Neon, Argon, Krypton, Xenon & liquified CO_2

An example of the diamond for Toluene is shown below which highlights its particular Health & Flammability issues:

Figure 1 - Toluene NFPA 704 Diamond

Alternatively, more detailed evaluation of chemical hazards could be conducted using the 9 categories of the Globally Harmonized System (GHS) Classification:

- Explosive
- Flammable
- Oxidising
- Pressurised Gas
- Corrosive
- Toxic
- Hazardous to Health
- Harmful
- Environment

Figure 2 - GHS Classifications

Each Properties/Chemical contribution is assigned an integer score (higher value indicates more severe potential for harm).

Process (Conditions)

The processing contribution is determined by the following components:

- Pressure (may include vacuum)
- Temperature (may include cryogenic)
- Inventory (considers regulatory thresholds)
- Exposure (to/from personnel, the public, vehicles/equipment and the environment)

On the basis that the more extreme the conditions under which the material is handled and/or the more material there is and/or the more exposed the material is, then the greater the potential for and scale of a loss of containment.

Again, each Process/Conditions contribution is assigned an integer score (higher value indicates more severe potential for harm).

Protection

Protection is also determined by two factors, the Prevention measures and their actual Performance.

Prevention (Leading)

These are evaluated using a short (but representative) list of 8 Leading indicators - for example from the IChemE Safety Centre (ISC):

- Failed Tests of Safety Critical Elements (SCE)
- Overdue (open) Process Safety Items (non-compliance/actions)
- Overdue Training or expired Evaluation/Accreditation
- Overdue SCE Tests/Inspections
- Overdue Emergency Drills
- Overdue (outdated) Procedures
- Standing Alarms (per EEMUA 191)

- Overdue Process Safety Audits/Inspections

Each Prevention/Leading contribution is assigned an integer score (higher value indicates greater protection). This will be based on the number/proportion of items that are overdue/failed as well as how late they are i.e. a few items which are long overdue items are equivalent to many items which have short deferrals.

Performance (Lagging)

These are evaluated using a set of 4 Lagging indicators - for example:

- Accidents (resulting in Fatal or Serious Injuries)
- Incidents (loss of containment but no injuries)
- Unplanned Demands on SCE
- Alarm Floods (per EEMUA 191)

These are similar to, but distinct from, the 4 Tiers in API 754;

- Tier 1 LOPC (Loss of Primary Containment) Events of Greater Consequence
- Tier 2 LOPC Events of Lesser Consequence
- Tier 3 Challenges to Safety Systems
- Tier 4 Operating Discipline & Management System Performance

Where Tier 1 serves as a Lagging indicator, Tier 2 serves as a Leading indicator in that it is predictive of Tier 1 events and Tiers 3 & 4 serve as indicators for use at individual facilities.

However, whilst both the ISC and API consider Demands on Safety Systems and Safe Operating Limit Excursion (Alarms) to be Leading indicators, this paper suggests that they are considered as Lagging indicators instead since, although they do not indicate a loss of containment (of materials or energy), they do reflect a loss of control which is worthy of attention.

Each Performance/Lagging contribution is assigned an integer score (higher value indicates greater protection). This will be based upon the severity of the event or criticality of the SCE/Alarm and the number/proportion of items i.e. a few items which are severe/critical are equivalent to many items which are less severe/critical.

Calculation

The calculation of the Process Safety Index is a simple arithmetic evaluation where each THREAT (Properties & Process) and PROTECTION (Prevention & Performance) is assigned an integer value. For Threats, higher values indicate greater potential for harm whereas higher Protection values indicate better 'safety'.

Threat & Protection elements are then multiplied together i.e.

- THREAT = [Σ(Properties)] * [Σ(Process)]
- PROTECTION = [Σ(Prevention)] * [Σ(Performance)]

The Process Safety Index is the PROTECTION score minus the THREAT score which results in either a negative index, where the Threats outweigh their Protection or a positive index, where Protection outweighs the Threats. A zero index is also a possibility where the Threats & Protection are equally balanced. The more negative or positive the index, the greater the imbalance in the respective direction.

For example, if the following scales were adopted:

- THREAT | Properties 4 off ranged 0 - 4
- THREAT | Process 4 off ranged 0 - 2
- PROTECTION | Prevention 8 off ranged 0 - 2
- PROTECTION | Performance 4 off ranged 0 - 2

Then the Process Safety Index would range from -128 (Max Threat & Min Protection) to +128 (Min Threat & Max Protection) and could be colour coded according to the following bands (comparable to risk tolerability):

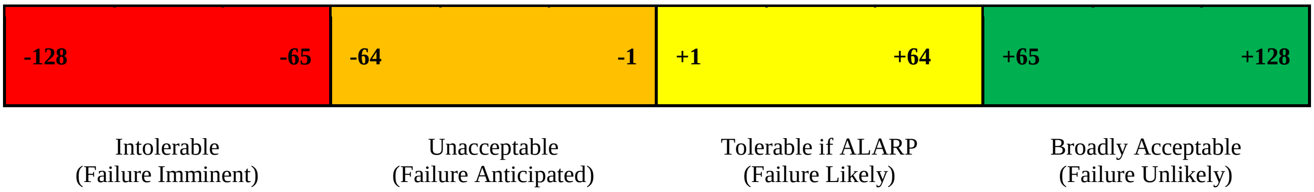

Figure 3 - Example Process Safety Index spectrum

Calibration

Threat and Protection components are weighted, and particular care must be taken to ensure that combinations of contributions do not cancel each other to provide misleading results.

It must be recognised that innocuous fluids such as water can be hazardous at extreme conditions i.e. high pressure/temperature steam and it may be appropriate to set the minimum Properties value to 1 (rather than 0) for materials that do not generate a conventional score (in NFPA 704 or GHS) to recognise the potential for harm.

Similarly, it is conceivable that high energy equipment, such as gas turbines or compressors can shed projectiles with devastating effects, however the method of scoring this is yet to be considered.

Process values should start from 1 (not 0) to ensure that “normal” conditions do not cancel out high property values.

With respect to Protection, high (good) Prevention (leading) values with low (bad) Performance (lagging) values may indicate that the wrong Leading indicators are being monitored/managed – since events are still occurring. Conversely, low (bad) Prevention values with high (good) Performance values may indicate that you’ve just been lucky – accidents are waiting to happen.

On this basis, poor Leading should not be compensated by good Lagging values (and vice versa) hence the minimum value for both should be set to 0 (not 1).

Applications

The Process Safety Index would be applied to a particular Unit Operation or Major Equipment which can then be aggregated up the asset hierarchy e.g. Unit | Area | Site | Region | Enterprise.

For maximum visibility & engagement, colour coded Block Flow Diagrams (similar to OSHA PSM Appendix B) could be used, for example:

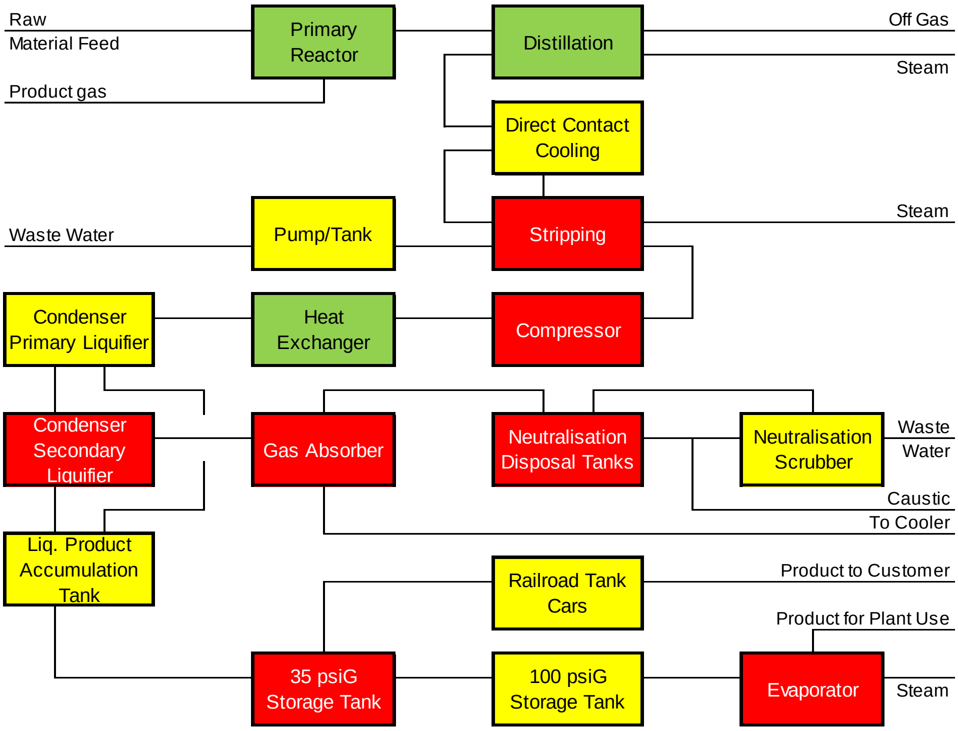

Figure 4 - Example Block Flow Diagram (OSHA PSM Appendix B)

This provides a high level ('drone') view of the interconnections between major process units/unit operations. This could be used to feed a management dashboard with clear, consistent thresholds for alarm & action e.g. when the index falls below certain values.

Ideally, the visualisation would be as 'live' as practical with interfaces to Process Control and Maintenance Management Systems. This could be used to predict future performance (expected to be Protection degradation rather than short/medium term Threat increases) in a similar way to stock/share prices.

Companies could compare internal performance across sites, business units or regions and also external performance against industry peers (competitors) – albeit this would require hosting by a 'neutral' body e.g. a professional institution.

It is conceivable that the Process Safety Index (or at least the colour) could be displayed at the entrance to a site to advise personnel of the current health of the facility e.g. in a similar way that the number of days since an accident/incident are often presented, however it is acknowledged that this could attract negative internal & external publicity and may be counter-productive.

Challenges

The success or failure of this method depends heavily on its calibration and it is acknowledged that, whilst certain components such as the NFPA 704 classification are clearly defined, the criteria for determining other contributions are more subjective e.g. pressure ranges/thresholds.

It is also recognised that there are a variety of similar Process Safety Leading Indicator guidelines which typically have around 20 components relating to both organisational and technical aspects. In order to make the index useable, a short list of 8 is currently proposed which focusses on metrics that are both Unit Operation or Equipment specific and also relatively dynamic.

For example, culture, competence & compliance are recognised as appropriate behavioural measures to gauge the organisational robustness, however these may be considered universal across a plant, site or region and therefore do not provide the necessary granularity to focus attention on weak or failing assets & activities.

Whilst it is acknowledged that many companies already have established PSPI systems and therefore don't wish to 'start again' or 'change tack', adopting a calibrated (consistent) but neutral (anonymous) format that is based on most of the metrics they are likely to track anyway, enables them to measure their performance against their peers to gauge if they are keeping up with good or best practice.

Conclusions

The principles of the Process Safety Index are similar to that of Risk where the Threat represents the potential Consequences and the Protection represents the Likelihood of these Consequences occurring, however by using internationally recognised components, the evaluation is less subjective, and the method of scoring Threats can also be used for risk ranking within conventional Process Hazard Analyses such as HAZOP.

A consistent approach to scoring Process Safety Threats & Protection allows clearer comparison within and between businesses and highlights weaker Prevention measures that require greater focus (it is simply assumed the Performance improvement will result from better Prevention).

Finally, future performance may be predictable (within reason) based on actual or anticipated degradation so that investment (or other) decisions can be made more confidently.

Industry engagement is sought (provisionally assumed to be in conjunction with institutions) to gauge interest from interested parties and identify pilot sites where the method could be trialled. In the era of big data gathering, analysing and sharing the index and its components is not a technology challenge but a cultural consideration.

References

AIChE: Dow's Fire & Explosion Index Hazard Classification Guide

API: RP 754 - Process Safety Performance Indicators for the Refining and Petrochemical Industries

EEMUA: Publication 191 Alarm systems - a guide to design, management and procurement

IChemE Safety Centre: Guidance Lead Process Safety Metrics – selecting, tracking and learning 2015

NFPA: 704 - Standard System for the Identification of the Hazards of Materials for Emergency Response

OSHA: 29 CFR 1910.119 Process safety management of highly hazardous chemicals.

United Nations: Global Harmonized System of Classification and Labelling of Chemicals (GHS)