*Capstone Project (Fall 2025)*
*Oral Report:*

# *Process Safety & Reliability Group*

# *Designing a Scalable Process Safety Performance Measurement System for Companies at Different Stages of Process Safety Maturity*


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# Agenda

1. Background and Challenges
2. Project Aim and Scope
3. Framework Development
4. KPIs & Maturity Model
5. Pilot Study- Framework Implementation & Validation
6. Results
7. Future Work

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# Background and Challenges

- Small to mid-sized companies lack structured systems for consistent performance measurement.
- Even large companies show non-standardized metrics across sites.
- Process safety performance often measured through lagging indicators.
- No structured, measurable way to track improvement.
- Scattered data, No performance visibility, Repeated incidents.

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# Project Aim and Scope

- Develop a practical Process Safety Performance Measurement System (PSPMS).
- Create KPIs, review questions, and a maturity model for 10 key process safety element.
- Ensure usability for companies with limited data and varying process safety maturity.
- Providing a way to evaluate performance without depending solely on audits.

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# Why OSHA Highlights 5 Elements for Small Companies

## OSHA 3908-03 2017 Process Safety Management for Small Businesses

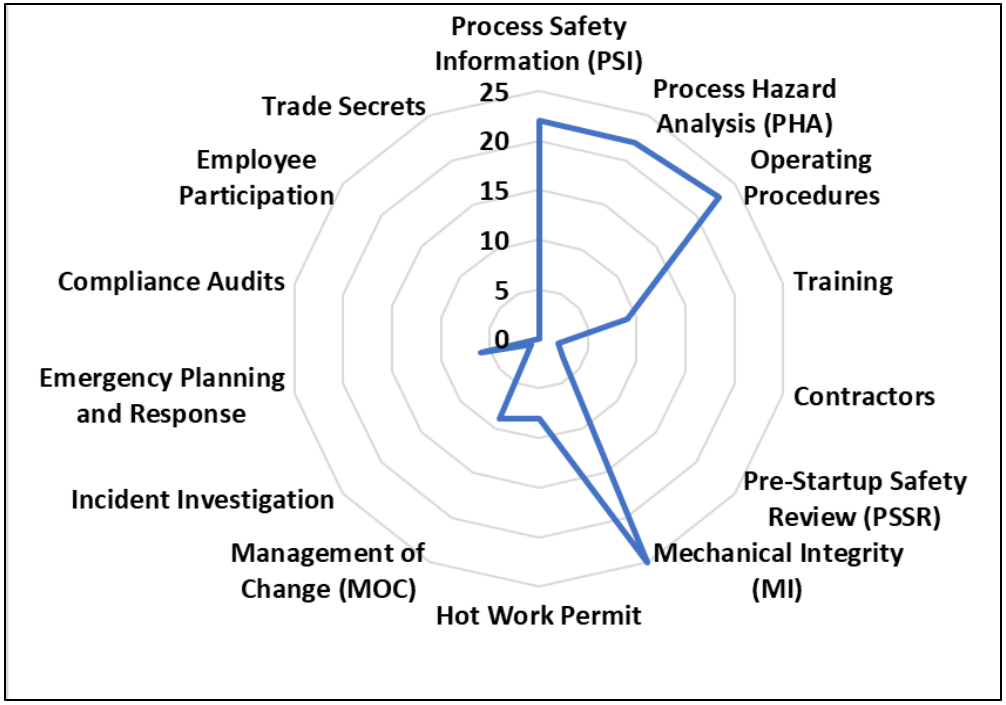
| Element | Why It's More Relevant |
|---|---|
| Process Safety Information (PSI) | Clear chemical and equipment info helps limited staff quickly understand hazards. |
| Process Hazard Analysis (PHA) | Simple methods (What-if/Checklist) make hazard reviews easier and cost-effective for smaller processes. |
| Training | Ensures all employees understand hazards and safe practices, critical when staff have multiple roles. |
| Mechanical Integrity (MI) | Equipment failures can be catastrophic; maintaining fewer but critical assets properly helps small companies avoid major incidents with minimal resources. |
| Compliance Audits | Regular audits catch gaps early and maintain compliance despite limited expertise. |

# Incident Investigation

## CSB incident reports

- 30 incidents from the past 3 years analyzed.
- Mechanical Integrity is the leading issue overall, followed by operating procedure (OP), PHA, and PSI.
- Additional elements identified as critical:
  - Operating Procedures
  - Management of Change
  - Hot work permit

Incident Analysis - PSM Deficient Elements




The spider chart depicts the no. of companies that experienced incidents associated with failures in the respective PSM element.

# Adding 5 More Elements

## Adopted from OSHA PSM & RBPS Elements

| Element | Justification |
|---|---|
| Management of Change (MOC) | Ensures disciplined review of modifications to avoid introducing new risks. |
| Operating Procedures | Regularly reviewed and simplified SOPs improve safety and operator consistency. |
| Permit System & Safe Work Practices | Standardized permits for hot work, confined space, and maintenance ensure consistent control of high-risk tasks. |
| Contractor Management | Helps small firms oversee contractors through qualification, training, and supervision. |
| Incident Investigation & Learning | Promotes quick learning and sharing of lessons to prevent repeat incidents. |

# Introducing the Process Safety Performance Measurement System (PSPMS) Framework

## Leading vs. Lagging KPI Logic

| Leading Indicators | Lagging | Review Questions | Maturity Level (1-4) | Dashboard |
|---|---|---|---|---|
| • System health | • System outcomes | • Self assessment | • Capability | • Decision support |

| Leading | Lagging |
|---|---|
| • Early warning signals.<br>• Proactive corrective actions.<br>• Provides basis for early intervention, preventing Tier 1/Tier 2 events. | • Measures actual outcomes and consequences.<br>• Helps identify recurring failure pattern. |

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# Maturity Levels (PSRG Maturity Model)

**Level 1 (Reactive/Initial)**

Immature safety system. No formal PSM. Risks managed on ad hoc basis.

**Level 2 (Dependent/Defined)**

Policies exist but are inconsistently applied. Basic PSM structure only.

**Level 3 (Independent/Managed)**

Well-defined PSM consistently applied. Individuals actively use tools.

**Level 4 (Optimized/Interdependent)**

Proactive, peer-to-peer culture. Continuous improvement and data-driven performance.

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# Maturity Model Levels

| Maturity Model Levels- Leading Indicators | |
|---|---|
| Level Range | Criteria |
| Level 1 | 0 - 30% |
| Level 2 | 31 - 60% |
| Level 3 | 61 - 85% |
| Level 4 | 86% - 100% |
| | |
| Maturity Model Levels- Lagging Indicators | |
| Level Range | Criteria |
| Level 1 | > 60% |
| Level 2 | 31 - 60% |
| Level 3 | 16 - 30% |
| Level 4 | 0 - 15% |
| | |

- Based on PSRG Maturity Model, the Level 1- Level 4 scale was selected.
- % metrics offer a simple and objective way to measure progress.
- More reliable than qualitative scoring by reducing subjectivity and bias.
- Uneven thresholds (30–60–85–100%) reflect increasing difficulty as maturity improves.
- Higher leading indicator performance and lower lagging event rates signify progression from reactive to predictive safety maturity.

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# Dashboard Example: Mechanical Integrity

Track what's strong. Fix what's weak. Transform compliance into measurable performance.

| Element: Mechanical Integrity | | | | |
|---|---|---|---|---|
| | **Key Performance Indicators** | **Company Data (%)** | **Level Assigned** | **Score** |
| | **Leading Indicators** | | | |
| 1 | % of pressure vessels/piping inspected on schedule | 90 | Level 4 | 4 |
| 2 | % critical safety interlocks tested as per schedule | 80 | Level 3 | 3 |
| 3 | % of pressure relief devices tested and recalibrated within prescribed intervals. | 70 | Level 3 | 3 |
| 4 | % of corrosion monitoring points inspected or sampled as per defined frequency. | 50 | Level 2 | 2 |
| 5 | % of maintenance procedures reviewed & updated annually | 40 | Level 2 | 2 |
| 6 | % of protective relays, MCCs, and UPS units tested | 20 | Level 1 | 1 |
| 7 | % of pumps inspected/tested | 10 | Level 1 | 1 |
| | **Lagging Indicators** | | | |
| 8 | % of failures occurring on equipment with prior maintenance or inspection within the last 12 months. | 10 | Level 4 | 4 |
| 9 | % of leaks, ruptures, or LOPC due to MI program failure (corrosion, thickness, overpressure, wrong MOC) | 30 | Level 3 | 3 |
| 10 | % of incidents caused by improper maintenance procedures or technician error | 50 | Level 2 | 2 |
| | **Review Questions** | | | |
| 1 | Does the MI program clearly identify and include all safety-critical equipment, instrumentation, and utilities? | | | |
| 2 | How do you schedule, document, and verify on-time preventive maintainence for all plant equipment? | | | |
| 3 | Are equipment failures or near misses systematically analyzed for root causes and used to strengthen the MI program? | | | |
| 4 | Is there a structured process to identify, track, and replenish safety-critical spare parts inventory? | | | |
| 5 | Does management review MI performance metrics regularly and act on trends or recurring deficiencies? | | | |
| | **Overall Score** | | **Level 2** | **2.5** |

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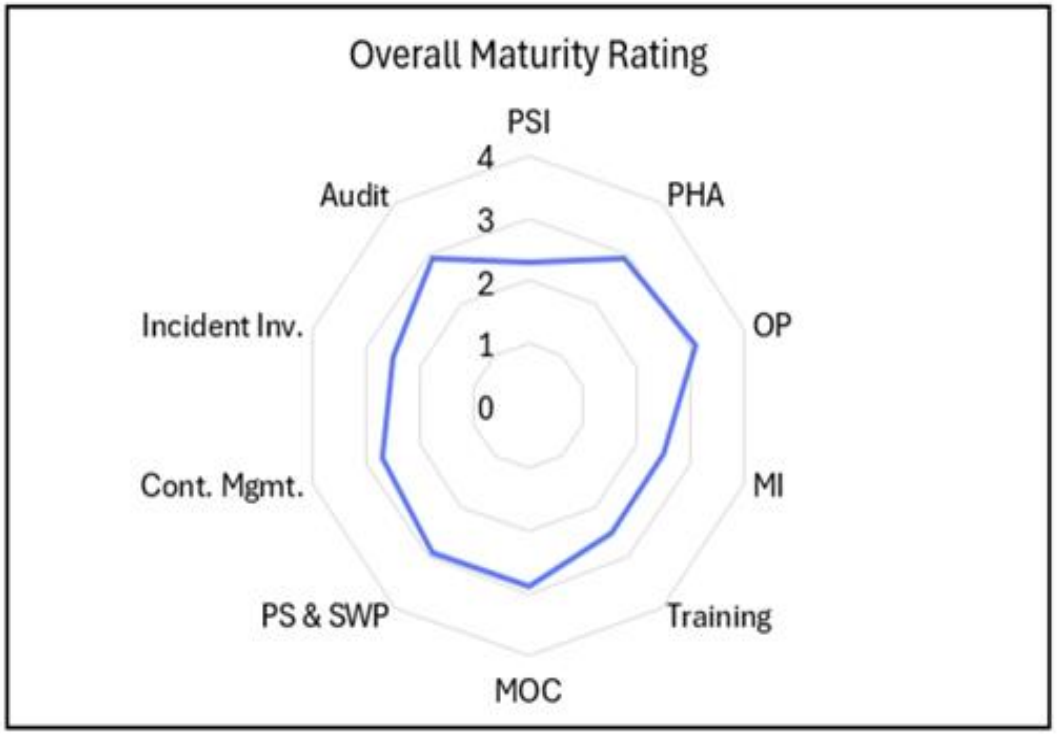
# *Matrix Level Example*

| No. | Element | Level | Score |
|---|---|---|---|
| 1 | PSI | Level 2 | 2.3 |
| 2 | PHA | Level 3 | 2.9 |
| 3 | OP | Level 3 | 3.1 |
| 4 | MI | Level 2 | 2.5 |
| 5 | Training | Level 2 | 2.5 |
| 6 | MOC | Level 3 | 2.9 |
| 7 | PS & SWP | Level 3 | 2.9 |
| 8 | Cont. Mgmt. | Level 2 | 2.7 |
| 9 | Incident Inv. | Level 2 | 2.5 |
| 10 | Audit | Level 3 | 2.9 |
| Overall Maturity Level | | Level 2 | 2.72 |

| Levels | Scoring | Description |
|---|---|---|
| Level 1 (Reactive/Initial) | <1.5 | Fragmented and non-systematic approach. |
| Level 2 (Dependent/Defined) | 1.5–2.8 | Developing; partial formalization. |
| Level 3 (Independent/Managed) | 2.8–3.4 | Structured and improving system. |
| Level 4 | ≥ 3.4 | Predictive, data-driven safety culture. |




Track what's strong, fix what's weak

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# Pilot Case Study: Maturity Assessment of a Small Chemical Plant in North America

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# Methodology & KPI Selection

- Collected **near-miss and incident data** shared by the site.
- Mapped each incident to **5 OSHA PSM** elements.
- **Developed KPIs** for each element directly from the site's near-miss trends.
- Applied **the Level 1–4 maturity scoring model** based solely on verified site evidence and documented practices.
- Where information was missing, assumptions were transparently made and treated as indicators of maturity gaps.

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# Element-Wise Strengths and Gaps (Based on Actual Site Evidence) - Weak Elements

## Mechanical Integrity (MI)

- Strengths: Reactors, tanks, and major equipment had inspection records.
- Gaps: Pipelines, corrosion monitoring points, and instrumentation lacked inspection/testing documentation.

## Process Hazard Analysis (PHA)

- Strengths: 5-year re-PHA cycle was completed on time.
- Gaps: Some PHA recommendations were not closed and updated within the timeline.

## Process Safety Information (PSI)

- Strengths: P&IDs and SDSs were available and accessible.
- Gaps: Chemical compatibility data and PRD sizing/relief basis were missing.

# Element-Wise Strengths and Gaps (Based on Actual Site Evidence)- Elements that appear to be Strong

## Operating Procedures (OP)

- Strengths: SOPs and batch records were well documented with daily operating instructions.
- Gaps: No documented emergency response instructions for power failure at each reaction/processing step.

## Training

- Strengths: Operators received regular training and refresher programs.
- Gaps: No formal competency verification or documented assessment of operator capability.

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# *Element-wise KPI Maturity Level Scoring Matrix*

| Element | Level 1 | Level 2 | Level 3 | Level 4 | Plant Score |
|---|---|---|---|---|---|
| **Process Safety Information (PSI)** | 1. % of safety-critical equipment with fully documented PSI<br>2. % of chemical compatibility assessments | | 3. % of leaks/corrosion/failures linked to wrong material of construction selection | 4. % of P&IDs verified/validated<br>5. % of SDS updated and accessible | **2.6** |
| **Process Hazard Analysis (PHA)** | 1. % of PHA recommendations tracked through MOC<br>2. % of incidents involving missed hazards during PHA | 3. % of PHA recommendations closed within timeframe | | 4. % of PHAs completed/revalidated in required 5-year cycle<br>5. % of PHAs updated following major changes | **2.4** |
| **Operating Procedures (OP)** | 1. % of procedures including corrective actions for emergency power failure | | 2. % of incidents where deviation from procedure was root cause | 3. % of procedures reviewed annually<br>4. % of shift-log checklists verified<br>5. % of operators trained on revised procedures | **3.2** |
| **Mechanical Integrity (MI)** | 1. % of pressure relief devices tested/recalibrated<br>2. % of corrosion monitoring points inspected | 3. % of equipment failures occurring despite maintenance | | 4. % of pressure vessels inspected on schedule<br>5. % of critical safety interlocks tested | **2.4** |
| **Training** | 1. % of training programs updated after MOC/incidents | | | 2. % of employees completing mandatory training<br>3. % of contractors completing safety induction<br>4. % of emergency drills conducted<br>5. % of emergency drill deficiencies corrected | **3.4** |

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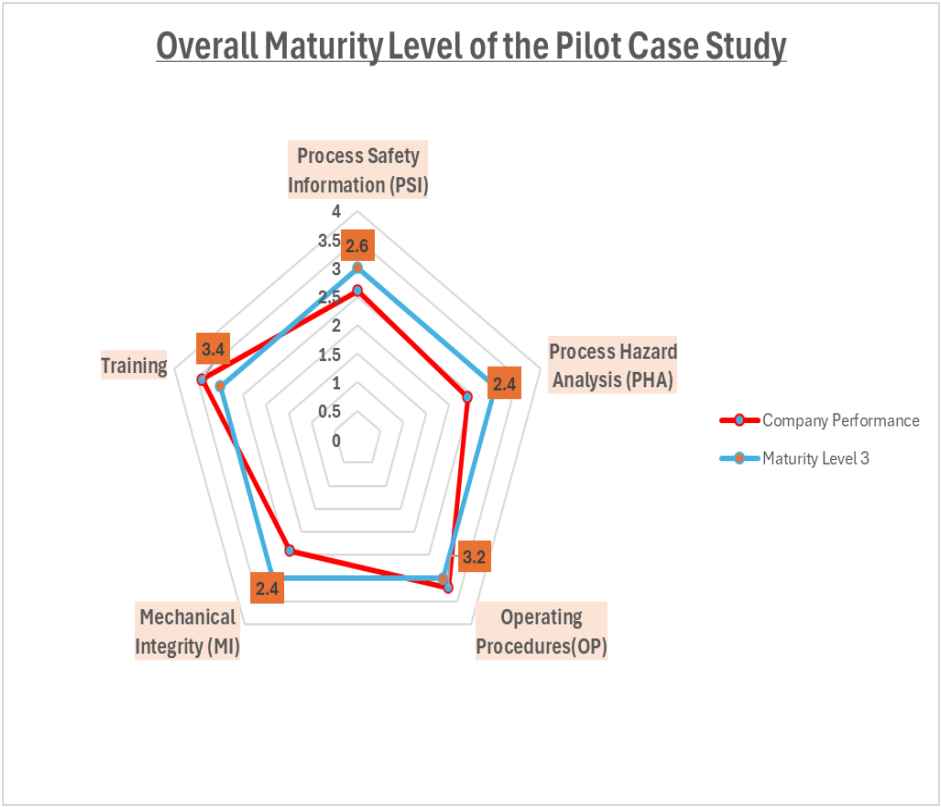
# Key Takeaways & Maturity Scoring

- The maturity scores accurately reflected the strengths and weaknesses observed in actual site data for the KPIs selected for the 5 elements.
- Elements with incomplete documentation & inspections (PSI, MI) naturally scored lower.
- Recurring themes in near-miss data aligned with lower maturity levels, confirming the framework's reliability.



# Training Score vs. Real Incident Patterns

- Training systems appear strong on paper.

- **However, year-wise incident trends show handling errors, incorrect chemical additions and few LOPC incidents.**

- These patterns indicate **operational discipline and task-specific competency gaps**, not captured by the leading indicators used for scoring.

**Key Limitations include:**

- The current KPI set measures *training completion*, not *training effectiveness*, procedural clarity, or operator competency during real work.

- But does **not fully represent on-the-floor human performance**, which the incident data highlights.

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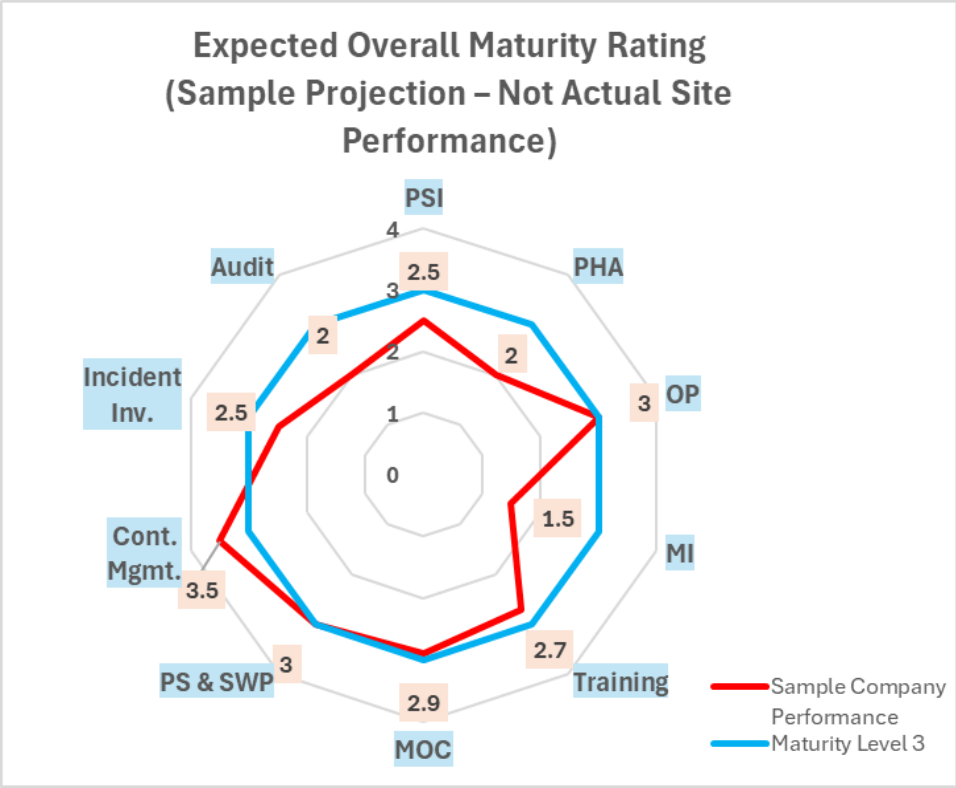
# Next Steps Toward a Comprehensive Maturity Model




- Expand the KPI set beyond the initial limited indicators to capture full process coverage.
- Include deeper evaluation of additional elements such as **MOC, PTW, Contractor Management, and Incident Investigation**.
- Replace assumption-based scoring with validated and complete site data.
- Strengthen the model using **fully verified KPI inputs** for accurate maturity determination.

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# What this work demonstrates?

- Transforms complex PSM expectations into measurable performance.
- Provides clarity, visibility, and predictive insight.
- Introduces internal benchmarking, allowing companies to compare maturity across production units or sister sites.
- Enables monthly performance tracking through dashboards, so leadership can see what is improving, what is drifting, and where interventions are needed.

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# Future Scope & Enhancements

**Smarter KPIs. Deeper Insight. Stronger Systems.**

- **Expand KPIs** to include qualitative KPIs and risk-based weightage.
- **Add guidance prompts** so companies know exactly what a low score means
- **Integrate framework into daily operations**, not as an audit or checklist
- **Automate dashboards** for monthly tracking and internal benchmarking,
- **Extend assessment** to cover all OSHA elements.
- **Validate across multiple sites** to strengthen industry applicability.

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# References


- Department of Labor, U. S., Herman, A. M., & Jeffress, C. N. (2000). Process Safety management. In OSHA 3132. https://www.osha.gov/sites/default/files/publications/osha3132.pdf
- Center for Chemical Process Safety. (2014). Risked based Process Safety Overview. American Institute of Chemical Engineers. https://www.icheme.org/media/17250/risk_based_process_safety_overview.pdf
- API Recommended Practice 754, 3rd Edition. (n.d.). https://www.api.org/products-and services/standards/important-standards-announcements/754.
- U.S. Department of Labor. (2017). Process safety management for small businesses. In U.S. Department of Labor. Process Safety Management for Small Businesses.
- Incident Reporting Rule Submission Information and data - Volume III of CSB Incident Reports. https://www.csb.gov/news/incident-report-rule-form-/.
- Kunt, T. et al. (2023) 'Maturity model approach for building effective process safety management systems,' Process Safety Progress, 43(2), pp. 233–238. https://doi.org/10.1002/prs.12543.
- Workplace Safety and Health Council (Chemical Industries) Committee (2018) Guidelines on Process Safety Performance Indicators, Workplace Safety and Health Council (Chemical Industries) Committee, p. 2.


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*Questions?*

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