

Determination of Common Root Causes of 300+ Global Process Safety Incidents

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INTRODUCTION

- Process safety incidents can cause widespread impact to humans, property, and the environment, so one tries to learn from such incidents to prevent them from happening again.
- Objective is to analyze previous incidents and categorize them based on the location / country, type of industry, number of incidents & fatalities, primary root causes, and public & economic impacts.
- Study treats process safety incidents more broadly than ‘unintended release of a hazardous substance, resulting in ... impacts’, EG – shipping, space shuttle, ...
- Lack of a comprehensive database of incidents is well-recognized challenge.

DATABASES

- Study consists of 331 incidents from three sources:
 - eight years of ~65 student investigation reports of author's process safety class (157 separate incidents after removing duplicates),
 - incident investigations of the Chemical Safety Board (CSB) (101), and
 - 28th edition report of Marsh's '100 Largest Losses in the Hydrocarbon Industry, 1974-2023' (73 incidents).
- DtB 1 includes broadest range of incidents, beyond chemical and oil & gas – Chernobyl, Fukushima, Halifax, Tx City shipping, Boeing 737, ...
- Incidents listed in DtB 2 were investigated more rigorously than others; thus duplicates removed from DtB 3 & 1, respectively. Common DtB 1 incidents removed from DtB 3. Incident details confirmed via internet.

Timeline	<u># Industry Types</u>
-Database 1: 1917-2023	14
-Database 2: 1998-2023	7
-Database 3: 1974-2023	5

INCIDENT ANALYSIS – root causes

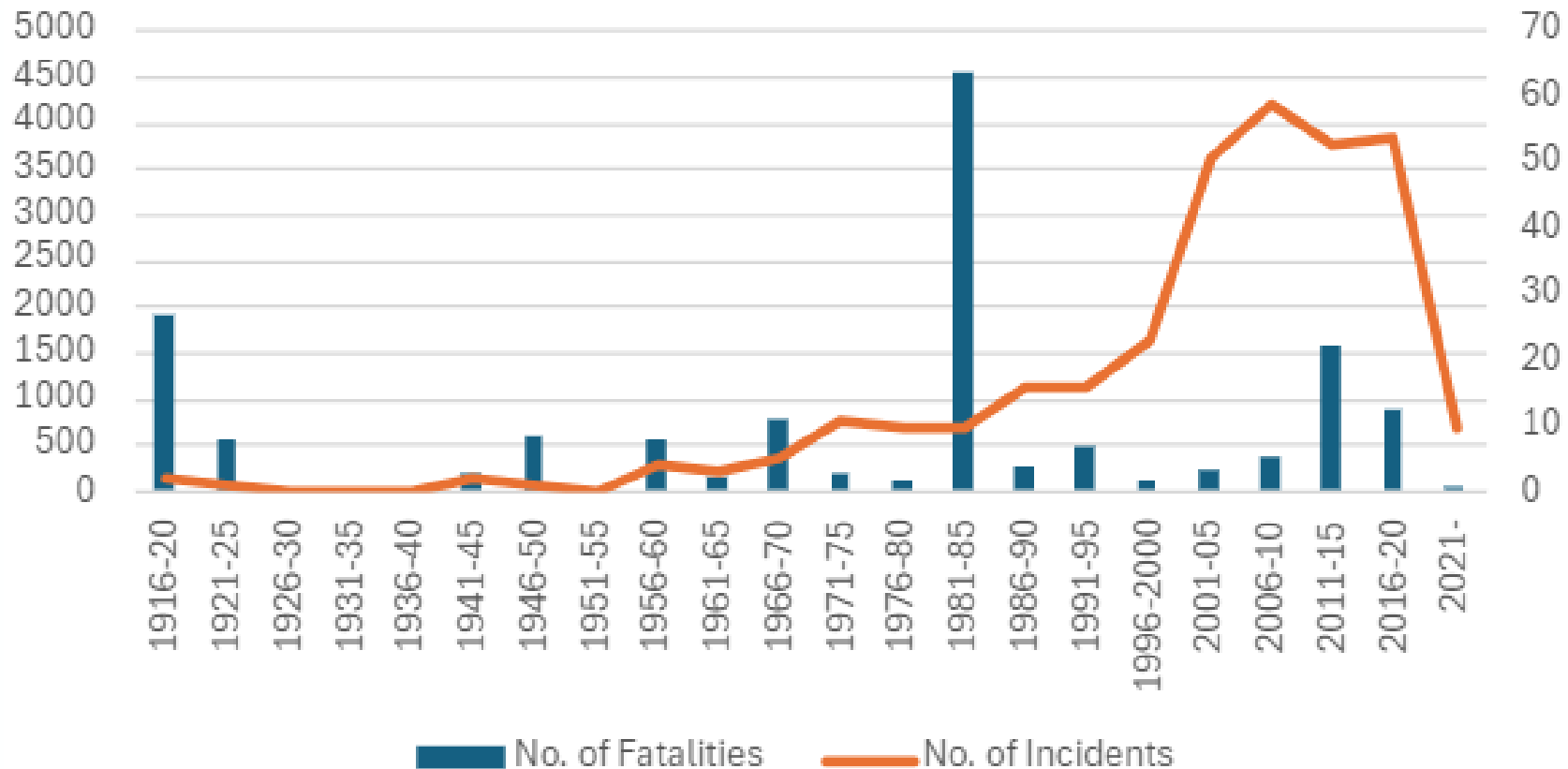
- Incident types include: agriculture, manufacturing, pipeline, oil & gas, chem ..
- Two primary root causes were chosen for each incident.
- 18 different types of root causes were included in study, per OSHA & CCPS:

1. Safety Culture (SC)
2. Hazard Awareness and Identification
3. Process Hazard Assessment (PHA)
4. Operating Procedures (OP)
5. Work Permit System
6. Personnel Training (PT)
7. Mechanical Integrity (MI)
8. Safeguards, Controls & Layers of Protection
9. Preventive Maintenance (PM)
10. Management of Change (MOC)
11. Contractor Management
12. Design
13. Human Factors (HF)
14. Facility Siting
15. Regulations and Regulatory Oversight (Regs)
16. Pre-startup Safety Review
17. Natural Disasters
18. Emergency Preparedness and Response (ER)

ANALYSIS - outline

- Significant flexibility in analyzing data in terms of region, industry, incidents, fatalities, impacts, root causes ... by database.
- Will share:
 - # incidents & fatalities over time
 - Distribution of incidents per country
 - # fatalities per country
 - # incidents per type of industry
 - # fatalities per type of industry
 - Economic & public impacts
 - Root causes by industry
 - Root causes post-2000 across all databases

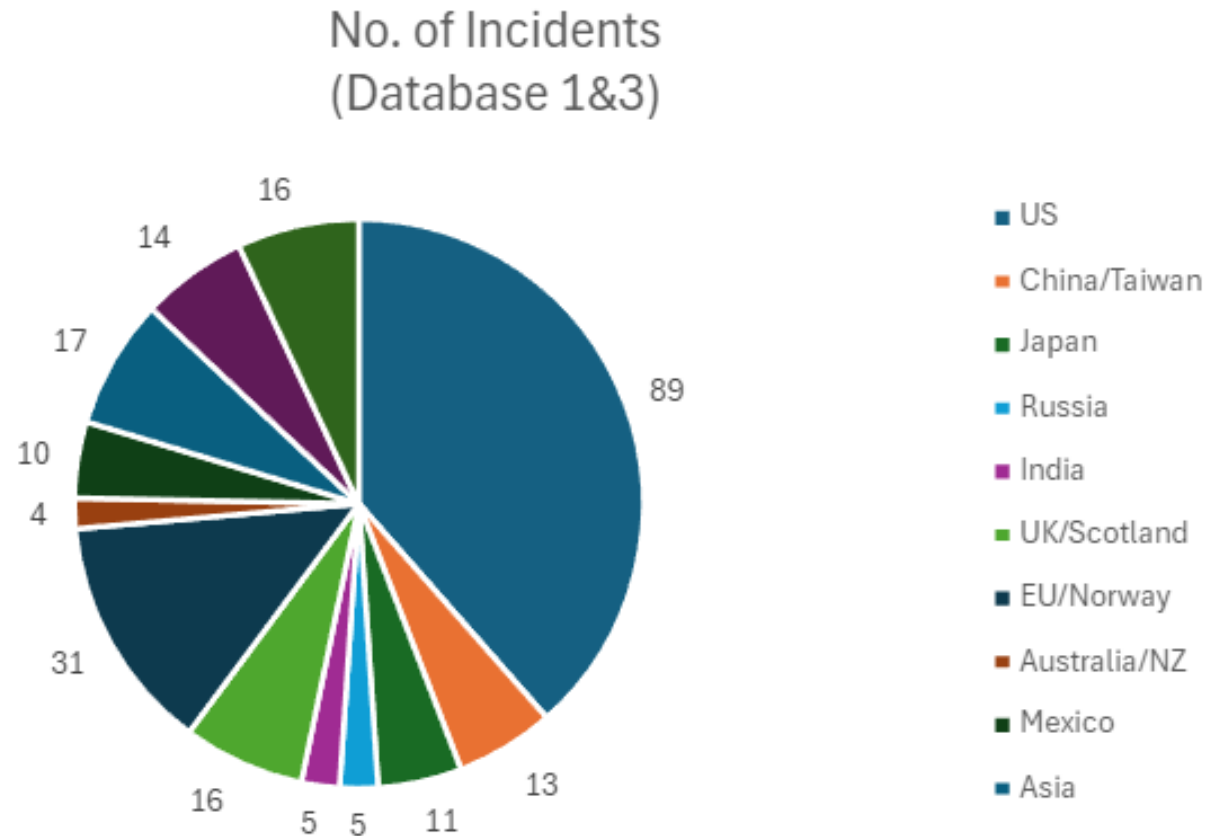
Number of incidents and fatalities with time



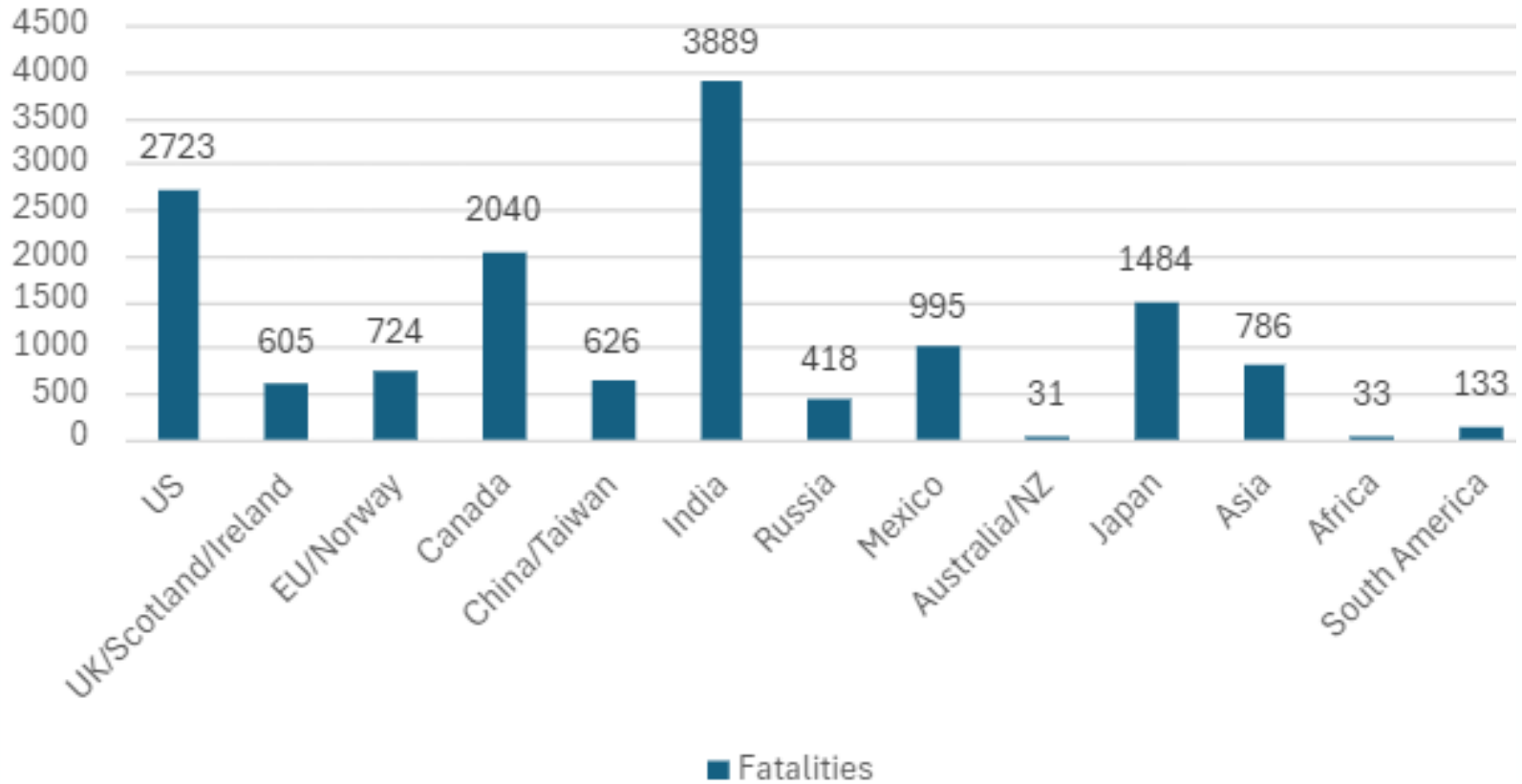
- Combination of all three data sets.
- The number of incidents per year is generally increasing with time while fatalities are relatively flat.

Incident distribution per region

- Chart does not include CSB, which are all US incidents
- Most incidents in US (89) followed by EU / Norway (31), then (17) in Asia
- Incident reporting is not consistent in all regions, although major incidents likely reported
- **Message:** no country is immune to incidents



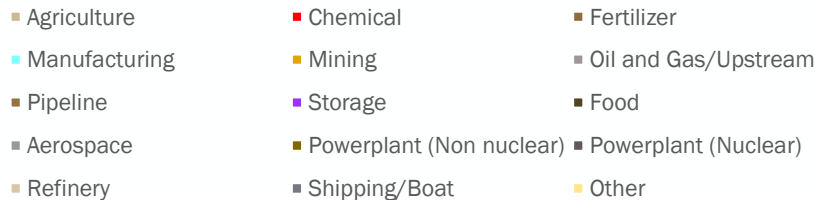
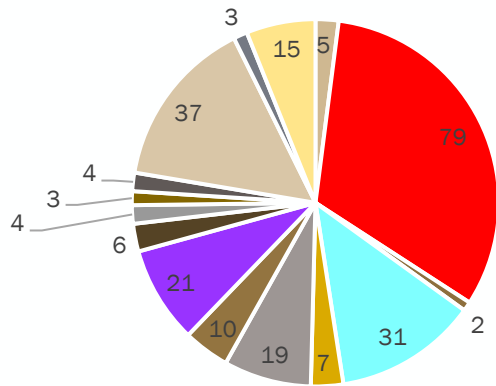
Fatalities per region; all databases



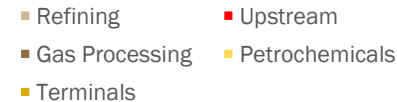
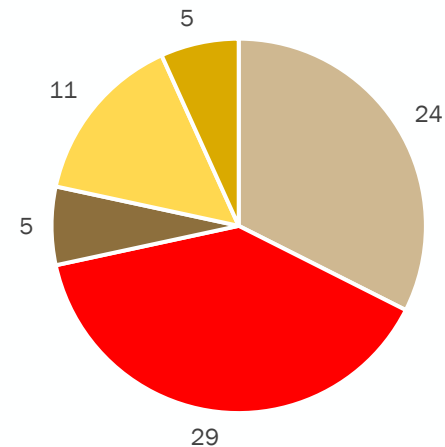
Data impacted by: India – Bhopal (3,787 fatalities); US - Love Canal (725), TX City Shipping (581), Boeing 737s (346); Canada - Halifax (1,900); Japan – Minamata Mercury (900)

Distribution of incidents per type of industry

No. of Incidents
(Database 1&2)



No. of Incidents
(Database 3)

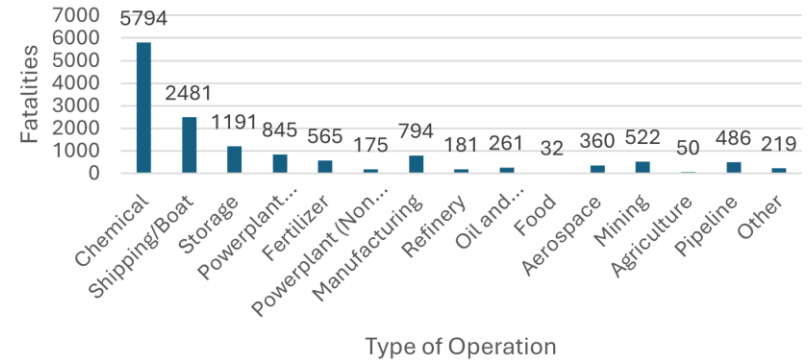


- Chemical industry had the most incidents in both DtB 1 & 2, followed by refineries and manufacturing
- Upstream sector had the most incidents in Marsh's DtB 3, followed by refining.

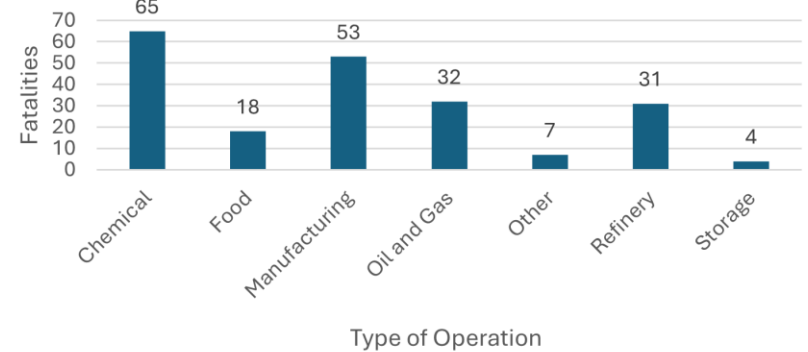
Fatalities per type of industry

- Chemical industry has the largest number of fatalities in both DtB 1 & 2, followed by the shipping & manufacturing sectors, respectively.
- Upstream dominated DtB 3 with incidents from hydrocarbon industries; *outliers - North Atlantic Ocean semi-submersible rig (84 fatalities), followed by the Terminals sector & Bantry Bay, Ireland explosion (50).*

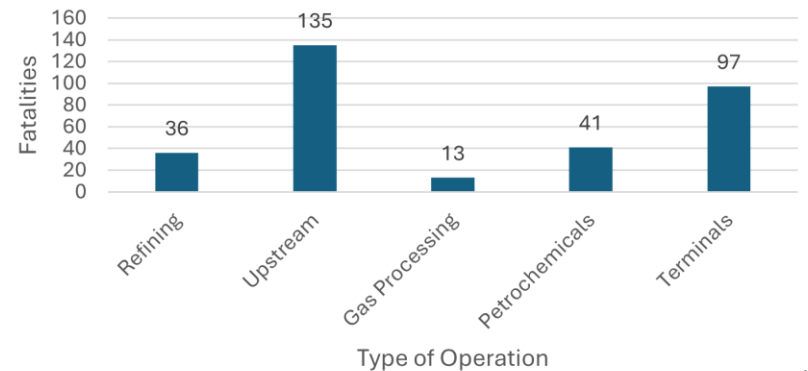
Database 1



Database 2



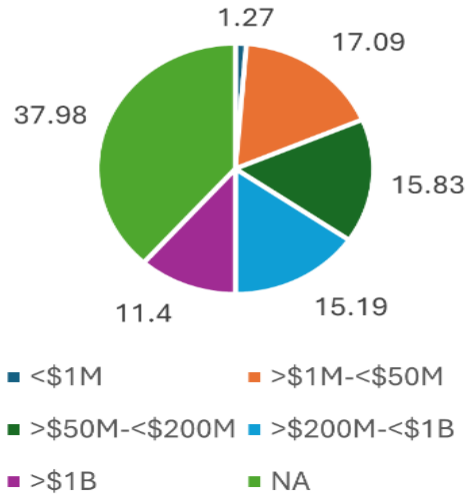
Database 3



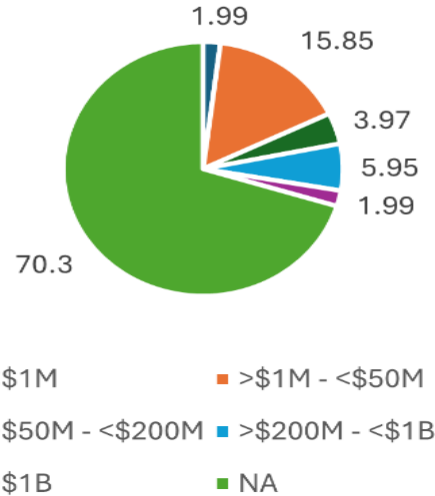
■ No. of Fatalities

Economic Impact*

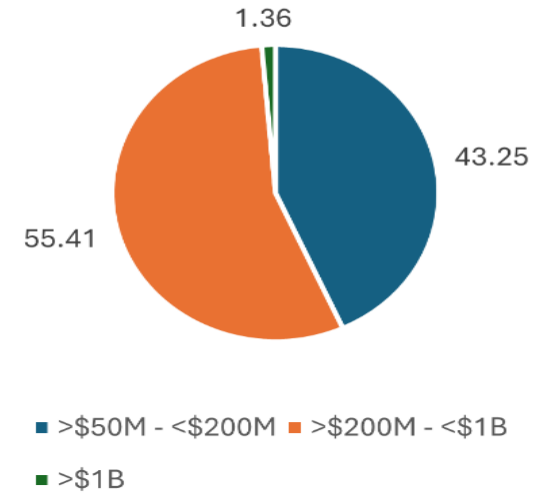
% of Incidents
(Database 1)



% of Incidents
(Database 2)



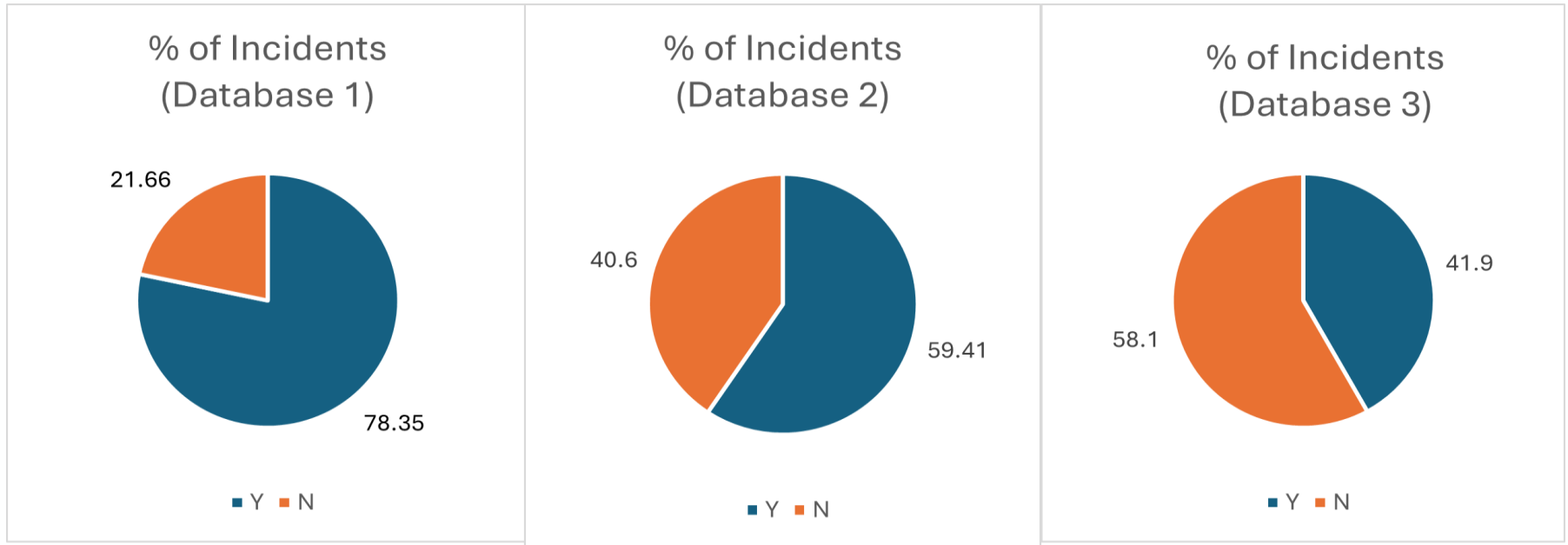
% of Incidents
(Database 3)



- Overall, 19 incidents had damages over \$1 billion, while only 3 incidents < \$1M.
- 38, 70 & 43 %, respectively, of DtB 1, 2 & 3, incidents had damages between \$50M & \$200M
- 15, 6 & 55%, respectively, of DtB 1, 2, & 3 incidents had damages between \$200M and \$1B.

*Note that impact not uniformly defined – damage estimate, lost revenue, initial \$\$

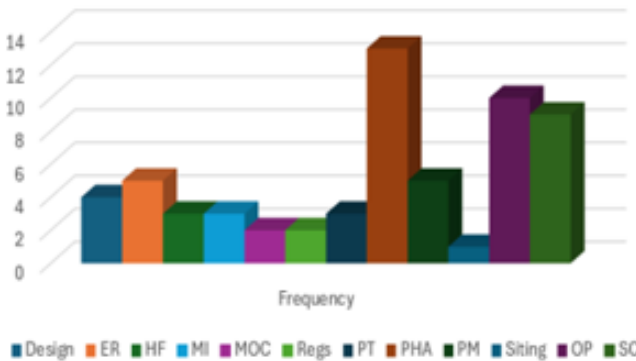
Public Impact (beyond plant fence ...)



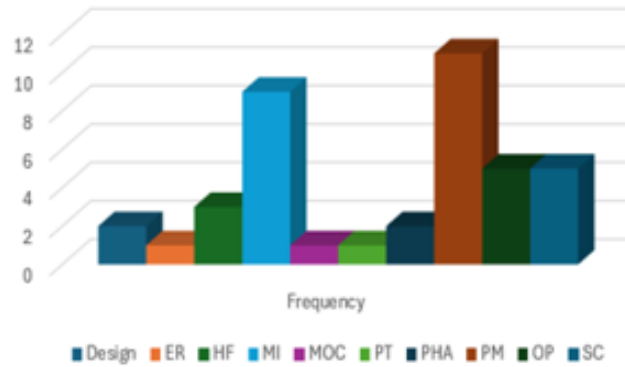
- Out of 331 incidents listed across all three DtB, 214 had public impact outside fence line of facility (65%).
- 58% of DtB 3 incidents had no public impact (in terms of damage to nearby neighbors, etc).

Industry specific root causes - DtB 1

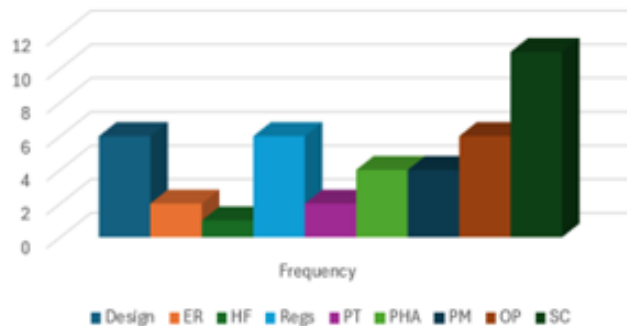
Chemical Industry Root Causes
(Database 1)



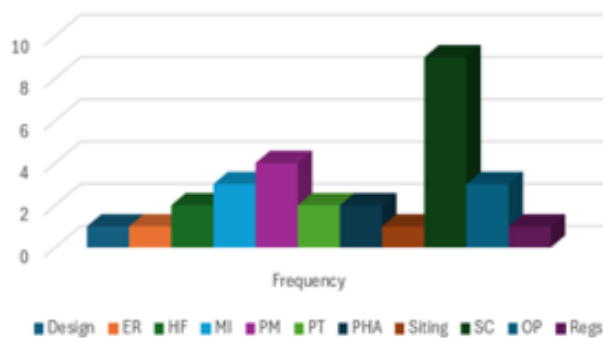
Refinery Root Causes
(Database 1)



Manufacturing Root Causes
(Database 1)

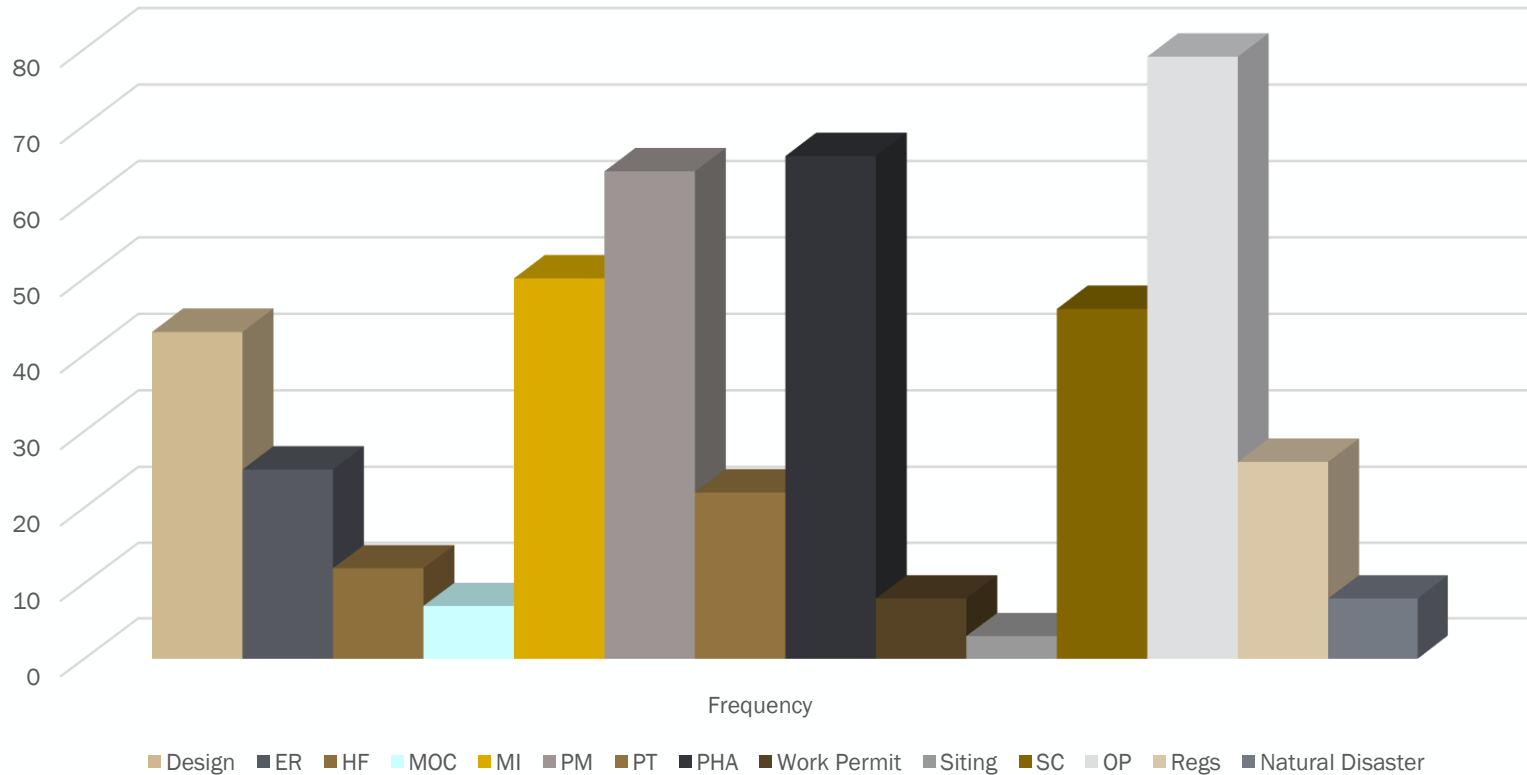


Storage Root Causes
(Database 1)



- PHA, **OP** & **SC** are most prevalent root causes in chemical industries.
- PM & MI dominate the shortcomings in refining.
- Manufacturing sector has **SC**, **OP**, Regs, and Design as the most common RCs.
- **SC** shortcomings dominate storage sector incidents, many involving hydrocarbon handling.

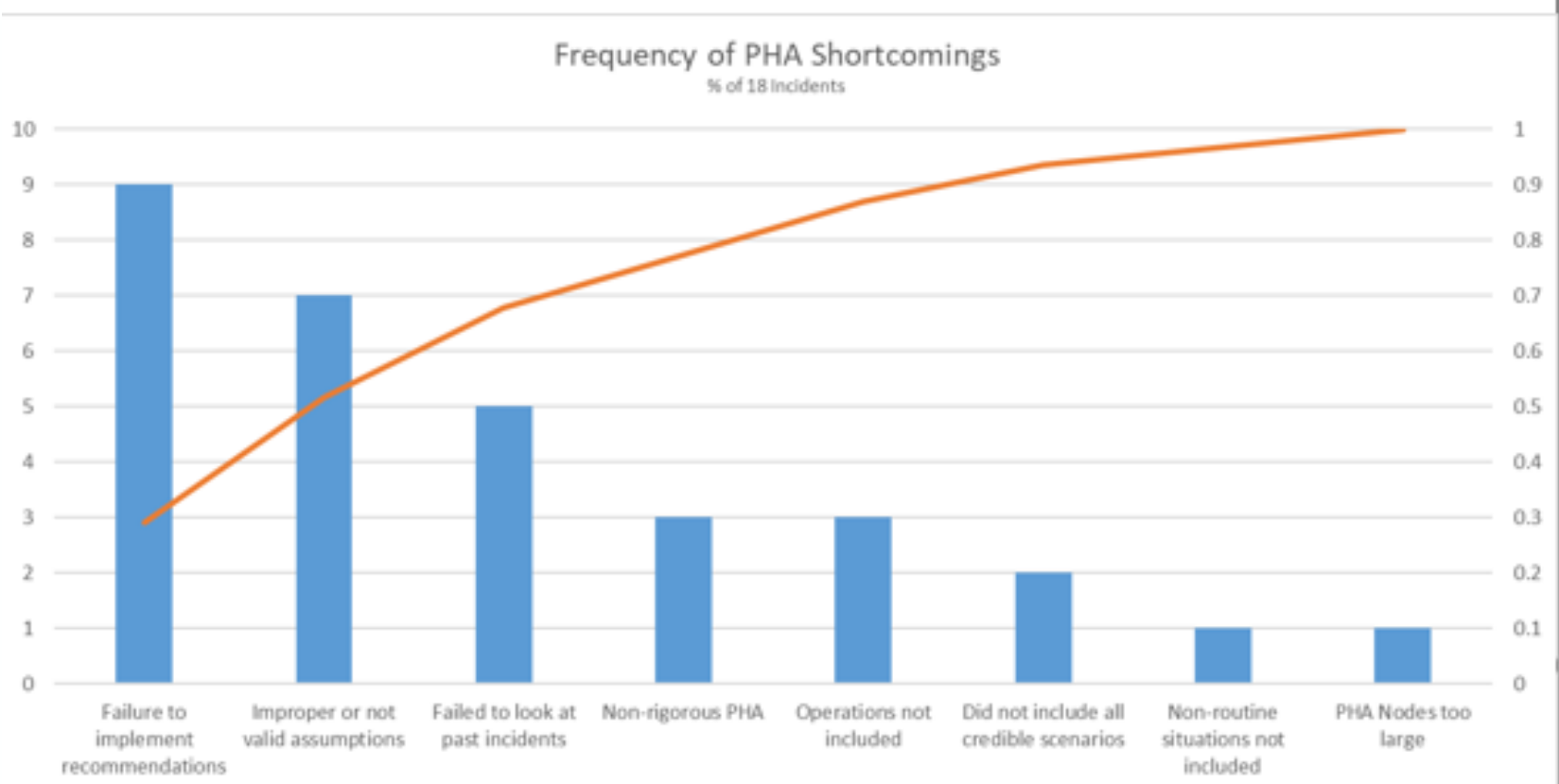
Common root causes seen in post-2000 incidents across all databases



- OP, PHA & PM are the leading three root causes of incidents studied.
- A similar result was seen for pre-2000 incidents as well. However, SC was more prevalent in the pre-2000s incidents as compared to post-2000s, while OP saw an increase with time. Frequency of MI was seen to decrease with time, while PM increased.

Potential future follow up analysis

- Knowing most common root causes & priority for addressing.
- Earlier work (2019) started with incidents where PHA shortcomings were a root cause and then delved deeper into incidents to categorize shortcomings.
- Could ultimately develop appropriate guidance materials.



CONCLUSIONS

- Number of serious incidents & fatalities not declining as desired.
- Majority of reported incidents are in developed countries, US & EU / Norway – but occurrence is widespread.
- Majority of incidents & fatalities occurred in the chemical industry, yet incidents spanned all 14 industries.
- Process safety incidents can be costly, few < \$1M. 2/3's of incidents where cost reported, impact >\$50M.
- ~2/3's had impact beyond the fence line, impacting the public.
- Operating procedures, PHA and preventative maintenance most prevalent root causes of post-2000 incidents.
- Safety culture & mechanical integrity also shortcomings, with latter a factor in 80% of hydrocarbon incidents, per Marsh.
- Robust database provides opportunity for numerous analyses

Postscript

MKO & P2SAC (Purdue Process Safety & Assurance Center) two notable process safety research centers located at universities

Both ChE departments teach required rigorous process safety courses; graduates sought after for these skills

Both aligned with meeting process safety research needs of industry

P2SAC has overseen ~25 research projects with PhD, MS & UG the last several years, with industry partners

Eleven on-going projects this fall semester; EX:

- *Estimation of minimum safe gas purge rates for open vents and flares - ExxonMobil*
- *Numerous AI related projects – EG, Using Commercial AI Tools to Develop a HAZOP Augmentation and Automation Chatbot – Kenexis / Dow*
- *Modeling reactions of interest to the pharmaceutical industry using CHETAH and Purdue's TCIT – GSK, Vertex, Amgen, JM, Lilly, Merck, Pfizer; on-going 3 yrs*
- *Investigating Hazards Related to Carbon Sequestration and Storage – PSRG*
- *Dynamic Modeling of High Pressure Releases for Complex Fire Suppression Systems – Fauske*
- *Improving the process of conducting inherent safety studies for safer technologies and alternatives analysis (STAA) EPA RMP - AcuTech*



Davidson School of
Chemical Engineering

Thank You