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Process Safety Performance Indicators for a Fuel Storage Site: a worked example

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Across the Process Industry including the HPI the Process Safety Performance Indicators are gaining a wider application being all the Process Industry sectors focused on the prevention of major accidents. That's also in response to recent major accidents with catastrophic impact on HSE involving both the Oil & Gas, Oil Refining and Petrochemicals process industry sectors. The Process Safety Performance Indicators (PSPIs) conceived to improve the process safety performance, including the asset integrity as well, can be considered as part of Safety Management System (SMS) compulsory for Major Accident Hazard (MAH) industries since ruled by the EU Seveso Directive. The PSPIs according to ANSI/API RP 754 "Process Safety Performance Indicators for the Refining and Petrochemical Industries" are conceived, implemented and monitored with the objective of minimizing the risk associated to primary loss of containment of hazardous materials leading to major accidents such as toxic release, large fires, explosions, large and/or irreversible environmental impact. The 6-Step approach for PSPIs Selection & Review, as per HSE HSG254 “Developing process safety indicators”, is aimed to ensure the management ownership, establish the implementation team, establish the PSPIs to assess the Company safety performance, identify and confirm critical process and integrity barriers to prevent major accidents, monitor critical barriers, collect quality data, analyze performance and use it to set improvement actions, eventually review the PSPIs effectiveness. A worked example is presented by the author to illustrate the 6-Step approach particularly in relation to a Fuel Storage Site to support the PSPIs analysis activity based on a practical implementation.

1. Major Accidents involving Fuel Storage Sites

The list of major accidents involving fuel storage sites is quite long and includes just including the last decade and the most known accidents:

- 2005: Hertfordshire Oil Storage Terminal, Buncefield, UK
- 2009: Caribbean Petroleum Refining Storage, Puerto Rico
- 2009: Indian Oil Corporation Oil Storage, Jaipur, India
- 2012: Paraguana Refinery Complex Storage, Venezuela.

Above accidents are featured by a significant array of consequences including fatalities, injures, health issues caused by massive explosions, extended fires, smoke and toxic vapor clouds formation, significant environmental damages, huge economical damages following asset and inventory losses, reengineering and reconstruction costs, production disruption, legal costs, punitive and compensation damages, increase of risk insurance premium costs, not to mention company reputation damage. The environmental damages very difficult to quantify and even to qualify are caused by pollutant emission of fuel uncontrolled combustion, by large dispersal of hydrocarbon vapors following tank flame impingement, by massive spills of liquid hydrocarbon caused by fire-water flooding, by primary and secondary containment integrity failure, land and waters contamination by fire-suppressant fluorinated foam (as recorded in Buncefield after the accident). In case of a potential catastrophic accident besides the industrial facility location (in industrial areas, rural areas, residential areas with buildings at high/medium/low concentration of residents, close to highways, primary and secondary roads), the day of

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the week and the hour of the day both play a very important role in the multiple fatality risk assessment. The death tall difference between Buncefield and Paraguana accidents is largely related both to day of the week and hour of the day factors. The assumption of a conditional modifier such as "day time" and "night time" fraction to reduce the multiple fatalities risk should be very prudently assumed by evaluating the consequences both inside and outside the fence. Outside the fence the "day time" and "night time" fraction assumption as conditional modifiers could lead to an insufficient risk reduction. As matter of fact the explosions at Buncefield Depot on December 11, 2005 outside the fence ripped office buildings with no persons because of week day (Sunday) and day time (6.01 am), whilst the explosions at Paraguana Refinery on August 25, 2012 outside the fence wrecked barracks and homes full of people because of night time (1.11 am). Poor or safety superseded engineering criteria - this list in Buncefield accident official reports is practically endless -, poor, missing or incorrect HazOp and SIL Studies, erroneous assumption of conditional modifiers all can lead to under-estimate the risk assessment of Fuel Storage Sites and that explains that so far the "lesson" is not yet learnt.

2. Process Safety Key Performance Indicators Selection and Review

Across the Process Industry sectors such as Oil & Gas, Oil Refining and Petrochemicals the Process Safety Key Performance Indicators are gaining a wider application being all the Process Industry sectors focused on the prevention of major accidents. That's also in response to recent major incidents with catastrophic impact on HSE involving the same sectors.

The Process Safety Performance Indicators (PSPIs) conceived to improve the process safety performance, including also the asset integrity can be considered as part of the Safety Management System. The PSPIs according to ANSI/API RP 754 "Process Safety Performance Indicators for the Refining and Petrochemical Industries" are conceived, implemented and monitored with the objective of minimizing the risk associated to primary loss of containment of hazardous materials leading to major incidents such as toxic release, large fires, explosions, large and/or irreversible environmental impact. The 6-Step approach for PSPIs Selection & Review, as per OGP Report No. 456 "Process Safety - Recommended Practice on KPIs", is based on the following steps:

Step 1: Ensure management ownership and establish implementation team
Step 2: Establish Tier 1 and Tier 2 PSPIs to assess Company performance
Step 3: Confirm critical process and integrity barriers to prevent major accidents
Step 4: Select Tier 3 and Tier 4 PSPIs to monitor critical barriers at facilities
Step 5: Collect quality data, analyze performance and use to set improvement actions
Step 6: Regularly review critical barriers, actions, performance, and PSPIs effectiveness.

The definition of Performance Indicators as ANSI/API RP 754 and Key Performance Indicators as per OGP Report No. 456 is quite misleading also due to the scarce availability of subject literature, so the author's decision is to adopt as general indication the term PI (Performance Indicator) limiting the term KPI (Key Performance Indicator) to performance indicators used to compare the performance results to a specific performance targets (e.g. Company benchmark) aimed to performance monitoring, performance gap analysis and performance improvement. A worked example is hereinafter reported to illustrate the 6-Step approach particularly in relation to above Steps 2, 3, 4.

3. Fuel Storage Safety Key Performance Indicators Analysis Worked Example

In the present Worked Example the selected facility is an "On-shore Fuel Bulk Storage".

The facility sections taken into consideration are Ship Tanker Offloading Portal, Transfer Pipelines, On-shore Fuel Bulk Storage, Fuel Pumping Station, Road Tanker Loading Bay.

3.1 Ensure Management Ownership and Establish Implementation Team

The first step can be summarized as follows:

1. Appoint PSPIs Selection & Review System Corporate Goal & Ownership (action by Company)
2. Set up PSPIs Selection & Review System Scope of Work & Preliminary Plan (action by Company)
3. Establish PSPIs Selection & Review System Implementation Team including at least the Facility General Manager, HSE Manager, O&M Managers, Technical Manager, QA/QC Manager, Corporate Engineering Manager, external consultant (action by Company)
4. Set up PSPIs Selection & Review System Detailed Plan (action by Consultant)
5. Site information and data collection including Hazmat classes & inventory (action by Consultant).

3.2 Establish Tier 1 and Tier 2 PSPIs to Assess Company Performance Team

The second step can be summarized as follows:

Tier 1 and Tier 2 PSPIs Establishment (action taken by Consultant)

Establish Tier 1 and Tier 2 PSPIs based on Loss of Primary Containment (LOPC) incidents reportable as facility Process Safety Events (PSEs).

For Tier 1 and Tier 2 metrics reference is directly made to API RP754.

Tier 1 and Tier 2 shall be reported for each facility section and merged for the entire facility

Tier 1 and Tier 2 shall be reported as combined PSE Rate based on workers exposure hours:

Total PSER = (Total PSE Count for Tier 1+ Total PSE Count for Tier 2) / MTHW (1)

where: PSER = Process Safety Event Rate; MTHW = Million Total Hours Worked

3.3 Confirm Critical Process Safety and Asset Integrity Barriers to Prevent Major Accidents

The third step can be summarized as follows:

Pro-active Input (action by Consultant)

Identify from available PHA (Process Hazard Analysis) the hazardous scenarios that can lead to incident, and the risk control barriers allocated to reduce the identified risks for Safety and/or Environment (process safety barriers), as well as the Safety Management System (SMS) elements to maintain the integrity of the risk control system (asset integrity barriers).

Reactive Input (action by Company and Consultant)

Investigation of root causes of LOPC incidents and near miss in the facility to identify the critical risk control barriers and the new barriers in case of any safety gap. Process Safety Audit is strongly recommended by the author to be part of this action.

External Input (action by Company and Consultant)

Any input deriving from experience and best practices of the Process Industry sector often as a result of past major incidents to identify the critical risk control barriers and the new barriers in case of any safety gap.

A Risk Control System Matrix is hereinafter reported for the On-shore Fuel Bulk Storage and the most likely hazardous scenarios leading to loss of primary containment of flammable fuels and to fire and/or explosion in case of delayed ignition source presence:

- Tank and piping mechanical integrity failure due to natural events;
- Tank mechanical integrity failure due to subsidence;
- Tank and piping mechanical integrity failure due to corrosion, erosion, stress, vibration;
- Piping mechanical integrity failure due to supports and/or structure failure;
- Tank and piping mechanical integrity failure due to damage caused by collision/impact;
- Incorrect Operation;
- Incorrect Maintenance;
- Accidental release caused by human error;
- Tank overfilling;
- Tank rupture caused by over- or under-pressure (vacuum);
- Valves, couplings and piping fittings leaks;
- Security issue (cyber-attack, fuel theft);
- Sabotage;
- Flammable cloud potential ignition sources (e.g. open flames, hot works);
- Earthing system failure;
- Static electricity.

Table 1: Risk Control System Matrix for On-shore Fuel Bulk Storage

	Asset Integrity Challenging Factors										
Risk Control System	**Tank Mechanical Integrity Failure**	**Piping Mechanical integrity Failure**	**External Damage**	**Tank Subsidence**	**Tank Over-/Under- pressurization**	**Piping Over-pressurization**	**Tank Overfilling**	**Other Accidental Release**	**Natural Hazards**	**Fire & Explosion Escalation**	**Sabotage (including cyber-attack)**
Design & Engineering	X	X	X	X	X	X	X	X	X	X	X
PCS + ESD + F&G Detection System + CCTV			X		X	X	X			X	X
Communication (including ship-to-shore transfer)					X	X	X	X	X	X	X
Tank Management System					X	X	X				
Earthing System										X	
PRDs/Vacuum Breakers					X	X					
Emergency Response System			X				X	X	X	X	X
O&M Procedures											
Tank loading/unloading remote operation					X	X	X				
Tank loading/unloading field operation					X	X	X				
Mechanical, Machinery, El./Instr. Maintenance	X	X			X	X	X	X		X	
Emergency									X	X	
Management of Change (MOC)	X	X			X	X	X	X		X	
Permit to Work (PTW)			X					X		X	
Inspection, Audit, Maintenance & Testing											
Tank mechanical integrity	X										
Tank subsidence integrity				X							
Tank vents functionality					X						
Tank drainage integrity								X			
Piping, fittings, supports mechanical integrity		X									
Piping supports mechanical integrity		X									
Pump alignment, sealing integrity & functionality		X									
Electric equipment integrity & functionality										X	
Earthing system integrity & functionality										X	
Process control system integrity & functionality								X			
Tank management system integrity & functionality					X	X	X				
Alarms system integrity & functionality					X	X	X				
PRDs/Vacuum Breakers integrity & functionality						X					
ESD integrity & functionality					X	X	X			X	
F&G detection system integrity & functionality										X	
Firefighting system integrity & functionality										X	
CCTV (flame imaging) integrity & functionality			X				X	X	X	X	X
Cyber-security											X
Staff Competence											
Tank loading/unloading CR/field operation			X		X	X	X	X			
Risk Management			X		X	X	X	X	X	X	X
Inspection, Monitoring, Maintenance & Testing	X	X	X	X	X	X	X	X	X	X	
Emergency Preparedness									X	X	
Staff Fatigue Risk Management					X	X	X	X			

3.4 PSPIs Assignment (action by Consultant)

Tier 3 and Tier 4 PSPIs are primarily designed for monitoring & review of Risk Control Barriers especially at operational level. Tier 3 PSPIs are more lagging indicators and record the number of actual or near miss failure of a barrier. Tier 4 PSPIs are leading indicators and monitor operational activity to maintain or strengthen a barrier

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3.4.1 Tier 3 PSPIs (lagging indicators)

Safe Operating Limit Excursion

The PSPI defined as the "Safe Operating Limit Excursion" refers to a process parameter deviation that exceeds the safe operating limit (SOL).

Primary Containment Equipment Operated Outside Acceptable Limits

This metric measures the number of operation hours of primary containment equipment found operating outside the acceptable limits vs. the overall operation hours of the equipment in the PSPI measurement period.

Number of Near-miss Loss of Containment from Primary Containment Equipment

This metric measures the leaks from primary containment equipment in the PSPI measurement period.

Number of Errors in Executing Operational Procedures

This metric measures the number of errors in executing procedures vs. the procedures executed in the PSPI measurement period.

Number of Errors in Executing Maintenance Procedures

This metric measures the number of errors in executing maintenance procedures vs. the overall number of maintenance procedures executed in the PSPI measurement period.

Number of Failures of Process Control System

This metric measures the number of reactive maintenance interventions following process control system devices failure or malfunction potentially leading to Safety Systems activation in the PSPI measurement period.

Number of Failures of Safety Systems

This metric measures the number of reactive maintenance interventions following Safety Systems devices failure or malfunction potentially leading to Safety Systems activation in the PSPI measurement period.

Number of Demands on Safety Systems

This metric measures the number of demands of activation of Safety Systems in the PSPI measurement period.

Number of Deficiencies in MOC relevant to Safety Systems

This metric measures the number of deficiencies in MOC relevant to Safety Systems found out by inspection in the PSPI measurement period.

Number of Physical Damage Incidents

This metric measures the number of physical damage incidents with consequences on HSE under the Tier 1 and Tier 2 classification in the PSPI measurement period.

Downtime caused by Unplanned Shut-downs

This metric measures the % of facility section down-time following unplanned shutdowns vs. the total operation time in the PSPI measurement period.

3.4.2 Tier 4 PSPIs (leading indicators)

The Tier 4 PSPIs (leading indicators) selected for this worked example are, as follows:

Number of Inspections of Primary Containment Equipment

This metric measures the percentage of inspections of primary containment equipment executed and completed on-time in the PSPI measurement period.

Number of Proof Tests of Safety Systems

This metric measures the % of proof tests on active Safety Systems executed and completed on-time in the PSPI measurement period.

Number of Safety Systems Performing within Specification

This metric measures the % of active Safety Systems found operating within specification when inspected in the PSPI measurement period.

Number of Preventive Maintenance Tasks on Safety Systems completed On-time

This metric measures the % of PM Tasks on Safety Systems completed on-time in the PSPI measurement period.

Planned Preventive Maintenance of Safety Systems

This metric measures the percentage of planned PM vs. the Total Maintenance of Safety Systems in the PSPI measurement period.

Mean Time to Repair of Safety Systems

This metric measures the % of MTTR after reactive maintenance of Safety Systems vs. the expected MTTR in the PSPI measurement period.

Mean Time between Alarm Activation and Operator Response

This metric measures the average mean time between alarm activation and operator response in the PSPI measurement period.

Number of O&M Personnel meeting the Facility Assessed Safety Competency Criteria
This metric measures the % of O&M line managers, shift-supervisors, field and CR operators, maintenance staff passing Safety Competency Assessment in the PSPI measurement period.
Average Scoring of Safety Induction Questionnaires
This metric measures the mean average scoring of Safety Induction Questionnaires answered by Facility Visitors and Contractors' personnel in the PSPI measurement period.
Average Overtime
This metric measures the % of mean average overtime of O&M personnel vs. the total number of standard working hours in the PSPI measurement period.

3.5 Collect Quality Data, Analyze Performance and Use to Set Improvement Actions

The fifth step can be summarized as follows:
Performance Data Management (action by Company)
Trending, correlations, and other statistical analysis to be performed which takes into account the PSPIs quality and the reproducibility. The performance data shall be transparently communicated to management for review resulting in improvement action (continuous improvement cycle).

3.6 Regularly review critical barriers, actions, performance, and PSPIs effectiveness

The sixth step can be summarized as follows:
Performance Data Review (action by Company)
Barriers and Tier 3/4 PSPIs shall be typically reviewed annually.

4. Conclusions

The same approach of this worked example here presented can be conveniently translated to any process facility where the major accident hazards are present and risk reduction is required against unwanted events impacting on safety, environment and economic losses. In the frame of an SMS and EMS compliant respectively with OHSAS 18001 and ISO 14001 the PSPIs can be adopted to meter, monitor and improve the safety and environmental performance. The application of PSPIs integrated into a Plant Performance Monitoring System (PPMS) provides to management real-time data about the facility status providing a powerful tool to match the zero-incident Safety and Environmental target.

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