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Assessing process safety culture maturity for specialty gas operations: A case study

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ABSTRACT

A process safety culture maturity assessment was conducted for the specialty gas processing sector that has the following sections: Gas-to-Liquid, Effluent and Disposal, Ammonia and Steam Utilities plants. The assessment utilised human factors dimensions related to man-machine, employee job roles and organizational culture interfaces. Numerous global process safety incidents resulted in catastrophic consequences originated from human factors and have encouraged the investigation of underlying human and organizational behaviors to manage key process safety risks. The research construct used a process safety culture assessment toolkit, perception survey and interviews, hydrocarbon leak incident history with audit results to assess implementation effectiveness of process safety management systems. Leadership behaviors that hindered process safety maturity included unwillingness to accept accountability, employee blame, fear and lack of trust were associated with inadequate process safety incident reporting and organizational learning. High level human factors risks identified from the case study were additional resources required to update operating procedures, competence of critical staff and ineffective safety communication that have created process safety incidents. Four process safety maturity models were used for the research based on commitment towards continuous improvement; incident reporting effectiveness and examining interdependent team leadership behaviors through process safety balance scorecard metrics. Process safety maturity levels in decreasing order were Gas-to-Liquid, Ammonia, Effluent and Disposal, and Steam Utilities plants.

1. Introduction

A specialty gas company consisting of 1100 full time employees and 1000 sub-contractors which provides Gas-to-Liquid, Ammonia, Steam Utilities and Effluent Waste Disposal processing, was assessed for Process Safety Culture Maturity. Process safety was implemented for several years although certain process safety elements have been used earlier without much emphasis on US Occupational Safety Health Association (OSHA) Process Safety Management (PSM), (2010) standards or guidelines derived from CSA,Z767 (2018) PSM. Process safety management implementation has arisen due to numerous incidents that occurred in the global petro-chemical sector, which resulted in fires, explosions and toxic releases. Process Safety audits from Petrochem, (2010) indicate that facilities have an effective process safety management system, however, plant observation audits indicated that employees do not display correct process safety behaviors when operating equipment. In most instances, employees neglect to maintain equipment or work without using any operating procedures or are provided with inadequate operator training. The audits indicated that active employee participation and management commitment were inadequate in selected plants, and methods thus need to be found to improve process safety culture.

Experience whilst implementing process safety management systems during 2007–2017 using methodology derived from CCPS (1994) indicated that employees feel burdened with process safety since they perceive it as extra work. Process safety systems were inadequately implemented included process hazard analysis (PHA), maintenance integrity, standard operating procedures (SOP), and revised process safety information (PSI). Results from human factors interviews identified high and medium level risks which include maintenance and integrity of safety critical equipment including labelling, critical operations and use of procedures in addition to incident reporting and organizational learning.

Two catastrophic process safety incidents have occurred in the US and UK. Cullen (1990) found that employees at the Pipe Alpha oilrig in Aberdeen inadvertently started the plant while equipment was out of commission, resulting in 200 fatalities. In the US incident, a Formosa Plastics Corporation employee accidently drained the wrong tank whilst in operation, which resulted in multiple fatalities. CSB (2006) indicated all tanks were identical and the employee

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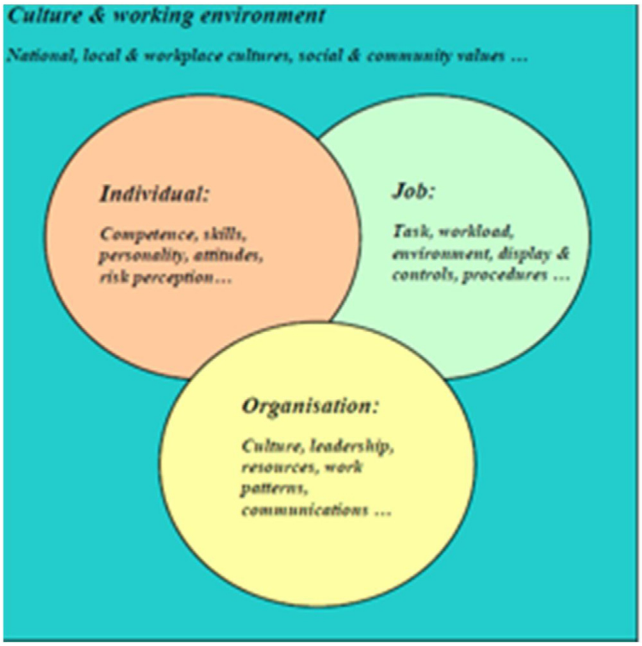

Fig. 1. Culture and Working Environment.
Source: HSE (1999b).

Table 1
Description on Culture and the Working Environment from HSE (1999b).

Process Safety Culture and Environment	Description
The job	Nature of task, workload, working environment, displays, and role of procedures and tasks. Align job to physical and mental strengths and limitations of people.
The individual:	Competence, skills, personality, attitude, and risk perception
The organization:	Work patterns, the culture of the workplace, resources, communications and leadership and has significant influence on individual and group behavior

did not realize the tank was in operation and contained an explosive mixture.

On site process safety deficiencies and the interaction of employees within the plant environment are currently addressed by UK Health Safety Executive HSE (2009) and US OSHA PSM (2010), which have developed and governed the subject of human factors. HSE (2009) mentions that 90 percent of accidents are attributed to some degree of human failure and major accident prevention depends on human reliability. HSE (1999b) describes:

> "Human factors refer to environmental, organizational and job factors, and human and individual characteristics, which influence behavior at work in a way which can affect health and safety".

The definition includes three interrelated aspects namely the job, individual and the organization, which is illustrated in Fig. 1 and described in Table 1.

HSE (1999a) states that "*human factors [are] concerned with what people are being asked to do (the task and its characteristics), who is doing it (the individual and their competence) and where they are working (the organization and its attributes), all of which are influenced by the wider societal concern, both local and national. Human factors interventions will not be effective if they consider these aspects in isolation*"

The study of human factors and integration with process safety culture maturity was studied to identify maturity states for various plant sections namely: Steam Utilities, Effluent and Disposal, Ammonia and Gas-to-Liquid Plants. The process safety culture maturity states were identified by conducting Human Factors Interviews that address process safety requirements for the petrochemical sector in addition to completing a human factors survey. A multi-disciplined team for each department completed the human factors survey and interviews such that key risks, and continuous improvement areas could be identified. Team leadership behaviors, hydrocarbon leak rates and site audit findings and implementation progress were also evaluated when assessing various process safety culture maturity frameworks.

2. Process safety culture and human factors

2.1. Process safety culture frameworks

Various process safety culture models were developed to address leadership maturity, safety and business management systems. The DuPont Bradley curve (2009), and an adapted version by Parker et al. (2006) and Hudson (2000) describe various behaviors related to an organizations workforce as a function of safety performance. ERM (2008) and HSE (2000) describe five safety maturity levels ranging from emerging to continually improving the safety management system. Eames and Brightling (2012) model emphasises five incident reporting and organizational safety learning maturity stages and the business excellence model from HSE (1999a) provides enablers for how process safety should be embedded and sustained to deliver results. The DuPont Bradley curve relates employee and organizational behavior and attitudes towards process safety incidents or leading-lagging indicators. Leadership development and employee emotional maturity is a central theme to the maturity assessment, whereas the adapted version in Fig. 2 shows HSE behavior traits when implementing the safety management system.

Safety maturity levels from ERM (2008) and HSE (2000) in Fig. 3 describes an emerging level 1 management commitment towards safety. Managing/Involving Level 2 and 3 consist of personal responsibility towards safety and employee engagement whereas involving/co-operating Level 3 and 4 describe safety behavioral interventions and proactive safety culture aimed at zero process safety incidents (Fig. 4).

Eames and Brightling (2012) describes five maturity stages namely: cognizant culture where safety is perceived as an uphill struggle and similar to reactive behaviors described above. The second level is effective incident reporting including near misses aimed at achieving safety performance targets. Level three maturity focus on systemic issues and challenges after an incident followed by level four that encourages safety operational discipline and team work whereas level five stimulates continuous improvement and learning from incidents.

2.2. Process safety culture assessment using human factors

Safety performance assessment, high performance organizations and safety culture maturity was investigated by Baybutt (1997), HSL (2002), Kletz (2006), Alp (2015), and Knegtering and Pasman (2009) over the last fifty years. Safety performance is influenced by human factors; management behaviors, health of safety management systems and safety culture, which originated during the mid-1990s and was also investigated by Cullen and Anderson (2005) to highlight the need for human factors assessment when managing top tier major hazard petro chemical sites and legislative compliance.

Fig. 2. DuPont Bradley Curve (2009).

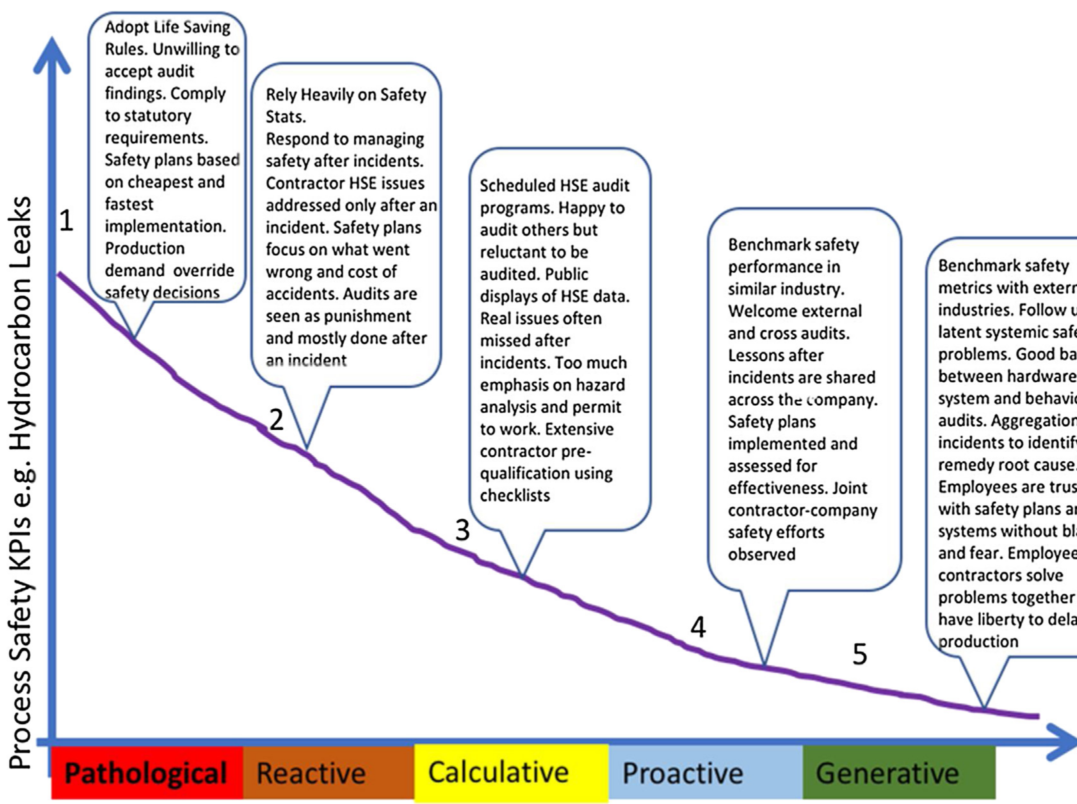

Fig. 3. Adapted Process Safety Culture, Source: Parker et al. (2006) and Hudson (2000).

The need for assessing process safety culture originated from major accidents e.g. Piper Alpha, BP Texas City explosion and BP Oil spill in Gulf of Mexico. The Piper Alpha enquiry, Cullen (1990) stated that "*. . .it is essential to create a corporate atmosphere or culture in which safety is understood to be and is accepted as, the number one priority*". The BP Texas City incident report by Baker (2007) stated the importance that "*. . .a process safety culture survey be conducted* amongst *the workforce at BP's U.S. refineries".*

Incident analysis in the petrochemical sector was evaluated by Foord and Gulland (2006) and later by Kiddam and Hume (2012) and 20% of all incidents were attributed to human factors deficiencies. Largest proportions of organizational and human failures were related to storage tanks, piping systems and process vessels accidents. Organizational failures contribute to 69 percent of all storage tank failures and related to poor planning (18 percent) and lack of analysis (16 percent), whereas 31 percent of human failures were due to misjudgement and not following procedures. Organizational failures account for 18 percent of piping system accidents, arising from contractor mismanagement (18 percent), work permit violations (12 percent) and ineffective management systems (10 percent), whereas main contributors of human failures resulted from inadequate checklists and procedures (25 percent),

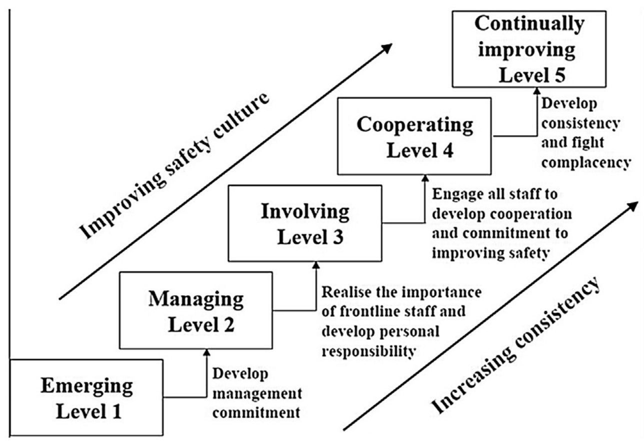

Fig. 4. Safety Culture Maturity Levels, Source: ERM (2008) and HSE, (2000).

misjudgement (14 percent) and not following procedures (14 percent). Highest organizational failures (83 percent) were noticed with process vessel accidents due to inadequate checklists and procedures (32 percent) and lack of analysis (21 percent), whereas 17 percent of human failures are mostly due to procedural violations of (67 percent).

It is thus critical to assess process safety culture while using a multi-dimensional approach based on human factors. The case study utilised results from interviews and a survey in addition to reviewing facility process safety audits based on OSHA PSM requirements, Barrett leadership behavior evaluations and hydrocarbon leak trend patterns for various plants such that key operational process safety risks were identified and organizational maturity states for present and successive states could be predicted.

3. Research methodology

The research methodology consisted of the following across each plant

1 Conducting individual interviews with multidiscipline team for various plants using Human Factors toolkit that was customised for the petrochemical sector and derived from HSE (2009) and OSHA PSM (2010). Questions were designed based on plant maintenance, emergency management, control room and alarms, process safety systems, communication and equipment labelling, operating procedures and shift work hand over. Interview results

Table 2
Human Factors Topics from Petrochemical (2013a,b).

Level 1 Core topics (Applicable to all Sites)		
1.1	Critical Operations Competence assurance	Fundamental to good human factors arrangements at all sites
1.2	Human factors in accident investigation and organizational learning	
1.3	Identifying human failure	
1.4	Reliability and usability of procedures	
Level 2 Common topics (Applicable to the Energy Sector)		
2.1	Emergency response	Relevant human factors subjects and applicable to all sites investigated
2.2	Safety Critical Equipment and Maintenance Deficiencies	
2.3	Safety critical communications	
2.4	Safety Critical Equipment Labelling	
Level 3 Specific topics (Typically used in the Petrochemical Sector)		
3.1	Alarm handling and control room design	Important human factors issues but only for some sites at certain times
3.2	Managing fatigue risks	
3.3	Organizational change and transition management	
4	Process Safety Culture and Incident Reporting	Assessing the maturity of process safety through organizational cultural norms

Table 3
Summary of Human Factors Risks from Behari (2013).

Human Factor Dimension	Human Factors Risk Description	Inherent Risk Rating
Safety Critical Equipment and Maintenance Deficiencies	Inadequate: maintenance checklists, maintenance access and no labelling of process safety critical equipment or identification	Level 2
Alarm Handling and Control Room Design	Inconsistent benchmarking on control room screen layout and parameter confirmation, inadequate review of alarm history and unauthorised trip bypasses causing operator to lose process	Level 3
Safety Critical Equipment Labelling	Inconsistent colouring of pipes and 'touch and tag' practises throughout multiple sites. Inadequate labelling/colouring of equipment, valves and switches and no reference to SOPs	Level 1
Managing Fatigue Risks	Inadequate number of people on shift to complete all tasks including issuing of permits in a short space of time, which may cause slips, violations, lapses or mistakes during process upsets or emergency situations	Level 3
Critical Operations and Competence	Standard Operating Procedures (SOPs) not compiled and employees not effectively trained for operational or maintenance work. Work excludes trouble shooting guides and safety critical equipment checklists and no task observations	Level 1
Safety Critical Communication	Ineffective communication devices (e.g. CCTVs and single channel two way radios) that may adversely impact response times during emergency situations	Level 3
Process Safety Culture and Incident Reporting	Management by fear, lack of trust and blame can cause repeat incidents due to inadequate incident reporting and ineffective organizational learning	Level 1

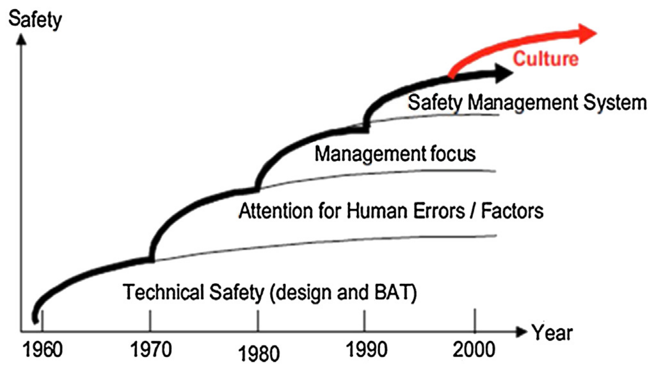

Fig. 5. Safety Performance Improvement, Source: Knegtering and Pasman (2009).

were used to develop a SWOT analysis to identify and assess key high to low process safety risks from Behari (2013)

2 Human factors survey developed by ERM (2007) with minimum of 25 survey participants that were not related to the interviews were conducted for each plant from various technical disciplines consisting of operations, maintenance-reliability, process engineering, and safety staff. Human Factor elements included: critical competence, operating procedures, staffing, change management, alarm management, behavioral safety, incident reporting and investigation, risk assessments and safety critical communication

3 Analysis of results from Barrett team leadership behaviors from Behari (2013)

4 Process Safety Incident trends causing hydrocarbon leaks and severity rates from Petrochemical (2013a)

5 Process Safety audit results derived from Petrochemical (2013b) for selected PSM standards namely: Maintenance Integrity, Pre-Start Up Safety Review (PSSR), Employee Participation, Process Safety Information (PSI), Process Hazard Analysis (PHA), Standard Operating Procedure (SOP), Training, Contractor Service Provider Management, Management of Change (MOC), Emergency Response Planning, Permit to Work

6 Process safety culture maturity assessment using frameworks described above

3.1. Human factors interview and survey results

The interview questions were customised for the petrochemical sector and derived from the Human Factors Inspectors toolkit by HSE (2009) with topics shown in Table 2. The revised questionnaire was developed by a team of safety psychologists, engineers, maintenance, reliability, project and operations teams for downstream petrochemical businesses.

Interviews were conducted with 25 multi-disciplined staff members for the Steam and Utilities, Effluent Treatment, Gas-to-liquids, and Ammonia plants. Results of the Human Factors interview were used to develop a SWOT analysis aimed at identifying key human factors process safety management risks. Table 3 summarises key risks from the study using an organizational risk assessment matrix that evaluates probability and impact of risk occurring derived from Behari (2013). Level 1 risk indicates high major hazard risk, level 2 is medium, whereas level 3 is a low risk

Preventative and corrective controls were suggested for each risk and key performance indicators (KPIs) can now be set for Level 1 high level risks related to incident reporting, safety critical operations and equipment labelling. The Human Factors survey developed by ERM (2007) used a well-tested format that provides semi-quantitative assessment of human factors using dimensions listed in Fig. 6. Respondents were asked to rank each dimension using a five point scale, ranging from 1 (reflecting underdeveloped approaches to human factor issues) to 5 (high performance on human factors). The perception evaluation process followed by Human Factors interviews attempted to provide deeper understanding of this assessment to clarify points and any differences in perception. The scoring highlights how human factors were perceived and experienced by individuals across different functions and organizational layers. The survey was conducted with maintenance staff, production and engineering supervisors, front-line staff and control room operator staff. Survey results in Fig. 6 provide a broad overview of the current human factors on-site and identify areas that would benefit from further improvement.

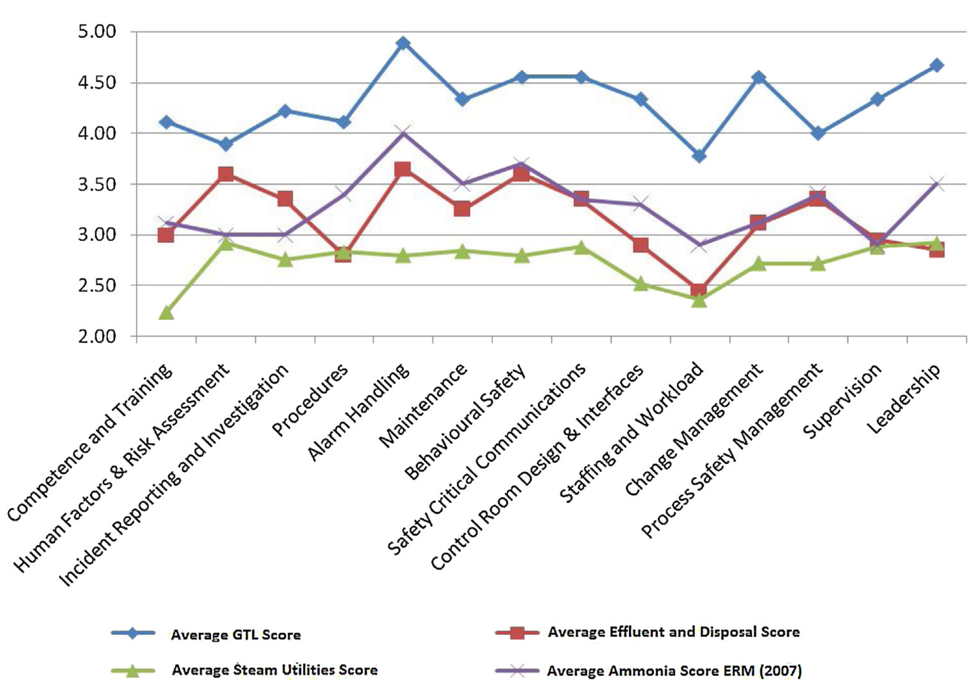

Fig. 6. Consolidated Human Factors Perception Survey Results. Source Behari (2013).

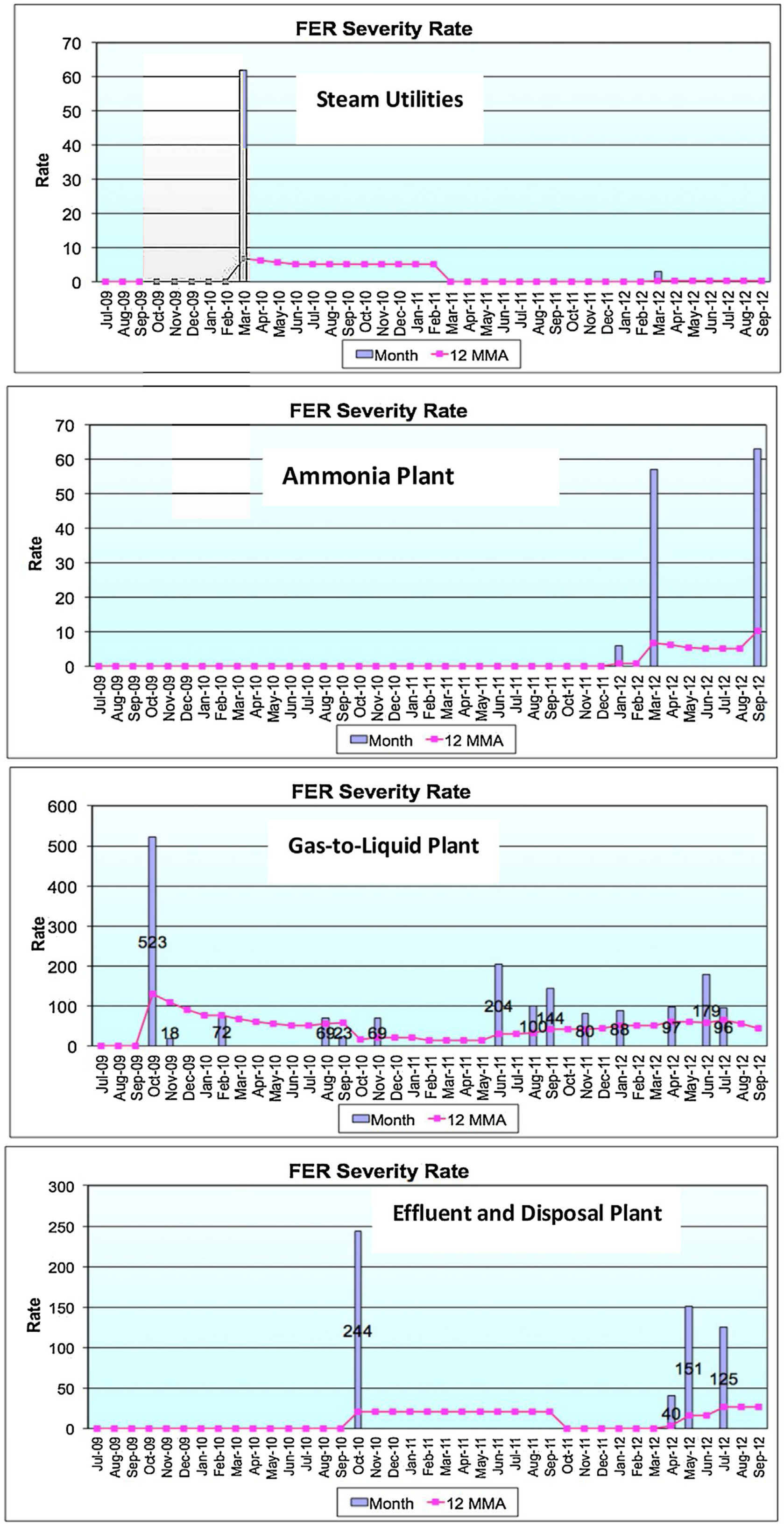

Fig. 7. Hydrocarbon FER-SR Leak Rates. Source Petrochemical (2013a)

A score of less than 3.5 indicates that there is room for improvement, whereas a score ranging from 4.5 to 5 indicates optimistic perceptions. Gas-to-Liquid employees are highly motivated towards living the value of safety; in contrast, Steam Utilities employees have the lowest scores due to organizational restructuring, employee demotivation and ineffective process safety leadership, and similar trend patterns occur at the Ammonia plant. Upward (positive perception) trends are noticeable for Human Fac-

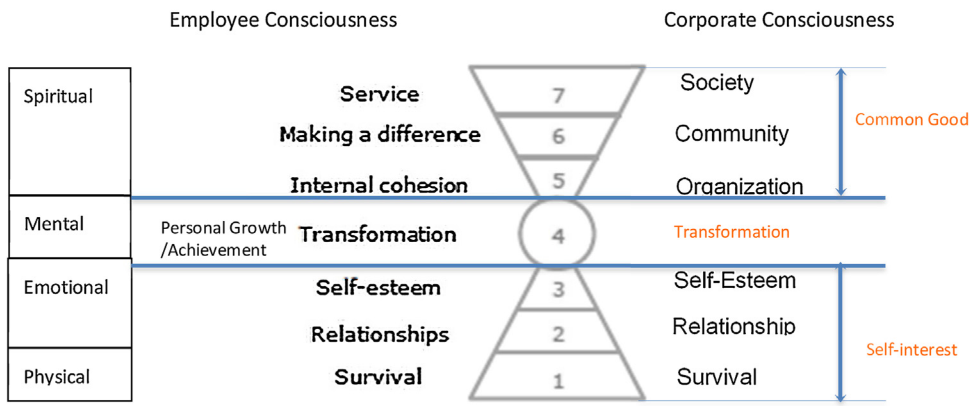

Fig. 8. Seven Levels of Consciousness for Employees and Organizations.

Source: Barrett (1998)

Table 4
Leadership Survey Results from Behari (2013).

Plant	Personal Values IRS(P)	Leadership Level	CC Organizational Values IROS(P)	CC Organizational Values IROS(L)	Organizational Entropy %
Gas-to -Liquid	7-5-0	5 – Internal Cohesion	1-2-7-0	0-0-0-0	13
Steam Utilities	5-8-0	5 – Self Esteem	1-0-7-0	0-1-1-0	22
Effluent and Disposal	6-4-0	3 – Self Esteem	3-1-7-0	0-1-0-0	21
Ammonia Plant	6-4-0	3 – Self Esteem	2-1-8-0	0-0-0-0	17

Key: CC - Current Culture.
IROS - (Individual, Relationship, Organizational, Societal).
IROS(P) – Positive (P) Values recorded for IROS.
IROS(L) – Limiting (L) Values recorded for IROS.

tors related Risk Assessments, Alarm Handling, Behavioural Safety and Change Management, whereas downward (negative perception) trends are seen for Competence and Training, Procedures, Maintenance, Safety Critical Communication, Control Room Design & Interfaces, and staffing and workload. The downward trends for are also related to the Human Factors risks identified in Table 3 for fatigue risks, managing procedures for critical operations and competence, and maintenance of safety critical equipment.

3.2. Hydrocarbon leak analyses

A Process Safety lagging indicator used in the energy industry is hydrocarbon leak quantification where leak quantity, incident severity, cause and consequence category are captured. Similar to API 754 (2016) the Fire, Explosion and Release - Severity Index (FER-SI) from CCPS (2009) is a cumulative severity weighting for a single process safety incident. It considers criteria that would make the incident more severe, and adds these up in a weighted fashion to get a severity score for that incident. These include, amongst others, the actual and potential consequences of the incident, the hazardous nature of the chemicals involved and whether protective controls failed. The FER Severity Rate (FER-SR) is the sum of all the calculated FER-SI of all incidents for a month, and is then normalised by using the hours worked. The hours worked is an estimate of the size of the operation, and therefore compensates for changes in the size of the operation. Fig. 5 below shows the FER-SR recorded over a two year period.

Two incidents were recorded at Steam Utilities due to oil spillage and fire with minor and moderate incident classifications, whereas the Ammonia plant experienced three minor incidents due to ammonia and natural gas releases. Adequate reporting after Q1 2012 was due to a new organizational structure, and merger of the Ammonia plant with the rest of the business. Inadequate incident reporting during July 2009 till early 2012, was due to punitive and

Table 5
Process Safety Audit Levels OSHA PSM (1993).

Audit Level	Area of Responsibility
First Party Audit	Plant Manager and employees conduct own audit in their plant
Second Party Audit	Process Safety Engineers and Technical Experts independent from the plant are responsible for conducting audits
Third Party Audit	External and internationally recognised companies conduct process safety audits

blame work culture since plant managers include FER statistics in employee performance contracts and employees feel prejudiced if the FER trends begin to increase because their performance ratings would be undermined.

Gas-to-Liquid plant has effective reporting, and root causes in the process safety management system could thus be addressed. Significant and moderate incidents occurred in October 2009 while the rest were minor incidents from November 2009 to July 2012. A downward trend is noticed for severity of the incidents and the 12-month moving average (MMA). Root causes associated with these incidents included bypassing management of change (MOC) process or not adhering to maintenance frequencies. Employees have no fear of reporting incidents since number and severity of process safety incidents were excluded in performance contracting and plant management continuously improve on their process safety performance scorecard. Effluent and Disposal plant have adequate reporting starting in October 2010, due to change in plant management. The management team is committed to process safety; however, operational employees may be reluctant to report minor process safety incidents due to performance pressure. An upward trend in the 12 MMA is seen from April 2012 to July 2012, resulting in minor incidents, whereas the October 2010 incidents resulted in significant and minor incidents as shown in Fig. 7 below.

Table 6
Process Safety Auditing Guidelines OSHA PSM (1993).

Score	Status	Guidance notes:
0	Not Implemented	Extensive failures to meet requirements. Facility has either not implemented the requirement, or failed to maintain systems that deliver compliance
1	Not Implemented, but a Gap Closure Plan Exists	Facility failed to maintain systems that deliver compliance and where compliance is a requirement. There is either a plan to implement requirement or corrective action to address compliance gap.
2	Partial Compliance	Significant information available, but insufficient to fully comply with the standard.
3	Full compliance	Information is sufficient to verify full compliance to standard. Documentation is complete and easily accessible.
NA	Not Applicable	Requirement is not applicable to the entity being audited and excluded from scoring methodology

3.3. Managing leadership behaviours

The Barrett team leadership survey was conducted by an independent organization and assessed leadership blind spots and contribution towards human factors concerns and safety culture maturity. Organisational ineffectiveness or leadership entropy was measured using Barrett Values Survey Tool (Barrett, 1998) and based on seven consciousness levels shown in Fig. 8.

Employee individual values (I), relationship (R), societal (S) present organizational values (O) and desired organizational values, were recorded and analysed through an online survey from Barrett (1998). An alignment exercise was executed to determine common organizational values and values that were positive (P) or virtuous (example honesty, trust and accountability) versus potentially limiting values (e.g. blame, revenge and manipulation). Values are rated according to self-interest (S), Common Good (C) and Transformation (T). Potential limiting values (L) support the ego since manipulation encourages exploiting others to satisfy personal needs, and blame is used to prevent humiliation or revenge and perceived as 'getting even'. Leadership authenticity begins to lack whenever egoistic behaviors are misaligned with the virtuous (P) values. A cultural entropy score was calculated which measured the amount of team disengagement, unproductive work or idleness resulting from friction, frustration or conflict in a plant and measured as proportion of limiting values selected by employees during the survey.

Table 4 shows Leadership survey results and employees have common IRS(P) values of safety, accountability and commitment whereas common organizational values IROS(P) are organizational safety, cost reduction, customer focus and productivity. No societal (S) leadership behaviors were observed in all plants thus indicating silo focussed views about information sharing, learning from each other regarding safety incidents, inclusion of contractors and other stakeholders in the business. Fear of blame is a contributing factor resulting in limited hydrocarbon leak incident reporting observed for two plants from Fig. 5. Internal cohesion at Gas-to-Liquids indicates a need for more team work and information sharing across organizational boundaries, whereas loss of self esteem due to fear of blame and reprimand were observed for the remaining plants. Limiting value behaviors IROS(L) are blame identified in both Effluent Disposal and Steam Utilities plants and job insecurity at Steam Utilities. Organizational entropy at Steam Utilities and Effluent and Disposal are higher due to proportion of limiting behaviors selected. Limiting behaviors of arrogance, image and power (Level 3) followed by blame, discrimination (Level 2) and job insecurity with excessive work pressure (Level 1) were major contributors to the entropy scores.

3.4. Process safety audit analyses

Process safety audits based on OSHA PSM (2010), which assessed management system implementation compliance requirements were conducted at three levels namely first party, second party and third party audits and described in Table 5.

Fig. 9. Process Safety Audit Scores.
Source: Petrochemical (2013b).

Audits discussed for Gas-to-Liquid, Steam Utilities, and Effluent and Disposal plants were based on second party and third party audits, whereas the Ammonia plant has only completed a first party audit. Process safety audit scoring guidelines described in Table 6 was used as comparative measure for implementation. Scores were calculated as percentage for each process safety standard using OSHA PSM (1993) audit protocol.

Second party audit results provide objectivity and thus lower scores were recorded, thus enabling continuous improvement, and highlighting deficiencies and need for resources. Employee participation had the lowest score and need for effective and consistent communication is lacking in the plants, including updated process safety information (PSI) from Fig. 9. Adequate standard operating procedures and effective training are required based on findings from the human factors perception survey, feedback from interviewees and audit scores below 85 percent. Although employees are satisfied with management of change (MOC) and pre-start up safety review (PSSR) processes, based on audit scores, the organizational change management process was not fully addressed. Contractor management scores are more than 60 percent for all plants; however there is silo focussed behavior with all plants that discourage them from team work with contractors as seen from Table 4.

Process hazard analysis (PHA) scores range from 45 to 83 percent, however limiting behaviors affecting the score is reluctance for the plants to implement PHA recommendations. The permit

Table 7
Process Safety Culture Evaluation Matrix.

Safety Culture Framework	Maturity Scale				
HSE (2000)	Level 1 (Emerging)	Level 2 (Managing)	Level 3 (Involving)	Level 4 (Cooperating)	Level 5 (Continually Improving)
Process Safety Culture Parker et al. (2006) and Hudson (2000)	Pathological	Reactive	Calculative	Proactive	Generative
DuPont (2009)	Reactive (Natural Instincts)		Dependent (Supervision)	Independent (Self)	Interdependent (Teams)
Reporting Culture Eames and Brightling (2012)	Cognisant		Informed Reporting	Just Culture	Disciplined and Learning
Total PSM 2nd or 3rd Party Audit Score (%)	< = 60		>60 < 75	>75 < 85	> = 85
FER-SR Incident Disclosure	Inadequate disclosure		Consistent disclosure of Significant and Major Incidents	Full consistent disclosure	Full consistent disclosure with continuous improvement
Barrett Entropy (%)	< 30	>25	< 25 >15	< 15 >10	< = 10
Human Factors Survey Score (%)	< = 60		>60 < 80	>80 < 90	> = 90

Table 8
Process Safety Performance Indicators.

Performance Indicator	Process Safety Performance Evaluation			
Average PSM 2nd or 3rd Party Audit Score (%)	None	Gas-to-Liquid (69) Effluent and Disposal (68)	Steam Utilities (80)	None
Hydrocarbon Leak FER-SR	Steam Utilities	Effluent and Disposal	Gas-to-Liquid and Ammonia	None
Barrett Entropy (%)	None	Effluent and Disposal (21) Ammonia (17) Steam Utilities (22)	Gas-to-Liquid (13)	
Weighted Human Factors Survey Score (%)	Steam Utilities (55)	Ammonia (66) Effluent and Disposal (63)	Gas-to-Liquid (86)	None

Note: Ammonia Plant first party PSM audit result is excluded from this assessment due to employee bias.

to work audit scores are greater than 90 percent and used as an ultimate protection layer in preventing an incident. The SOP and training scores are lower compared to the permit to work process, since manpower resource allocation is reduced to compile SOPs and conduct employee training. Inadequate progress was made for implementation of maintenance integrity, with scores ranging from 52 to 90 percent due to shortage of skilled labor and uncertainty regarding the identification of process safety critical equipment.

4. Results and discussion

The human factors interview has identified high level risks regarding safety critical equipment labelling, critical operations and competence using standard operating procedures and the need for organizational learning and communication of incidents. The human factors perception survey supports the findings of the key risks related to maintenance management of critical equipment, using procedures and workload planning. Dedicated resources are required for compiling SOPs and employee on-the-job training as additional layers of protection, should not be compromised in favour of overemphasising the permit to work system.

Process safety leadership is required for frequent reporting of low severity hydrocarbon leaks since the analysis indicates that leak severity rate below 40 is seldom recorded. The change in leadership at Steam Utilities plant has discouraged reporting of any hydrocarbon leaks whereas the leadership team at Ammonia plant focus only on large scale leaks, in contrast Gas-to-Liquid plant which has frequent incident reporting data ranging from 18 to 523 thus encouraging organizational learning. The entropy scores which is driven by blame and discrimination are the main contributors for infrequent incident reporting at the Ammonia, Steam Utilities and Effluent and Disposal plants.

Absence of positive societal leadership behaviors driven by Level 3 organizational self-esteem suggest that there was resistance towards external stakeholders process safety decision making, e.g. team work with contractors, acceptance of external process safety auditor and PHA findings and addressing regulatory compliance using the PHA process whereas common organizational leadership behaviors of safety, cost reduction, customer focus and productivity were observed in all plants. An internal customer delivery mind set discourages active external stakeholders engagement thus suggesting need for changes to organizational values.

Second party scores below 85% indicate deficiencies in safety management systems for: employee participation, PSI, PHA, SOP, contractor management, maintenance integrity and emergency response planning. Low maintenance integrity audit scores suggests a long-term maintenance strategy is required for safety critical equipment. Absence of societal leadership behaviors can influence communication and interaction with union groups related to employee participation, hoarding of safety critical information (PSI) and reluctance to engage with contractors to address process safety concerns.

Tables 7 and 8 show maturity scales for various process safety culture frameworks together with performance indicators. Human factors survey scores were derived from the five point scoring scale for each plant. A calculative, dependant and informed incident reporting culture exists for the Effluent and Disposal Plant. Steam Utilities plant have a cognisant culture due to blame and discrimination when reporting incidents and is proactive when addressing process safety audits, however the entropy level indicates a dependant culture with on the job supervision to prevent incidents. The Gas-to-Liquid plant relies on personal leadership behaviors when addressing safety and has a just culture for reporting incidents, whereas active staff engagement within the team is encouraged to promote safety. The Ammonia plant also has a just culture for incident reporting however their reluctance to conduct external audits indicate a calculative process safety maturity. The low process safety audit scores at the Gas-to-Liquid plant is caused by lack of external stakeholder management and has undermined their safety maturity to transition from Level 4 to Level 5, whereas the remaining plants are transitioning from Level 2 to Level 3 maturity.

5. Conclusion and recommendations

A customised Human Factors Checklist and survey were used to identify high and medium risks for process safety related to maintenance integrity, critical equipment labelling, critical operations using procedures and incident reporting. These risks can be minimised by using mitigating and corrective control measures, which would allow for fast tracking of the PSM OSHA implementation effort for all plants. Four process safety culture frameworks were presented together with process safety performance indicators related to the Human Factors Checklist interview and survey outcomes, hydrocarbon leak incident severity, leadership behaviors with organizational entropy and process safety audits. The performance indices were assessed against each framework to identify current and future maturity states. Some of the critical success factors that can accelerate process safety maturity are organizational learning and continuous improvement supported by interdependent team leadership behaviours. Maturity scales in decreasing priority are Gas-to-Liquid, Ammonia, Effluent and Disposal, and Steam Utilities plants measured as a function of management commitment, leadership behavior entropy, human factors scoring and hydrocarbon leaks. Each plant has a common set of potential limiting factors related to blame, fear, silo mentality, excessive management control, image concerns and discrimination, which undermine leadership development and safety maturity.

Recommendations for fast tracking process safety maturity include conducting ergonomic studies for handling equipment and managing maintenance priorities on critical equipment. Regular employee testing on operating procedures for critical operations are required in addition to ensuring that actions for all plants are identified and implemented whenever hydrocarbon leaks occur.

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