Effective Implementation of Process Hazard Analysis in Challenging Working Environments

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A survey was conduct to identify challenges in implementing Process Hazard Analysis in large process facilities. A diversified audience were surveyed with backgrounds covering technical, professional and management roles. The survey identified the top challenges facing the proper implementation of Process Hazard Analysis. The results revealed several contributing factors related to resources, qualification and organizational commitment. Inadequate qualification of the team conducting the study, unavailability of process safety information, and quality or feasibility of recommendations produced by the study ranked as the top three main issues of concern to participants. Other important issues were related to the lack of proper performance monitoring metrics to ensure recommendations and action items are adequately resolved on time. This paper will present the survey results and provide recommendations to enhancing the effective implementation of Process Hazard Analysis as a key tool leading to better process safety management practices.

Introduction

Process Hazard Analysis (PHA) is defined as the systematic process for identifying, evaluating, and controlling hazards in facilities that process/handle hazardous materials. PHA is an essential component of maintaining safety and managing the risk posed by hazardous operations. PHA includes identifying the hazard, risk ranking it and evaluating mitigation measures to address it. Some of the most common PHA techniques in the process industry include:

- Preliminary Hazard Analysis:
- Hazard and Operability Analysis:

Some of the less common or more specific techniques include:

- What if Analysis:
- Fault Tree Analysis:
- Failure Mode Effect Analysis:

Detailed description on the characteristics and utilization of these different PHA techniques is beyond the scope of this paper, but is given in the literature [1-11].

PHAs are typically conducted in brainstorming sessions or workshops, involving a team of experience stakeholders and Subject Matter Experts (SMEs) that understand the process design, operation and maintenance as well as hazard/risk posed by the process and how to assess and mitigate it. The workshop is facilitated by an experienced PHA facilitator, who is typically helped by a scribe that document all discussions, recommendations and action items during the workshop. The PHA is conducted for specific processes using available information that have to be up to date and reflect the as-built conditions. Lack of proper process information (including P&ID, PFD, material and energy balance, design intent, design and operating conditions, instrumentation diagrams and cause/effect charts, …etc.) will lead to improper assessment and misleading/invalid recommendations and risk mitigation proposals. In addition, sufficient amount of time is needed to allow for adequate discussion and evaluation of all types of hazards applicable to the process sections (i.e. nodes) being evaluated. These factors mentioned above are applicable to all types of brainstorming PHA sessions.

Several assessments and reviews of major industrial incidents in the process industry have concluded that lack of proper hazard identification and understanding has contributed significantly to these incidents or increased the intensity of the incident after it has happened [12-16]. For example, lack of proper hazard analysis has contributed to the major incidents of 1988 Piper Alpha offshore incident, 1984 PeMex LPG fire/explosions, 2003 Sour Gas well blowout incident in China, 2005 BP Texas City Refinery explosion [16]. Incident investigations in all these incidents showed that incidents have been either caused by or escalated due to lack of proper hazard identification or improper hazard analysis and risk mitigations. Hence the importance of this topic.

In this paper, the proper implementation of process hazard analysis will be discussed and recommendations will be presented to improve the effectiveness of process hazard analysis. The work presented in this paper complements others' work that attempted to address the same issues related to ineffective implementation of PHA [17-20]. However, the current work focuses on surveying experts about how to improve PHA implementation, and therefore is dealing with the practical challenges preventing PHA implementation..

Challenges to Effective PHA Implementation

The main challenges facing effective implementations of PHA in dynamic/challenging operating environment are linked to the different phases of the PHA implementation process. These are related to the planning for PHA workshops, competency and expertise of the PHA team members, availability of resources (tools and availing enough time to conduct the study), availability of relevant process information and documents, timely implementation of all recommendations, proper performance measurements metrics, and documenting the whole process for future references. A survey was conducted to assess factors contributing to ineffective PHA process, which will be discussed below.

Survey Questions

The survey included a total of 116 individuals ranging from plant operators, to line managers, plant managers, and process safety engineers and experts. A breakdown of the total participants in this survey is given in **Figure 1** below. This demographic represents a wide range of business functions including Upstream, Downstream, Engineering and Loss Preventions. So, the audience cover a wide range of operating backgrounds, which increases the survey's relevance. In total, seven (7) questions were asked as shown in **Table *1***.

Table 1: PHA Effectiveness Survey Questions

Question			# of Responses	Choices presented to participants
#	Issue			
1	What concerns do you have about PHA?		78	• Team qualification (participants and facilitator) • Quality and effectiveness of recommendation • Update and availability of documentation • Communication of PHA results to affected employees and contractors • PHA tools (spreadsheet and software) • Availability/adequacy of process safety data
2	Assess the use of KPI:	Overdue number of PHA Studies	78	• Good • Bad • Not Used
3		Overdue number of PHA Recommendations	78	
4	Which KPI do you prefer to have in your facility?		76	• Timely Completion of PHAs • Number of qualified PHA leaders and participants • Timely Resolution of PHA Recommendations • Average time to resolve PHA recommendations • Percentage of repeat recommendations • Percentage of recommendation for engineering controls, administrative controls, and PPE
5	Are there any other issues or concerns you would like to highlight?		60	Open-ended questions allowing participants to provide their input based on their specific experience
6	Can you share your facility's best practices in PHA planning and execution?		49	
7	Which topics you would like to discuss in future events?		55	

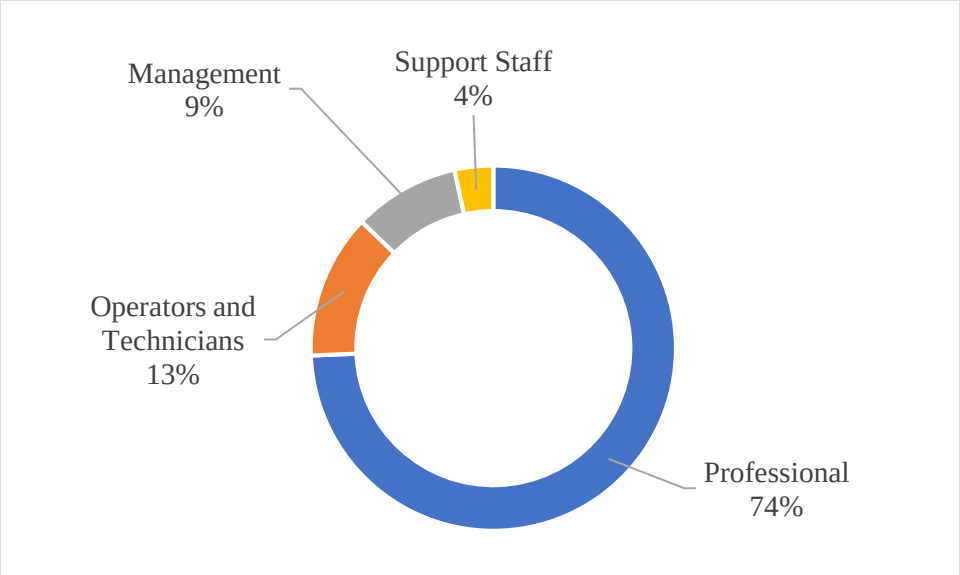

Figure 1: Breakdown of Surveyed Participants

The majority of the surveyed participants are experts in process industry with strong field/operation experience. The median years of experience of participants was more than 10 years. The mix of expertise and roles of participants ensures that the issue under investigation is covered from different angles and considering all relevant stakeholders interests/views. In general, most of the surveyed personnel use HAZOP more than the other techniques and so the results should be viewed with that in mind.

Survey Results: Major Concerns about PHA Effective Implementations

The response to the questions mentioned in **Table *1*** is analyzed and presented in this section. **Figure *2*** shows the main concerns the participants had on PHA implementations in their organizations. Team qualifications and competency, recommendations quality, and availability of process safety information ranked at the top of these concerns. Communication of PHA results to affected parties were critical as well. PHA tools were not as critical, but still impacted effectiveness of PHA implementation to some degree. Those results are not surprising knowing that a PHA study would be conducted by a team of experts using relevant updated information about the process to assess the hazard and provide recommendations to improve the process and mitigate the hazards. The recommendations would have to be relevant and should be communicated to all stakeholders. The implementation of easy to use tools can contribute also to making the assessment smooth.

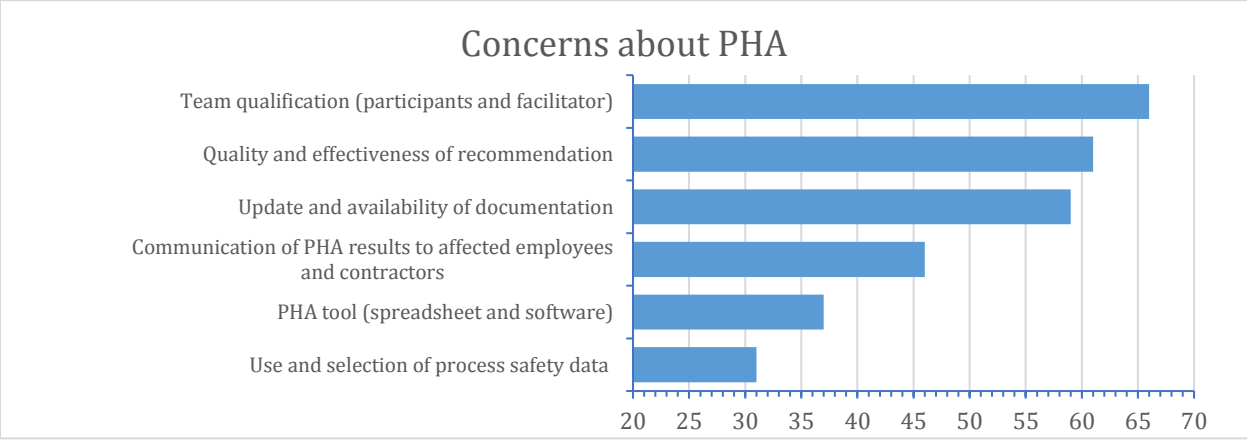

Figure 2: Survey Results for Participants Concerns about PHA Implementation

When asked to freely express any concerns they might have, the participants listed similar issues, which were summarized in the following categories:

- Access and availability of Process safety Information (PSI) and data including material/energy balance, drawings and diagrams (P&ID, PFD... etc.), cause and effect charts, etc. unavailability of process data or use of outdated

information/data and drawings can significantly affect the quality of the PHA study and makes it's recommendations ineffective/irrelevant. It is important to ensure all required information is available and up to date and reflect the as built conditions in the field. This is one of most frequent challenges preventing the effective PHA implementation.

- Adequacy and enforcement of guidelines and best practices related to PHA. Lack of guidelines or not following them is one of the most common factors contributing to incidents, especially if they affect PHA implementation as this could also affect the hazard identification. Sufficient time allocation for properly conducting PHAs without rushing the assessment. Often, facilities are busy and cannot afford to release their most experience experts for long time even for PHA workshops despite their importance. As such, there is always pressure and tendency to reduce the time/duration of the PHA workshops. This can lead to insufficient assessment of the hazard and ineffective recommendations for mitigating the risk. This is one of the most critical challenges facing effective PHA implementation. Guideline are available to plan sufficient time for PHA workshops depending on process complexity and PHA types [20-22].
- Management commitment to proper PHA implementations and oversight of the entire process of implementation. Lack of proper commitment from management, sends the wrong signal and subsequently, reducing the importance and significance of effective PHA implementation throughout the organizations. This can create a culture of indifference to to the value of PHAs, which can adversely affect the safety of the facility and its working personnel.
- Misalignment between PHA and LOPA guidelines/practices. This is important since PHAs and LOPAs are often interlinked and feed into each other's. Alignment between PHA and LOPA can reduce the amount of work needed to interpret the results and increases the effectiveness of PHA implementation process.
- Misuse of PHA to adversely influence process design and inadequately ignore certain hazards. Biases toward one idea from team members, can jeopardize the quality of the PHA and its recommendations. It is the role of the PHA leader to reduce that as much as possible, hence why having an external PHA leader can be very helpful.
- Team composition and representation, in addition to PHA leaders' selection, ensuring adequateteam competency is very important to have a quality PHA. If the team members do not have the right level of experience/familiarity with the operations being evaluated, or missing critical discipline representation, or if the PHA facilitator/team leader are not qualified to play this role or are not independent in their views and opinions, then the results will be compromised. Management commitment can ensure these issues are addressed by committing the right resources/team members to the study.
- Recommendations adequacy, timeline and tracking to ensure proper implementation of the results of the PHA for hazard and risk mitigation. Recommendations have to be relevant to the hazard being assessed, and have to be practical and measurable. Otherwise, they may not yield the expected risk reduction.
- Risk ranking of PHA results and recommendations to define criticality of recommendations, so that proper resources and attention is given to recommendations based on priority and impact on hazard control and risk mitigation

These concerns, once added to the data shown in **Figure *2*** above, provide a more comprehensive picture of factors that can adversely affect PHA implementation and reduce its effectiveness. Two critical points, highlighted in the participant feedback shown above are related to lack of proper comprehensive guidelines or lack of enforcement of these guidelines, as well as inadequate management commitment to (and oversight of) the PHA implementation process. Both elements are directly linked to the culture at the organizations, where the former indicates noncompliance elements and the latter indicates lack of leadership on process safety and hazard analysis. These elements require a consistent systematic effort and leadership from the organization's management to ensure they send the right signal showing the importance of PHA implementation and the role it plays in maintaining safety of personnel and protecting the asset at the facilities.

Survey Results: PHA Implementation Performance Measurement

Key Performance Indicators (KPIs) are used to measure the effectiveness of programs and processes such as the PHA implementation. Using the right/relevant KPIs is critical to ensure that the process is working as intended and identify any gaps in the implementation that need to be fixed to avoid deficiencies. Some of the most commonly used PHA related KPIs are associated with the overdue number of PHA studies, and number of overdue PHA recommendations. The survey asked the participants about the impact of these two KPIs, then asked which other KPIs the participants would like to see used in their organizations. The results are summarized in **Figure 3** – **Figure 5**.

Figure 3 shows that more than half of the surveyed participants believe that the KPIs to track the number of PHA studies not conducted on time is a good KPIs. This is almost 3 times more than the percentage of the participants who believed it has a negative impact in their own experience. Roughly one fifth of the surveyed participants indicated that the KPI is not used in their organizations.

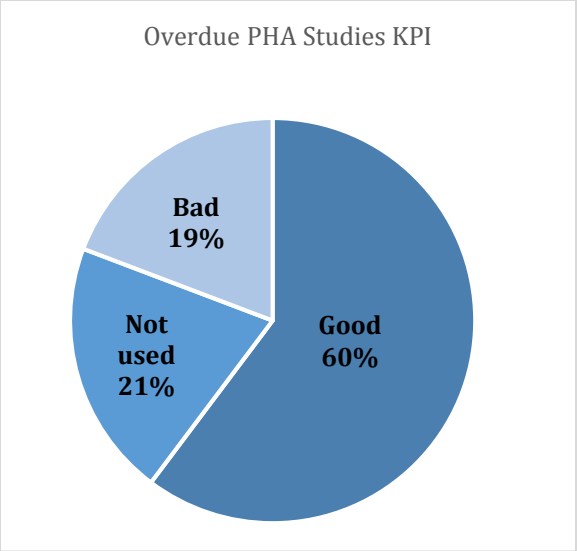

Figure 3: Impact of KPI on Overdue PHA Studies

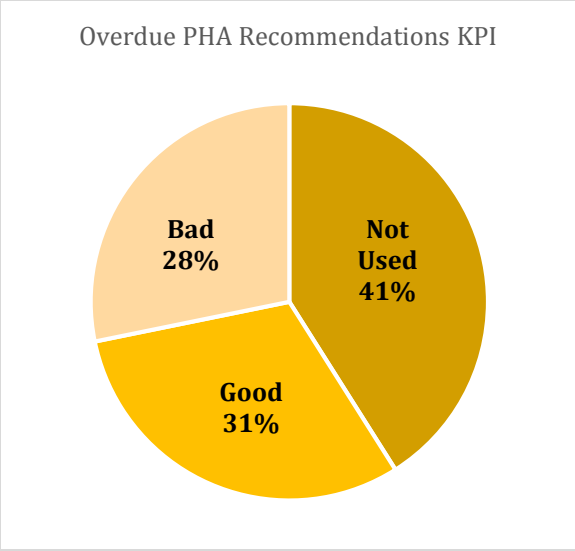

Figure 4: Impact of KPI on Overdue PHA Recommendations

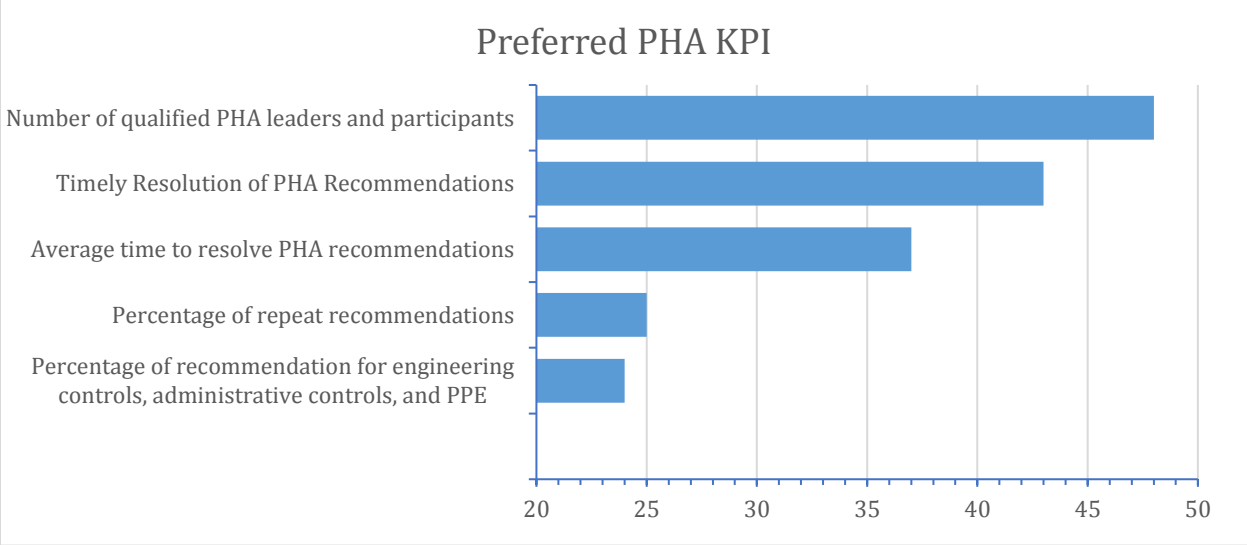

Figure 5: Survey Results for Preferred PHA-Related KPIs

It is clear that this KPI (**Figure *3***) is likely to yield positive impact. One reason for this, is that it can keep PHA studies on track, and highlights any overdue studies that have not been conducted. This is a clear metric with strong impact on PHA implementation targets. However, it is possible that participants who do not support this KPI could lure to the fact that meeting the target on number of studies conducted does not necessary mean that the studies have been properly conducted or their recommendations have not been fully implemented. These thoughts were not assessed during the survey, but are based on the interpretations of the authors given their understanding of who PHAs are conducted and what this KPIs really measures. Nonetheless, this remains a good KPI to be used as supported by this survey.

The second KPI to measure PHA implementation effectiveness is similar in its structure to the first one. It is related to the number of overdue PHA recommendations, as shown in **Figure *4***. More people (a little less than half of surveyed participants) indicated that this KPIs is not used in their organizations compared to the first KPI as shown in the Survey results in **Figure *3***. This could be due to the unavailability of a systematic way or an automated system/database to log and track PHA recommendations once the study is done. The ones using this KPI split almost equally (28% to 31%) on the impact of this KPI. This could be attributed again to the lack of a proper mechanism/system to authenticate the proper closure of the PHA recommendations, thus reducing the effectiveness of this KPIs. If that was the case, then compliance review and independent verification of the recommendations closure could improve the impact of this KPI. Corporate compliance teams (such as loss prevention team, who is independent of the operating organizations), or external insurance review/auditor of the PHA recommendations closure can increase the effectiveness of this KPI. Given that this KPI ranked second among all preferred KPIs that the participants would like to see implemented in their organizations, as shown in **Figure 5**, it would be worthwhile to ensure there is a system in place to effectively track their recommendations before implementing the KPI.

Further questions to assess potential causes of ineffectiveness of these two KPIs were not assessed at the time of the survey, but these could be included in future surveys/assessment of KPIs assessments. When asked about what topics the participants wanted to discuss in future events, 13 out of 55 responders indicated they want to discuss KPIs further. This is almost one in four, which shows that this subject remains as interesting and further work can still be done in this area.

When asked which KPIs the participants wanted to see, a KPI to measure the competency of PHA leaders and team qualifications was rated at the top, indicating that the participants appreciate the importance of PHA team and leader qualifications/expertise and team compositions/proper representation of all relevant disciplines in ensuring effective PHA process implementation (**Figure 5**). The participants also wanted to see KPIs on the quality of the PHA itself. Two KPIs related to the repeated recommendations and content of the recommendations (on engineering and administrative measures) are presented as well. Although these two KPIs ranked at the bottom of the list, they are still relevant. Since these KPIs are indirect and somewhat difficult to measure, this could be why they were ranked lower than the other more direct KPIs related to quantity rather than quality. However, this was not confirmed by the survey, but should still be assessed further in future surveys. In the current survey summarized in this paper, choices for the KPIs were given to the participants, in future assessments, participants should be given the opportunity to provide their suggestions which would enrich the discussion and could identify relevant choices not indicated in the list provided here in Question # 4 of **Table *1***.

Survey Results: PHA Implementation Good Practices

The participants identified some of the best practices related to PHA implementations in their organizations (Question # 4, in **Table *1***). The responses of 49 participants was categorized to the following points:

- Access and availability of process related data that is relevant to conducting PHAs such as material/energy balance, process drawings and diagrams, as well as cause and effect diagrams and others. This point was a major concern for some participants, but also seems to be a point of strength for others among the surveyed participants. In both cases, there is an indication of the importance of this point in the PHA effective implementation. In future assessments, these best practices should be shared among all concerned parties and participants.
- Adequacy and enforcement of guidelines and best practices related to PHA: same issue was highlighted as concern for participants as indicated earlier. This indicates that availability of guidelines and enforcing their use is critical.
- Conduct PHA outside facility to reduce distraction, and combine the study with LOPA to reduce subjectivity and optimize resources utilization.
- Adequate PHA leaders and team competency, through training and continuous practices, as well as ensuring that the team includes all required disciplines and adequate level of experience and expertise to effectively contribute to the hazard analysis.
- Proper evaluation of safeguards is conducted during the PHA workshop to ensure only relevant safeguards are credited and accounted for controlling the hazard and mitigating the risk.
- Tracking recommendations timeline to ensure timely closure of the recommendations based on criticality and risk ranking of the recommendations. This requires the use of a proper tracking system/tool to document all recommendations and their expected closure times.

- Some participants indicated that they could not identify any best practices to share in this survey. If true, that could be alarming as it indicates that the process is not working at these participants organizations. However, this could also be due to lack of proper understanding of the PHA implementation process, or lack of will to share these practices.

These best practices should be assessed and shared to ensure they are adopted for more effective PHA implementation. This could be the subject of further work in the future.

Conclusions and Recommendations

The work presented in this paper shows that effective PHA implementation requires addressing several factors related to resources, qualification and organizations' commitment to PHA implementations. Inadequate qualification of the team conducting the study, unavailability of process safety information, and quality of recommendations produced by the study were found to be very critical, followed by the lack of proper performance monitoring metrics to ensure recommendations and action items are adequately resolved on time. Based on the work shown in this paper, a framework of three main pillars is recommended to ensure smooth and effective PHA implementations in challenging working environments:

I. **Governance:** adequate set of guidelines and best practices should be developed/revised to ensure they cover the requirements and procedures for conducting PHA including (but not limited to) the following:

a. When a PHA should be conducted

b. How to conduct the PHA

c. What type of PHA is to be conducted

d. How to properly plan for a PHA implementations

e. Ensuring all required information and resources are available, including process information, team's proper composition, and competency, time allocation, tools and software

f. Assigning responsibilities and establishing accountabilities and ensuring commitment from different stakeholders to this process.

g. Developing systems/tools that are required to ensure proper documentation and tracking of studies and their recommendations

h. Developing required processes for PHA implementations in line with the guidelines and best practices.

II. **Assurance:** systems in place to ensure that all requirements and processes are implemented as required. This could follow a "three lines of defense" model as shown below:

a. Site own compliance team (first party) that verifies internal processes are aligned with corporate guidelines and industry best practices. Also ensures that PHA implementation is conducted per the applicable processes.

b. Corporate independent compliance team (second party) that reports to independent line of management from the subject organization, and conducts regular review and compliance/audit of the PHA implementation process and practices.

c. External audit/compliance review team (third party) from outside the corporate such as external auditors or insurance review team that can verify findings of previous two lines of defense, highlights deficiencies, and provides more independent comparison with industry practices to further strengthen the PHA implementation process at the corporate level.

III. **Performance measurements:** a comprehensive system to define and track relevant Key Performance Metrics (or KPIs) that do not only measure the quantity of PHA studies conducted or recommendations closed, but also measures the quality of the PHA studies and recommendations issued as a result of these studies. The following KPIs can be used as needed, with the first three as a minimum:

a. Number of overdue PHA studies not conducted on time

b. Number of overdue PHA recommendations not properly closed on time

c. Number of repeated major recommendations

d. Number of studies inadequately conducted (e.g. without proper planning, with missing information, without enough time allocated, or without proper team competency/compositions…etc.)

e. Training and competency of PHA team/leaders

In addition, the effective PHA implementation framework is summarized in **Figure *6*** as shown in this figure the process is dynamic and interrelated. Different elements feed into each other and interact in a systematic manner to achieve the best

performance/implementation of the PHA process. Following this model can lead to continuous improvement in the implementation process as well.

It is also recommended to conduct further studies/surveys to assess the conclusions made in this paper, and close any gap identified in this study/Survey.

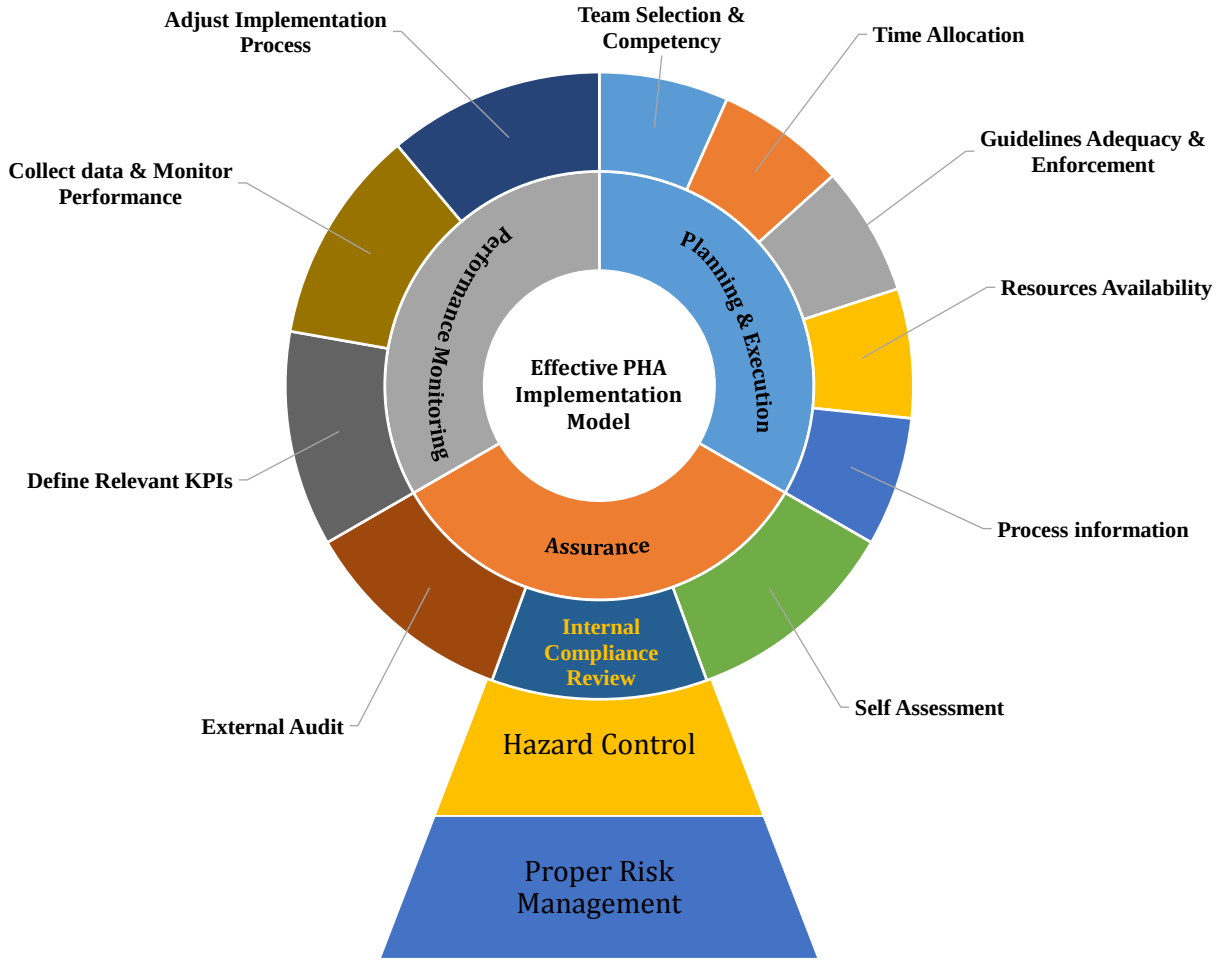

Figure 6: Effective PHA Implementation Framework Model

References

1. Arafat Aloqaily, "Cross Country Pipelines Risk Assessment and Mitigation Strategies", GPP-Elsevier, 2018
2. Preliminary Hazard Analysis Objectives, www.chambers.com.au.
3. Denis P. Nolan, Safety and Security Review for the Process Industries, Application of HAZOP, PHA, What-If and SVA Reviews, GP, Third Edition
4. V. A. Kunte, et. al., Useful tips for a successful HAZOP study, Hydrocarbon Processing, 2016
5. Paul Baybutt, A critique of the Hazard and Operability (HAZOP) study, Journal of Loss Prevention in the Process Industries, Volume 33, 2015, Pages 52-58
6. Paul Baybutt, Requirements for improved process hazard analysis (PHA) methods, Journal of Loss Prevention in the Process Industries, Volume 32, 2014, Pages 182-191
7. Trevor A Kletz, HAZOP & HAZAN, Hazard Workshop Modules, IChemE information Exchange Scheme, 1986

8. Primatec Inc., Comparison of process hazard analysis (PHA) Methods, white paper, 2017
9. William Bridges, "Selection of Hazard Evaluation Techniques", ASSE Middle East Chapter Conference, Bahrain, February, 2008
10. Ian Cameron and Raghu Raman, Process Systems Risk Management, Volume 6, Elsevvier Academic Press, 2005
11. Clifton A. Ericson, "Hazard Analysis Techniques for System Safety", Chapter 8/Section 8.10, Wiley, 2nd edition, 2016
12. Paul Baybutt, Insights into process safety incidents from an analysis of CSB Investigations, Journal of Loss Prevention in the Process Industries 43 (2016) 537 – 548
13. Ron Jarvis, et. al., An Analysis of Common Causes of Major Losses in the Onshore Oil, Gas & Petrochemical Industries, Presentation
14. Doug Jeffries, et. al., Learnings from Major Incidents – 2007, Presentation by Chevron, COE F2F - San Ramon, October 2008
15. Pranav Kannan, et. al., A web-based collection and analysis of process safety incidents, Journal of Loss Prevention in the Process Industries 44 (2016) 171 – 192
16. Arafat Aloqaily, "Industrial Disaster Management Systems – Lessons Learned", Kuwait Process Safety Management Conference, www.processsafetyconference.com, 2013
17. Arturo Trujillo, et. Al., "Common Mistakes When Conducting a HAZOP and How to Avoid Them", Chemical Engineering, December 2015.
18. Collin Howat, "Avoiding Common PHA Mistakes", Conference Presentation, AIChE Spring Meeting and Global Congress on Process Safety, April 2012
19. Dave Grattan, "Improving Human Factors Review in PHA and LOPA", presentation, 13th Global Congress on Process Safety, San Antonio-TX, March 2017
20. Faisal Alshethry, Ms. Thesis on Process Hazard Analysis, Marry Kay O'Connor Process Safety Center, Texas A& M University, August 2017
21. Murray Macza, HAZOP Budgeting Tool, ACM Automation Inc., Calgary – AB
22. Faisal Khan and S. A. Abbasi, Mathematical Model for HAZOP Study Time Estimation, J. Loss Prev. Process Ind., Vol. 10 (No. 4), pp. 249-251, 1997

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