HAZOP Revalidation and Focus on Major Accident Hazards

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Management of Major Accident Hazards (MAHs) is critical for long term sustainability of companies which use hazardous materials. ExxonMobil has a suite of Process Hazard Analyses (PHAs) which have been used successfully for many years to identify and mitigate risks. These are ongoing processes which are repeated, in order to ensure that existing hazards remain under control and to incorporate any new learnings in process safety. Recently ExxonMobil benchmarking has identified the need for us to focus on the health of critical safeguards to prevent MAHs. Analysis of our risk identification techniques has led us to introduce new and enhanced methodologies which target this area, as well as causing us to evaluate the current value added from repetition of prior PHAs. For units which have previously been through at least two Hazard and Operability studies (HAZOPs), there is increasingly less risk discovery when common techniques are utilized. An alternative approach is to identify changes since the previous HAZOP, and ensure that the associated hazards are known and adequately managed. This is particularly important for subtle changes, which can lead to degradation of the design safeguards. Review of changes since the last HAZOP coupled with trending of data associated with MAH Key Performance Indicators results in a study which is focused on the highest consequence events. Studies which use this approach have been found to result in a different risk profile, with a concentrated output which is focused on MAH. This "Delta HAZOP" approach focuses the site resources and activities on MAH prevention, partly due to a shorter overall resource commitment to execute this type of revalidation study.

Case for Action

Major Accident Hazards Focus

Major Accident Hazards (MAHs) are events which can have catastrophic consequences for companies. MAHs have shaped, and continue to shape, the current work practices of the broader Refining, Chemical and Petrochemical industries and regulations.

As articulated in the Process Safety Across ExxonMobil guide [(1)], "Safety is a core value at ExxonMobil. Nothing is more important than managing process safety risk effectively. It is integral to what we do and who we are. We must translate this value into execution excellence in order to protect our people, our communities, the environment and the future of our business.

We continue to have too many process safety events and serious near-misses at our facilities. Recent events such as the Mayflower Pipeline Release, Bakken Well Fire, Rotterdam Reformer Fire and OSO RG Platform Fire are simply unacceptable.

We realised that we must change our way of thinking and our behaviors to prevent similar events from occurring. During the past three years, we have worked with both internal and external groups to evaluate our process safety performance and we have realised that we need to improve our process safety performance to become an industry leader.

Through that review, we identified four critical areas that provide the opportunity for us to achieve a step-change improvement in our process safety performance:

- Fully commit to the effective execution of our updated Operating Integrity Management Systems (OIMS) process safety-related systems.
- Understand the operating scenarios that may lead to process safety events and ensure the right safeguards are in place to prevent them.
- Ensure a Precise Execution mindset is in place by identifying process safety critical tasks, establishing clear responsibilities, and equipping team members to execute these tasks effectively.
- Share and apply lessons learned from incidents, operating experience and assessments.

ExxonMobil provides guidance on the use of PHAs at manufacturing sites. This provides a "suite" of overlapping methodologies which make sure each site is aware of its hazards and that the associated risks are managed appropriately. The HAZOP PHA, in particular, has been used extensively and has provided systematic insight into the hazards which could be posed by our operations. These global requirements have been successfully implemented at the ExxonMobil Fawley Refinery and Petrochemical site (referred to as "Fawley site" or "Fawley" in this paper) for many years. However, in the light of our reviews [(1)], ExxonMobil analysed whether our risk discovery processes were supporting our change in focus. As a result, ExxonMobil has introduced new scenario based techniques which deliberately focus on identification of MAHs and their associated critical safeguards. We have found that these new techniques have added value through a change in focus, particularly when the existing PHA techniques are mature.

Diminishing Risk Discovery from HAZOPs

Where the HAZOP process on a unit is mature, the number of medium and higher risks discovered substantially decreases during each subsequent HAZOP. This is to be expected, from the rigorous application of a robust, systematic and well established technique.

Table 1 shows the decrease in risk discovered for several common Refinery units, as HAZOPs are repeated. Note: these are presented in a dimensionless format of Risk Units (RU), which have no absolute meaning but are used to portray relative risk significance. The conclusion from this is that there is substantial risk reduction from application of this process in early cycles and that this is a valuable and robust risk identification technique. However there are less significant findings in later cycles, as the higher risks will have been identified and mitigated through our systematic risk management processes.

Process Technology (sample units)	1st HAZOP Cycle	2nd HAZOP Cycle	3rd HAZOP Cycle	4th HAZOP Cycle
Process 1	33004 RU	5291 RU	1739 RU	259 RU
Process 2	1480 RU	1295 RU	148 RU	400 RU
Process 3	13209 RU	2738 RU	263 RU	463 RU

Table 1: Decreasing Risk Discovery from HAZOP Repetition

Learning from Incidents

MAHs tend to occur due to degradation of several safeguards along a critical path. Bow Tie diagrams [1], such as Figure 1, are often used to visually depict this:

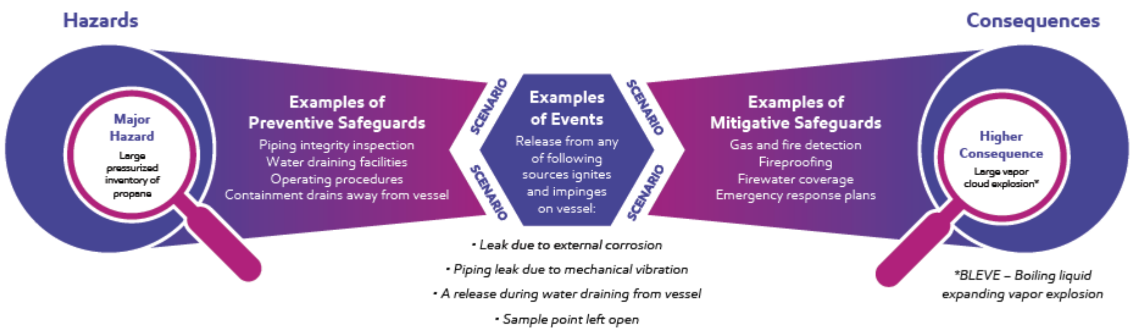

Figure 1: Sample Application of Process Safety Event Model (Bow Tie Diagram)

At Fawley site, the number of medium or higher severity potential incidents with root causes linked to the hazard identification studies has been very low for several years. In 2017 and 2018 only two root causes have been linked to our risk assessment and management system. Effective implementation of HAZOPs and resolution of their items is likely to have contributed to the current performance, as indicated by the data in Table 1.

Although a MAH has not occurred at Fawley within operations memory, we recognise that there is the potential for one to occur due to the inherent nature of the processes at the largest Refinery and Petrochemical complex within the UK. Learnings from higher potential events across industry have highlighted that the non-functioning of the design safeguards is often the root cause of these events.

An example of a high consequence incident which was caused due to longer term subtle changes was highlighted in the November 2018 AIChemE Process Safety Beacon [2]. This resulted in a tank explosion which led to one fatality and thirty six injuries. There were several small changes to the original design intent and operation of the tank. These ultimately led to increased temperatures at the inlet to the tank and an exothermic reaction which overpressurised the tank. One of the key learnings was that the accumulation of small changes can cause an incident with a big consequence. All small changes must be identified and the risk to the total system analysed and adequately managed.

Finally, HSE have recently published the "Creeping Change" Hazard Identification (HazID) technique [3]. This is a new hazard identification technique to help identify key types of change with the potential to lead to a significant incident. The driver for this has been the outcome of various studies and incidents, which have been linked to the management of risks associated with Ageing plant.

In conclusion, operators should be aware of the importance of critical safeguards and be alert to any changes which may cause them to not perform to their original functional intent. Fawley site deliberately set out to target the area of "Creeping Change" in its HAZOP programme in 2018, to complement the introduction of the new ExxonMobil scenario based risk identification techniques. This is consistent with the four critical areas from our Process Safety Across ExxonMobil guide [(1)].

Updated Approach

Identification of Changes

The Delta HAZOP (referred to as DHAZOP) was proposed as an alternative method of Process Hazard Analysis. The DHAZOP is not a replacement for the HAZOP but a different tool intended to produce similar results. This is a more efficient method to reduce the manpower required to conduct a HAZOP. The DHAZOP methodology, as described in this Paper, is a review of the changes to a facility since the last HAZOP, with the goal of identifying hazards resulting from those changes. The reduction in resources to conduct the study frees up that resource to concentrate on the range of new, scenario based, higher consequence identification and risk assessment techniques which have been introduced by ExxonMobil in the last several years. It is also designed to focus on the performance of critical safeguards. The overall output, for a mature site, is an enhanced focus on those scenarios and safeguards which relate to MAHs.

In the period between HAZOPs there are many potential changes possible within a facility. These include changes in facilities, operating procedures, feed and product slates, operating conditions, hazardous chemicals, corrosion, safety-critical devices, standards, local regulations, site practices and discipline, resolution of findings from previous HAZOPs, and new learnings from incidents. Many of these changes would be captured by the site's system for Management of Change (MOC). By focusing on the changes since the last HAZOP review, the man-hours to conduct a review are reduced. And by alternating between the methods (HAZOP, then DHAZOP, then HAZOP and so forth), facility risks can be managed with less manpower than required if a full HAZOP was conducted every cycle.

Key pre-requisites:

1. The unit has undergone at least two prior HAZOPs.
2. The revalidation was thorough and covered any recognized deficiencies in the initial HAZOP in terms of team composition, methodology, or incomplete process safety information.
3. Essentially all findings of the previous two HAZOPs have been resolved (resolved, found to be an acceptable risk, or with remediation planned within next five years) and most medium or higher risk items have been implemented (remediated).
4. All modifications to the unit since the last HAZOP have been controlled by the system for Management of Change (MOC). In case of a major unit revamp, it may be more efficient to conduct another revalidation for the entire unit using the HAZOP method to cover possible hazardous interactions of multiple modifications, interactions with upstream and downstream facilities, and limiting the amount of documents to be collected and retained.

Outline of the DHAZOP Process and Information Requirements:

All of the normal HAZOP preparation materials are required. Additional preparation is also required, to gather the data needed to understand where changes have occurred. It is important to understand how these materials will be used in the DHAZOP, which may involve a different focus from a "ReDo" HAZOP. For example:

1. Heat and Material Balance and Process Trending historical data on feed rates and composition, major product rates and recycles showing changes since the previous HAZOP and new chemicals used in the unit. The Team will determine if changes in feed rate or composition and operating conditions have been handled via MOC, including effects on size of the pressure relief system.
2. Basis for the plant operating envelopes. The Team will compare the plant historical data to the envelopes and confirm that the plant is still being operated within its design envelope.
3. Process & Instrumentation Diagrams (P&IDs), with changes highlighted.
4. Plot Plans, with changes highlighted. These are field visited, to confirm that the assumptions within the Occupied Buildings Risk Assessments remain valid.
5. All new MOC documentation, except alarm set points, including pre-startup safety review documentation for new facilities and compliance audit results. The Team will review the human factors topics and creeping changes of the MOC reviews and consider possible interactions. The Team will also identify changes that inadvertently bypassed the MOC procedure and whether any temporary MOCs have been open too long.
6. List with changes in focus of site-wide programs, such as Emergency Block Valves (EBVs).
7. Near misses and incidents for this unit since the prior HAZOP.
8. A list of incidents in similar units elsewhere and the general lessons that apply. The Team will determine if the applicable lessons learned have been implemented to this unit and the current status of the implementation program.

9. Equipment failures, particularly Safety Critical Devices (SCDs). The team will trend these numbers and compare to benchmark data.
10. Learnings from Key Performance Indicators (Process Safety Performance Indicators).
11. Data showing the number of demands on SCDs.
12. Staffing level changes. The Team will determine if there is adequate competency to carry out their duties safely, including responding to emergencies.
13. Changes in regulatory, industry or company standards with the potential of a re-evaluation of the acceptance of higher risk/ consequence scenarios in a HAZOP study.
14. Copy of the previous HAZOP and status of resolution of the findings. The Team will verify that the higher risk resolutions still accurately address the hazards of the process and that adequate controls are provided to manage those hazards.

Key Performance Indicators and Data Trending

HSE inspection programmes have identified a lack of both the use of KPIs and the lack of data trending as significant to the management of Ageing plant [(3)]. KPIs can be both lagging and leading. Examples of lagging indicators are the number of loss of containment events and demands on safety systems. Examples of leading indicators are safety critical procedures updated per plan and pass/ fail performance from testing of SCDs.

Trending of appropriate KPIs can highlight that equipment is not performing to its design intent and hence that the assumptions within the previous HAZOP may not be valid. Ultimately the risk may be higher than that residual risk envisaged by the design intent.

Within ExxonMobil there are many items which are recorded within company databases and may be trended and analysed within a revalidation HAZOP. These include both lagging and leading indicators. These are most useful in the identification of creeping or subtle changes i.e. items which may not have been formally captured in a MOC but are changes nonetheless. Choosing KPIs which relate to safeguards from pre-identified MAH bow-tie diagrams will mean that the revalidation HAZOP will focus on preventing and mitigating the higher potential consequence events. The choice of KPIs can then vary for each site, to meet its needs.

Example of the use of KPI Data Trending:

The near miss history was trended for a revalidation HAZOP on a petrochemicals unit. The HAZOP Team noticed that there were a significant number of near miss reports raised for activation of high priority (Priority 1 or "P1") alarms associated with high level in towers with safety valves which relieve to atmosphere. This is a heritage design of plant and the Team were aware of the 2005 BP Texas City Vapour Cloud Explosion, which was caused by overfilling a similar tower at startup. This had led to several ExxonMobil standards upgrades, as part of the learning from this incident. These apply to new facilities but existing facilities are subject to risk assessment to help determine whether upgrade is reasonably practicable. A previous risk assessment was completed and assessed the risk as low and so no additional facilities were retrofitted. ExxonMobil risk management processes require that these higher consequence/ lower probability risks are reviewed periodically in order to confirm that the risk has not increased. This can be done in several ways but we deliberately chose to use the DHAZOP process to make this assessment in 2018.

The high level alarms had previously been identified as critical safeguards to preventing this hazard from occurring. During the DHAZOP review of plant operating data it was identified that there were multiple activations of this key safeguard. This caused the HAZOP Team to focus on this risk assessment, to understand whether the assumptions remained valid in the light of current operating practices.

For the worst case alarm, since the prior risk assessment, there were several near misses raised relating to its activation. Data from the associated investigations revealed that many of these alarms were caused by changes in the unit operation and by unplanned unit shutdowns. Trending the P1 alarm activation history data showed that, for the worst case alarm, there were 14 activations since the previous risk assessment. This data showed that this was a step change increase from the several prior years and was an indication of "Creeping Change" in a critical area.

From the alarm activation history it was noted that in recent years, the P1 alarm had become activated more often due to unplanned unit shutdowns or "squats" and the associated startups. Many of these were associated with reliability issues within the steam supply to the unit which resulted in "shedding" the steam to this unit in order to maintain steam to other, more critical, users. In the last several years it had become common to have two or three unplanned squats each year.

The Team's qualitaitve view was that many of the activations could not have credibly led to an overfilling event however there was a concern that the startup related activations, in particular, could lead to an overfill event. In order to determine if these activations could have credibly resulted in overfill of the tower, several key parameters were trended using plant historical data. Figure 2 shows a typical recent startup from a steam load shed "squat". This initially follows the startup procedure, by introducing liquid feed into the tower whilst at a low level (the blue line). Feed is recycled around the tower and heat is introduced via steam, to achive normal operating conditions within the tower. However this is a complicated operation and the level increased above the operating envelope of 100% during the optimisation. The console operator monitors the level in the tower through mass balances and checks of field instruments to confirm that overfill is not occurring during this time.

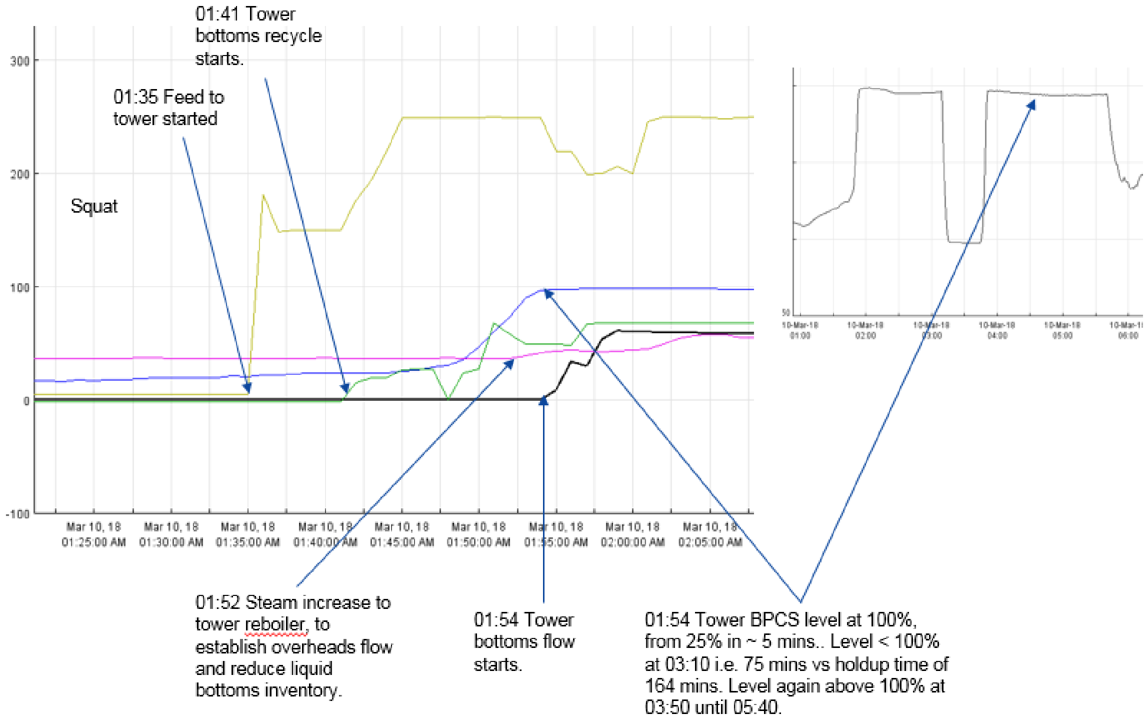

Figure 2: At a typical restart from a steam load shed "squat", it can be seen that the level was above the operating envelope range for a time period greater than the potential holdup time.

A field visit as part of the HAZOP revealed that the P1 alarm tappings are located very low in the tower and are within the Basic Process Control System (BPCS) level range as shown in Figure 3. This means that there is the potential loss of an effective safeguard, as console operators may become normalised to its activation.

Figure 3: The P1 alarm tapping (painted yellow at the bottom of the ladder) is within the range of the BPCS level instrument

Finally the preventative maintenance history was checked for this alarm. Data from the site computerised maintenance system shows that the test interval had been increased from several/ year at the time of the previous HAZOP, to once every three to four years. Plant data shows that this instrument is generally a good performer, with only one item raised since 2007 to indicate that the instrument was not functional.

The data from these trending exercises was compared to the existing risk assessment, to validate its assumptions. The existing risk assessment was broadly correct however it did not recognise the increased number of plant restarts per year, caused by the steam load sheds. This increased the frequency by an order of magnitude. This increased the risk up to a "Medium", as no credit could be taken at a startup for console operator response to the P1 alarm. As there are eight similar towers on this unit, this resulted in eight Medium risks being discovered.

Outcome

ExxonMobil has found the revalidation DHAZOPs significantly reduce the amount of resources required to conduct a HAZOP. For a very large site which conducts HAZOPs very frequently, this typically leads to a reduction of several HAZOP team weeks per year, provided that more time is spent in preparing for the DHAZOP to allow it to run efficiently. The time saved in completing the HAZOP review and in assigning resources to resolution of the HAZOP comments allows time to focus on other types of risk discovery, such as learnings from incidents and Occupied Building Risk Assessments. After several cycles of HAZOP, ExxonMobil has found that these other risk discovery processes tend to add more value. In particular the DHAZOP approaches complements the HAZOP approach well, by bringing the team's focus onto the area of critical safeguards and making best use of the resource/ time reduction from this technique.

The HAZOP methodology has been found to result in more comments however often the additional comments are of lower risk. This is not unexpected considering: the unit has been HAZOPed several times beforehand and the comments from those previous HAZOPs have been mostly resolved; there have been no major facility changes; and Management of Change (MOC) is a fully functional management system.

The first two DHAZOPs at the Fawley site are consistent with the global findings. Table 2 shows that the number of comments from the revalidation DHAZOP is approximately half of the those which could be expected from a HAZOP. Pertinently the DHAZOP focus on plant data to identify subtle change with implications for MAHs, has led to the identification of more significant risks. The prior unit HAZOP had identified these hazards however the understanding of the risk level had increased, due to learnings from external incidents and subtle changes in plant operation.

HAZOP	# Safety Items	Medium	Med/ Lower	Low	Do
Prior unit HAZOP	66	0	47	19	0
Recent HAZOP on a similar unit	69	0	17	22	11
2018 DHAZOP	31	10	10	4	7

Table 2: Comparison of HAZOP Output from Similar Units

Discussion

Risk discovery is mainly from "subtle" or "creeping" changes. Recurring near misses in similar areas, particularly those with a higher potential consequence are a particularly good source of relevant plant data. Similarly data related to demands on safety systems is seen as being of high value, due to the inherent high consequence and potentially higher than anticipated frequency of demand.

Some risk discovery can be found related to less than adequate closeout of known risks. Formal MOC reviews generated little risk discovery. Plants with a mature MOC system manage known changes well.

Very limited risk discovery from "standards creep" unless it is associated with a major (external to the unit) incident.

This process appears to be consistent with the driver and intent associated with the HSE's new Creeping Change HAZID (CCHAZID). Major Incidents, such as the: space shuttle Columbia; Kings Cross fire; and Texas City explosion, often have root causes linked to subtle/ creeping change. HSE inspections find lack of plant data analysis as significant to ageing plant management. The use of KPIs and Data Trending of leading and lagging indicators, focused on MAH, focuses the revalidation HAZOP on moving the "Unknown knowns" into "Known knowns". Weak or overlooked areas can then be addressed [(3)].

Conclusions

After several cycles of HAZOP, there is progressively less risk discovery from this technique and approach. Alternative risk discovery techniques, focused on Major Accident Hazards, can add more risk reduction value to a site. Conducting revalidation HAZOPs, using plant operating data linked to MAH KPIs, has been shown to result in a different risk profile. These are not a substitute for HAZOPs, but are intended to complement them particularly when a MAH focused scenario based approach is also conducted on the same unit. The site is significantly more focused on MAH related activities, both in execution of the study and in its followup.

- A revalidation Delta HAZOP is an option at this point if the following prerequisites are met:
    1. An initial HAZOP is completed
    2. A revalidation HAZOP showing marked reduction in number and severity of comments is completed
    3. Management Of Change system is in place
    4. Previous HAZOP comments have been resolved

- DHAZOP cuts review time in half
- DHAZOP increases preparation time
- DHAZOP generates significantly fewer HAZOP comments but focuses on those with the highest risk, focusing follow-up resolution efforts by the site
- DHAZOP misses comments not identified by previous team

The Fawley site has incorporated the use of DHAZOPs into its suite of Process Hazard Analyses and will continue to evaluate their suitability going forward, to ensure the site remains focused on identification and control of our higher risks.

References

(1) ExxonMobil, Process Safety Across ExxonMobil guide.

(2) American Institute for Chemical Engineering (AIChE) and the Center for Chemical Process Safety (CCPS), November 2018, Process Safety Beacon: Accumulation of small changes leads to an explosion, https://www.aiche.org/ccps/resources/process-safety-beacon/201811/english?utm_source=Informz%20Email&utm_medium=Informz%20Email&utm_campaign=Informz&_zs=ogv2X&_zl=vVCP1.

(3) Goff, R., Holroyd, J. and Birkitt, K., 2018, Managing Ageing Assets – Creeping Changes, Data Trending and Experience from Incidents Training Course, Health and Safety Executive (HSE).