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Results Matter: Three Case Studies Comparing and Contrasting PFFM and HazOp PHA Reviews

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Abstract: Complete, thorough, and correct process safety management depends to a large extent on complete, thorough, and correct process hazard identification, both before and during the process hazards analysis (PHA) review. Findings from the examination of incidents and disasters in industry indicate that PHA reviews fail to identify a significant number of process hazards. This is unacceptable: we cannot manage a hazard if we don't know that it exists, and incidents will continue to occur if PHA reviews continue to overlook process hazards.

HAZOP is widely recognized as the standard for conducting thorough PHA reviews, but it is not the only technique available. In this paper, outcomes of three actual HAZOP reviews in the oil & gas industry are compared and contrasted with the results for the same facilities using Process Flow Failure Modes (PFFM). PFFM is a unique method, best described as a highly efficient, highly effective cross between FMEA and HAZOP, enhanced by a customized visual tool. Differences in the success rate of the two methodologies to identify process hazards are quantified and discussed with the aim of improving the industry success rate in identifying process hazards during PHA reviews in a cost-effective, straightforward manner.

Keywords: Hazard and Operability (HAZOP) Studies; Failure Mode and Effects Analysis (FMEA); Process Hazard Analysis (PHA)

1. Introduction

One of the major goals of a Process Hazards Analysis (PHA) review is to identify process hazards. For identified process hazards, safeguards (i.e. protective devices and/or practices) are then listed and recommendations are made when necessary. However, analysis of industrial disasters in the U.S. between 1998 and 2008 shows that one of the main contributing factors in those disasters was the failure to identify that the hazard existed in the first place. The sustained rate and severity of process safety incidents in the past decade demonstrate that PHA reviews are still leaving process hazards unidentified. This is unacceptable: We cannot manage a hazard if we don't know that it exists.

The Hazards and Operability Review method (HAZOP) is widely recognized as the standard for conducting thorough PHA reviews, but it frequently fails to identify process hazards. This is usually blamed on an inexperienced facilitator, lack of management support to the review team or meeting, and so forth. It is rarely blamed on the method itself, implying that the method itself is without fault and that there is no better way to conduct a PHA review.

In this paper, three separate HAZOP reviews are analyzed and categorized, expanding upon previous work (MacGregor, 2012). These are actual reviews for actual facilities, and the companies who commissioned the reviews were satisfied with the results. The results of the HAZOP reviews are compared with an analysis of the same facilities using PFFM. Comparing the two methods proves that PFFM is superior to HAZOP in identifying process hazards, in less time and with less stress on meeting participants.

2. The Process Hazards Analysis (PHA) Review

Essentially, a PHA review is a study of a given process scope (pump station, oil well battery, process unit, i.e. Crude Unit, Gas Recovery Unit, etc.) to:

1. Identify process threats to the facility that may lead to an uncontrolled loss of containment (LOC) of a hazardous material. Typically, a LOC is considered to be possible if the equipment is taken outside of its design envelope (design pressure (min./max.), design temperature (min./max.), or if an atmospheric vessel is flooded (causing a spill to grade), or if material is inadvertently released to the atmosphere by incorrect valve operation.
2. Identify the controls in place to prevent the uncontrolled loss of containment identified in step (1): PSVs (pressure safety valves), alarms, automatic trips or shutdowns, operating procedures, etc.
3. Decide whether the controls in place are adequate to control the risks, and if they aren't, to make recommendations to improve them.

The purpose of the PHA is to protect people and equipment. The means of identifying the threats that exist is by considering disturbances to the normal operations of the process: blocking flow, changing compositions, power failures, etc.

The scope of a given review is usually too large to be considered as a whole. Therefore, it is typical to divide the review scope into "nodes", or "sections", typically numbered and highlighted in different colours. Disturbances to the nodes or sections of the process facility are then evaluated, with the intent that the overall effects of the disturbance will be considered wherever they occur (upstream of the node/section, within the node/section, downstream of the node/section, or a combination thereof).

PHA reviews are properly conducted by multidisciplinary teams of individuals who are knowledgeable in the process and the equipment in the scope of the review. Participation by both operations and technical people is essential to a successful review.

3. Setting a Baseline

The U.S. Chemical Safety Board (CSB) conducts investigations of selected process safety incidents in that country. Incidents examined that occurred in the U.S. between 1998 and 2008 (Kaszniak, 2009) are summarized below in terms of the causes of serious process safety incidents:

- Twenty-one (21) major incidents were studied.
- The total number of injuries from those incidents was 282.
- The total number of fatalities from those incidents was 39.

The data for the property loss and other financial losses from those incidents is not available in the report, but it was likely substantial.

The descriptions of the incidents studied detailed the various types of failures that contributed to each incident (Kaszniak, 2009). Figure 1 displays the number of incidents in which each type of failure contributed to an incident. Several of the incidents had multiple contributing factors. Failure to identify credible causes during PHA reviews occurs with the greatest frequency; reducing the frequency of this deficiency could save lives and reduce injury frequencies. Since HAZOP is almost the universal method used for PHA review in the U.S. and has been for the past thirty-five years, ensuring the ability of HAZOP reviews to identify **all** credible failure scenarios would reduce the number of incidents, fatalities, and injuries in future. A short foray into Process Safety networking websites (for example, Linked In) indicates that this is a formidable challenge and that success is elusive and difficult to sustain.

Another option is simply to adopt a better PHA review technique that has the strength of HAZOP, with fewer of its deficiencies—namely, a technique that is significantly better at identifying **all** potential causes of process safety incidents.

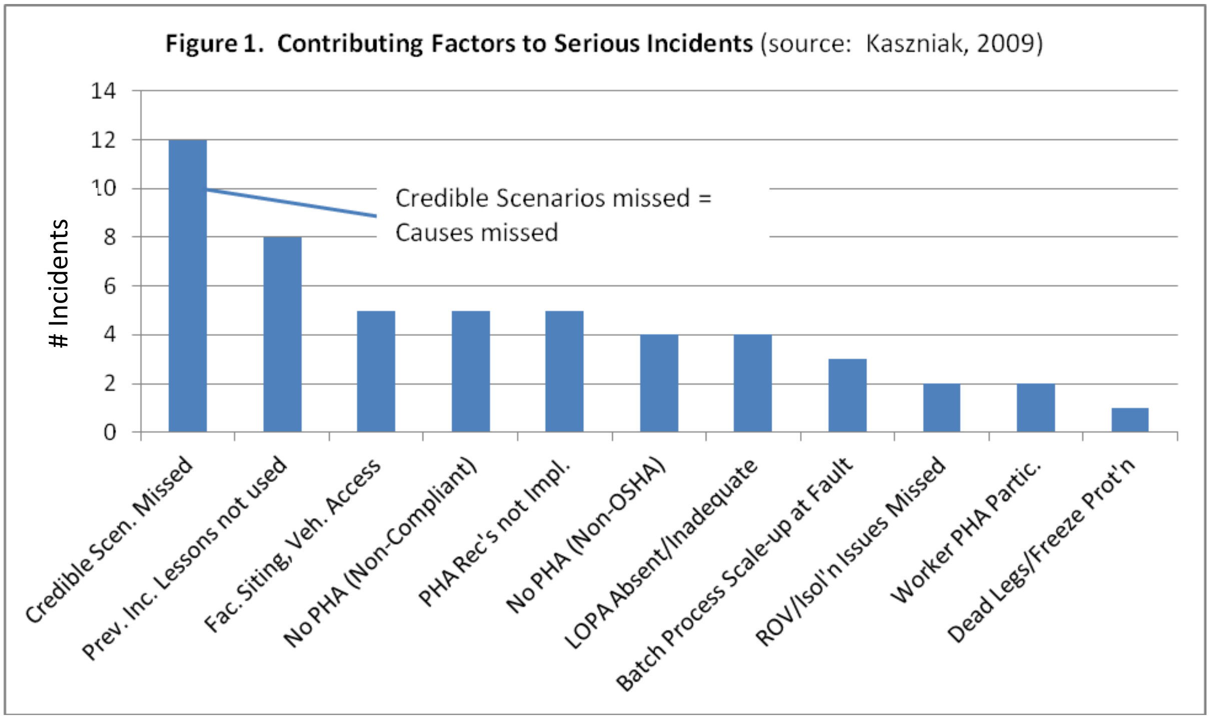


Figure 1. Contributing Factors to Serious Incidents (source: Kaszniak, 2009)
Incidents
14
12
10
8
6
4
2
0
Credible Scenarios missed =
Causes missed
Credible Scen. Missed
Prev. Inc. Lessons not used
Fac. Siting, Veh. Access
No PHA (Non-Compliant)
PHA Rec's not Impl.
No PHA (Non-OSHA)
LOPA Absent/Inadequate
Batch Process Scale-up at Fault
ROV/Isol'n Issues Missed
Worker PHA Partic.
Dead Legs/Freeze Prot'n

4. Approach Used for the Case Studies

The CSB paper (Kaszniak, 2009) examined serious incidents. But fortunately, serious incidents are the exception rather than the rule. Perhaps their PHA reviews were unusually deficient, and the typical HAZOP review done today is much more complete. To test this, the two PHA methodologies were compared for the same three facilities:

1. A Heavy Oil facility upgrade, involving gas receiving, separation, and compression facilities
2. A Natural Gas well installation
3. A Delayed Coking Unit

The two methodologies compared are:

1. HAZOP
2. Process Flow Failure Modes

HAZOP is the most widely-known PHA methodology, typically using these steps:

- Select a node
- Describe intention of the node
- Identify major hazards
- Apply a deviation (temperature/pressure)
- Brainstorm possible causes
- Develop potential consequences
- Determine the safeguards / barriers
- Propose recommendations / action items
- Apply the next deviation in the same way until all deviations have been considered
- Proceed to the next node

The scope of the review for a given facility is encompassed by the nodes. If any of the review scope is missing in the nodes identification, this may or may not be obvious to the review team when looking at the process and instrumentation drawings (P&IDs). The deviations are generally pre-determined according to the company HAZOP procedure and/or template: failure to identify deviations may or may not be a concern—in fact, too many deviations may also be an issue.

In PFFM, coloured sections of the facility (similar to nodes) are defined, but the review process is slightly different:

Prior to the meeting:

- Following the process flow sequentially, disturb the normal process operation by failing system components or committing operator errors. Use these to pre-populate the causes for each component in each section

During the meeting

- Select a section
- Consider the pre-populated causes in order of the process flow
- Develop potential consequences
- Determine the safeguards / barriers
- Propose recommendations / action items

- If pre-population has missed any causes, the team adds the causes in the order of the process flow and determines safeguards/barriers and recommendations/action items in the same way as for pre-populated causes
- Proceed to the next section

PFFM is described in more detail elsewhere (Ego, 2004, and MacGregor, 2013).

A precursor to identifying all credible failure scenarios is to identify all of the potential causes of those failure scenarios. It is stated above that missed credible failure scenarios was an issue in major incidents in the past. Failure scenarios are in the "consequences" category. But to identify all potential failure scenarios, all potential causes must also be identified. This is where failures can be missed, and it is where the analysis of the case studies has been focused.

For each case study, the HAZOP review was done first, with a review team in a meeting room, as per common practice in industry. Each HAZOP review meeting had an experienced HAZOP facilitator whose method is to examine the facility drawings prior to the review meeting, lay out the nodes, and make separate notes on what he views as being the potential hazards and areas that need particular attention. Again, as per common practice, these facilitators did not enter causes into the worksheets prior to the review meeting to avoid "leading" the review team and reducing participation. Each review followed the same overall methodology: a HAZOP deviation approach, with 15 "standard" deviations to prompt team thought, risk ranking, and recommendations assigned to identifiable individuals. These reviews relied on facility P&IDs as their primary reference drawings.

To minimize bias and maximize applicability of the findings, the HAZOP reviews selected involved:

- Three individual experienced safety professionals facilitated the reviews, to avoid bias due to the preferences/strengths/weaknesses of any one individual
- Three separate types of oil & gas facilities were selected, designed by separate project design teams in separate client firms
- Three different review teams, with no one individual appearing on any of the other two teams
- Three different client sites with different ownership histories.

The drawings from each of the three reviews were then used with the Process Flow Failure Modes technique. The drawings with the coloured nodes indicated were used, so that the statistics generated could be broken down cleanly between the two methodologies, node by node. The HAZOP worksheets were not opened, to prevent any biasing of the PFFM worksheets with information from the HAZOP worksheets.

First, the PFFM worksheets were pre-populated with causes for all three case studies. For the Case Study #3, a full PHA review was conducted[1]. Finally, the worksheets were compared between the HAZOP and PFFM methodologies for each case.

5. The Case Studies

[1] This included development of a Safeguarding Flow Diagram (SFD) for Case Study 3, which was used as the primary reference drawing in the PFFM review meeting

One of the frustrations that emerged during this study is the frequency of duplication of line items (including causes) that occurs in HAZOP reviews[2]. Clients may see a thick pile of worksheets and from that assume that there has been a very thorough and systematic review of the facility. However, very often there is a lot of duplication of line items in the various deviations in a node. There is frequently duplication of line items among several neighbouring nodes as well. The duplicate causes/safeguards/recommendations sets do not compensate for the failure to identify missed causes.

5.1 Case Study 1: Heavy Oil Facility Infrastructure Upgrade

The facilities examined in C.S. #1 are fairly simple. No heat exchangers or rotating equipment is involved. However, H2S is present and flammable gases and liquids are present at elevated pressures. A LOC from this facility could result in one or more fatalities as well as financial losses in excess of $1 million Canadian dollars. The results of the reviews are displayed in Table 1.

Table 1. C. S. #1: Heavy Oil Facility Infrastructure Upgrade, Total & Unduplicated Causes Compared

Node Number	Node Description	HAZOP Total # Causes Listed	HAZOP Total # Unduplicated Causes Listed	PFFM Total # Causes Listed	PFFM Total # Unduplicated Causes Listed	% HAZOP Causes Identified, vs PFFM (Unduplicated)
1	Pig Catcher	24	23	24	24	96%
2	Gas/Liquid Separator	18	15	13	13	115%
3	Gas Handling Piping	18	18	46	46	39%
4	Flare Interface	2	2	10	10	20%
	TOTAL	62	58	93	93	63% average

A significant number of unduplicated causes were identified by PFFM as compared with HAZOP. These can be grouped into categories:

- System failure causes: The HAZOP review included no system failure causes at all (pool fire scenarios, loss of power, loss of instrument air, etc.). Using PFFM, every applicable system failure cause is listed
- In the Gas Handling Piping Node, Node 3, several incoming streams enter the scope of the review. In PFFM, each of these streams is subject to 6 questions: high/low incoming pressure and temperature, and contamination (unwanted phases, composition changes)

[2] Since PFFM lists each cause only once, *by design*, there is inherently no duplication of cause/safeguard/recommendation line items.

- In the Gas Handling Piping Node, there are several control valves. PFFM, properly done, asks what happens when the control valve fails open. It also asks what happens if the control valve fails open, with its bypass open, as this can present a hazard not previously identified in the design stage, and which does not exist with the control valve open alone
- In the Flare Interface Node, several streams leave the scope of the review. In PFFM, each of these streams has two causes associated: blocked flow downstream, and backflow into the facilities from the downstream unit

In C.S. #1, five causes were identified in the HAZOP review that could not have been identified via PFFM pre-population from P&IDs[3]. These five causes dealt with physical equipment locations, pigging frequencies, and special maintenance concerns. The extra items identified in the HAZOP review that were not listed in the pre-populated PFFM worksheets were, without exception, identifiable only by operations or maintenance personnel from the facility, and therefore were not identifiable prior to the review meeting.

One other observation that can be drawn from C.S. #1 is the trend in the number of causes identified. Early in the HAZOP review meeting, the number of causes identified is nearly on a par with the PFFM technique. However, later in the review, the percentage drops. One possible reason for this is that the team was getting tired and was unable to be as thorough as they were earlier in the review. (HAZOP teams get tired more quickly due to the non-intuitive nature of the HAZOP review process (Effect→Cause approach vs Cause→Effect approach used in PFFM.)) Another possible reason is that the meeting time was running out, and the team was rushed to complete the review. Perhaps it is a combination of both—either way, the number of causes identified later in the review meeting is much lower compared with those generated by PFFM.

5.2 Case Study 2: Natural Gas Well Surface Facility

The facilities examined in C.S. #2 are fairly simple. Again, no heat exchangers or rotating equipment is involved. However, flammable gases and liquids are present at elevated pressures, and the facility feeds a downstream unit that handles sour fluid. A LOC due to a failure in this facility could result in one or more fatalities as well as financial losses of up to $1 million Canadian dollars. The results of the reviews are shown in Table 2. In every node, the PFFM technique identified more potential causes of process hazards; in the first two nodes, more than twice as many causes were listed.

[3] Resources did not support production of SFDs for C.S. #1 & #2, and the same P&IDs for the facilities that were used for the HAZOP reviews were also used for the PFFM worksheets preparation.

Table 2. Case Study 2: Natural Gas Well Surface Facility, Total Causes Comparison

Node Number	**Node Description**	**HAZOP Total # Causes Listed**	**HAZOP Total # Unduplicated Causes Listed** (Notes 1-4)	**PFFM Total # Causes Listed**	**PFFM Total # Unduplicated Causes Listed**	**% HAZOP Causes Identified, vs PFFM (Unduplicated)**
1	Wellhead	11	11	24	24	46%
2	Methanol Injection	20	18	41	41	44%
3	Separator	21	20	34	32	63%
4	Fuel Gas System	20	18	20	20	90%
	TOTAL	72	67	119	119	56% average
Note 1. 3 items related to maintenance and physical location Note 2. 1 item about injection quills for methanol injection points Note 3. 1 out of scope item, hail storm, forest fire Note 4. 3 items maintenance related or out of scope						

A significant number of unduplicated causes were identified by PFFM as compared with HAZOP. These can be grouped into categories:

- System failure causes: The HAZOP review included fewer system failure causes (pool fire scenario, loss of power, loss of instrument air, etc.). Using PFFM, every applicable system failure cause is listed
- In the Wellhead Node, Node 1, two incoming streams (well tubing and well casing) enter the scope of the review. In PFFM, each of these streams is subject to 6 questions: high/low incoming pressure and temperature, and contamination (unwanted phases, composition changes)
- In Nodes 2 and 3, holding tanks are included. The Methanol Tank in Node 2 is filled by tank truck, while the Produced Water Tank in Node 3 is emptied by tank truck. In PFFM, truck loading/unloading activities entail 8 causes for truck offloading to a tank, and 5 questions for truck loading from a tank. Most of these were not discussed in the HAZOP review.
- There are several piping segments in Node 3 for draining of vessels, level bridles, and strainers to the Produced Water Tank. PFFM follows the process flow, considering each failure as it progresses through the drawing. HAZOP does not, typically, and it did not for Case 2. More general "catch-all" causes were phrased, as is typically the case for HAZOP reviews when the size of a node starts to get out of hand.

The extra items identified in the HAZOP review that were not listed in the pre-populated PFFM worksheets were, with three exceptions, identifiable only by operations or maintenance personnel from the facility, and therefore not identifiable prior to the review meeting. The exceptions were:

1. The HAZOP team recognized that there are no injection quills for the methanol injection points. Presence of design engineers in the review meeting made this identifiable.

2. Forest fire and hail storm were identified as being potential emergency situations for this facility. Typically, personnel who work at the facility will identify such hazards, based on their experiences at that geographical location. While such items could be listed beforehand by the facilitator, PFFM practice so far has been not to pre-populate for them. This is because process hazards are not typically influenced by storm or other external conditions except with respect to power and utility outages, fire case, blocked flow downstream, loss of flow upstream, etc. Of course, individual client preference can allow for pre-population of any number of "non-traditional" causes, as desired, similar to HAZOP reviews.
3. Maintenance or operational concerns related to unique equipment and its physical location.

In C. S. #2, the HAZOP review showed more consistency in identifying hazards as the nodes progressed, which is a difference from the trend in C. S. #1.

5.3 Case Study 3: Delayed Coking Unit

C. S. #3 involved complete HAZOP and PFFM reviews, and therefore more comparing and contrasting is possible for this case. The complexity of the process unit contributes to the validity of the findings. Briefly, a Delayed Coking Unit (DCU) is one in which heavy, thick oil is heated in fired heaters to temperatures at which thermal cracking of the large hydrocarbon molecules occurs (see schematic, Figure 2). The hot fluid is carried from the fired heaters to an in-service, or on-line, coke drum, where the thermal cracking reactions stop due to cooling by quench oil. Thermal cracking forms lighter, more marketable hydrocarbon molecules and coke. The coke settles in the coke drum, while the oil continues through to a fractionation column downstream. When the coke drum is full of coke, the drum is taken off line, isolated, cooled, and the coke is removed. DCUs have at least two coke drums in parallel, so that one drum can be on line while the other is having the coke removed.

The DCU studied for this paper included:

- Two fired heaters, totalling three process stream passes plus two steam superheating passes
- 25 pumps, 11 pressure vessels, 10 heat exchangers
- Coke drilling and coke removal equipment
- 6 main coke drum operating modes (each with several steps involving multiple swings of switching valves), on a 15-20 hour cycle)

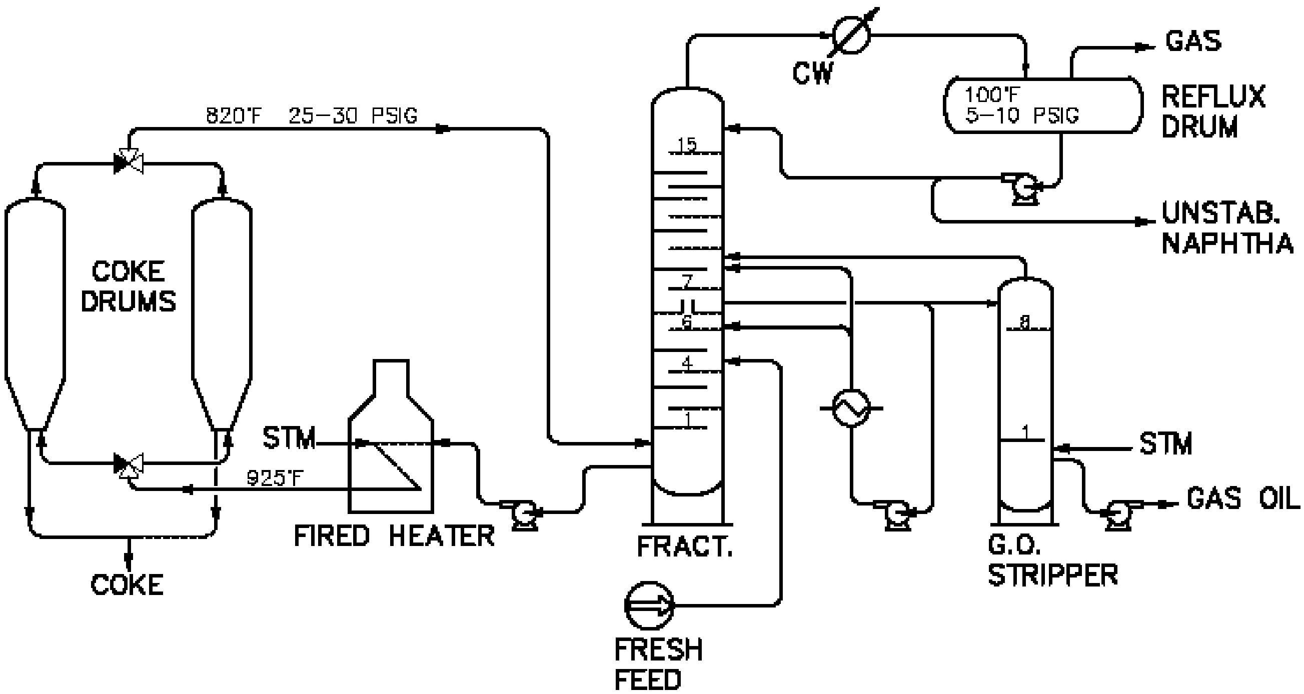
A HAZOP review was conducted in first, and a PFFM review was conducted at a later date. Only one team member, an operator, was common to both reviews. The HAZOP was not made available to the PFFM review team until most of the PFFM review was complete, and none of it was used to influence the PFFM review. As it happened, the PFFM review covered more scope than the HAZOP review. To enable a direct comparison of the two methods, then, the PFFM review results were rearranged into two groups: (1) matching the HAZOP review scope, and (2) additional scope. Then, the material in group (1) was rearranged to match the noding used for the HAZOP review.

A direct comparison of the findings from the two reviews *with matching scopes* is displayed in Figures 3, 4, and 5. For the same review scope:

1. PFFM identified more than twice the number of causes identified by HAZOP
2. PFFM identified more than 2.5 times the number of consequences identified by HAZOP

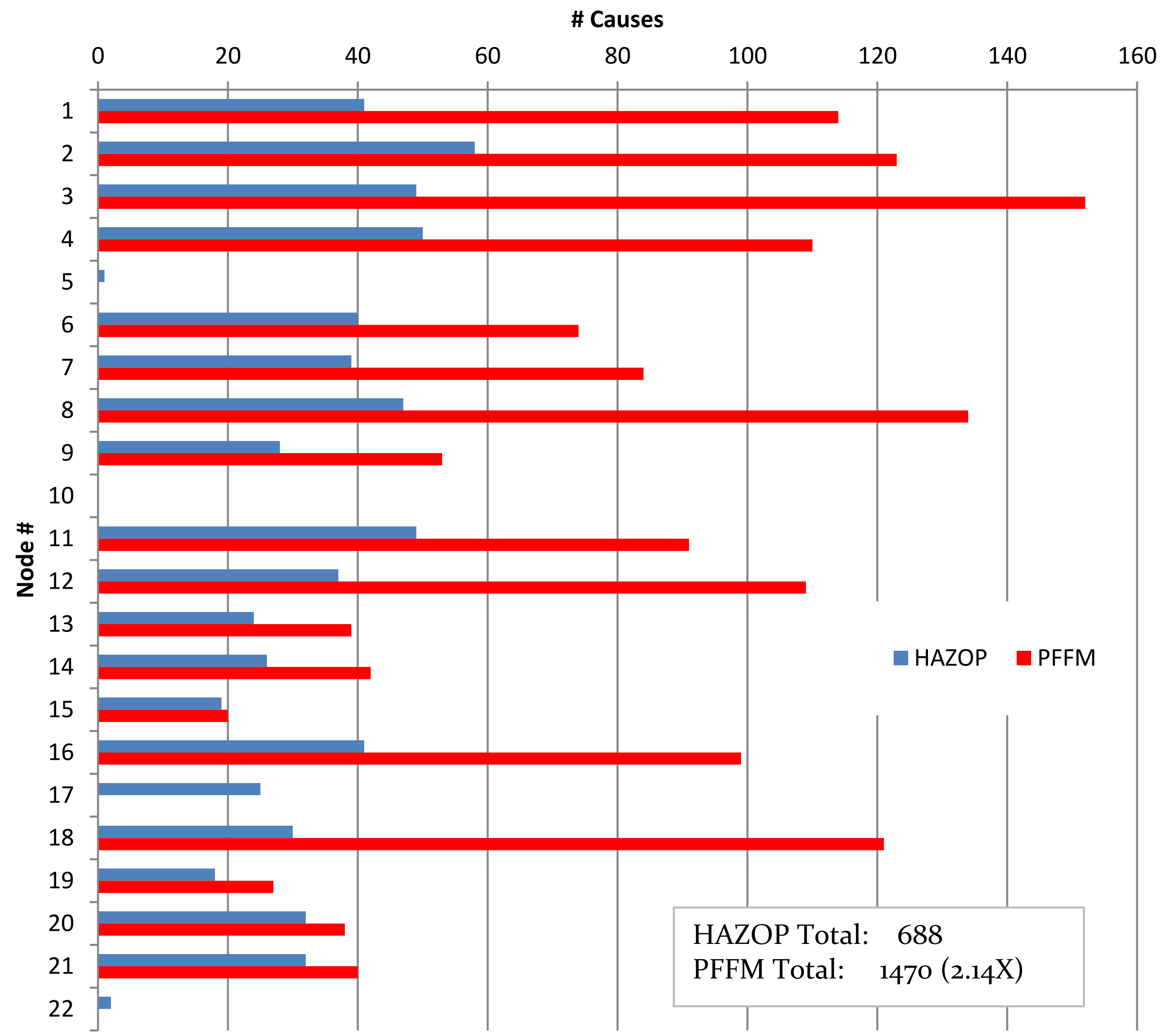
3. PFFM generated over one third more recommendations than were generated in the HAZOP review[4]

Figure 2. Delayed Coking Unit Schematic



[4] Since the operating company had some time in which to implement the HAZOP review recommendations because it was done earlier, there should have been fewer recommendations from the PFFM review, not more. Further, the HAZOP review recommendations contained many specific changes to specific valve operations, which were encompassed in a single PFFM review recommendation to implement a planned, well defined controls improvement project.

Figure 3. C.S. #3: No. of Causes in Each Node (Matched Scopes)



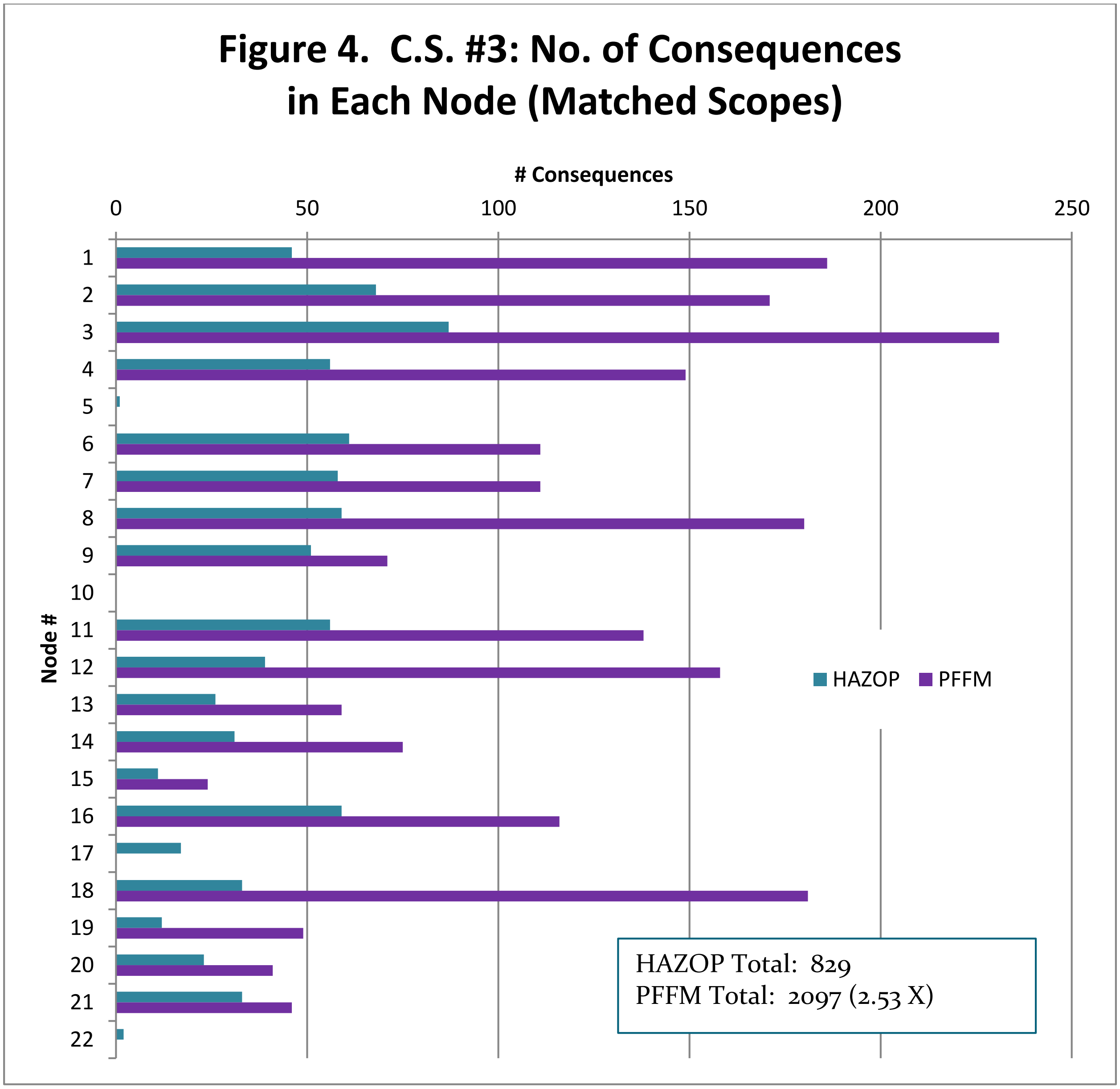
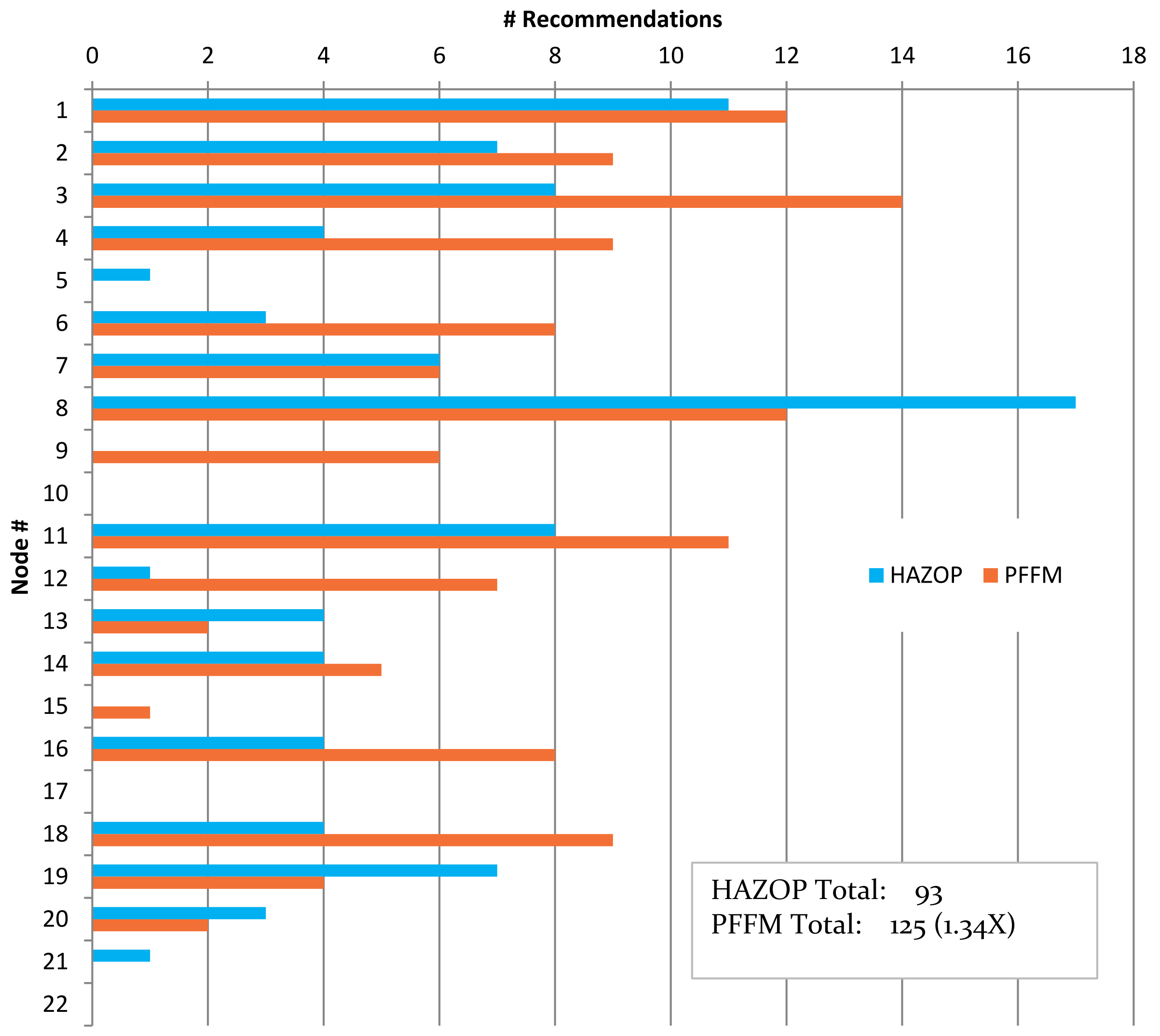


Figure 4. C.S. #3: No. of Consequences
in Each Node (Matched Scopes)
Consequences
0
50
100
150
200
250
Node #
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
HAZOP
PFFM
HAZOP Total: 829
PFFM Total: 2097 (2.53 X)

Figure 5. C.S. #3: No. of Recommendations in Each Node (Matched Scopes)



An estimate of the review meeting time necessary for the matching scope PFFM review is 10.1 days; the HAZOP review took 12 days. (While no such direct comparison was possible for C.S. #1 or #2, a similar wellsite review to C.S. #2 was conducted by the author which showed 25% savings in review meeting duration using PFFM.)

Due to the large scope of C.S. #3, it would be onerous to analyse all of the causes in both reviews and to compare and contrast these in detail. However, some general observations can be made (these from a review of the first 3½ nodes out of 22). The HAZOP review:

1. Failed to consider disturbances in feed streams entering the unit in a systematic way (high and low pressure, high and low temperature)

2. Included heat supply failure to O'Brien boxes in most nodes as a cause. Since such failures generally result in control valve or other failures, which are already considered in other types of causes, this is redundant
3. Used six different causes for high aerial cooler temperature, with mostly common safeguards. PFFM used two. In spite of this, the HAZOP missed design temperature issues on two overhead drums
4. Neglected valves and blinds that were incorrectly positioned in the field, since it assumed that the P&IDs represented the actual facility (PFFM includes field checking to confirm actual positions of manual block valves and blinds, including the positions of locked or car sealed valves)
5. Missed some maintenance isolation concerns
6. Did not consider pool fire or jet fire scenarios
7. Missed overheating potential for a shell and tube heat exchanger in the no flow case, as well as overpressure risk in the tube rupture case
8. Missed potential for some pumps to overpressure downstream equipment in blocked flow cases
9. Scope did not cover the entire process unit, and therefore some hazards were missed, such as the potential to overpressure turbine steam exhaust lines due to blocked flow and the potential to overpressure drain or pumpout lines by incorrect operation of manual block valves.

Because C.S. #3 had complete reviews for both PHA methods, further comparison is possible. For instance, was the higher number of causes posed by PFFM produced a greater number of unique causes—or were the causes just paraphrasing each other? An analysis of the two sets of worksheets was done side-by-side, and all causes that were essentially the same in both reviews were deleted. What remains is a set of unique causes that were identified by the two reviews The results are shown in Table 3. Table 4 shows the number of recommendations generated with respect to the same analysis.

Table 3. Case Study 3: Delayed Coker, Total & Unique Causes Comparison (for Same Review Scope)

HAZOP Total # Causes Listed	PFFM Total # Causes Listed	% HAZOP Total Causes Identified, vs PFFM	HAZOP Total # Unique Causes Listed	PFFM Total # Unique Causes Listed	% HAZOP Total Unique Causes Identified, vs PFFM
688	1470	47%	95	1024	9.3%

Table 4. Case Study 3: Delayed Coker, Total & Unique Recommendations Comparison (for Same Review Scope)

HAZOP Total # Rec'ns	PFFM Total # Rec'ns	% HAZOP Total Rec'ns, vs PFFM	HAZOP Total # Rec'ns for Unique Causes Listed	PFFM Total # Rec'ns for Unique Causes Listed	% HAZOP Total # Rec'ns for Unique Causes Identified, vs PFFM
95	123	77%	27	111	24%

Table 4 shows that the unique causes identified by PFFM produced four times as many unique recommendations. Furthermore, at least five of the HAZOP recommendations had become obsolete by the time the PFFM review was held, because they had been implemented.

5.3.1 Additional Scope Reviewed by PFFM for C.S. #3

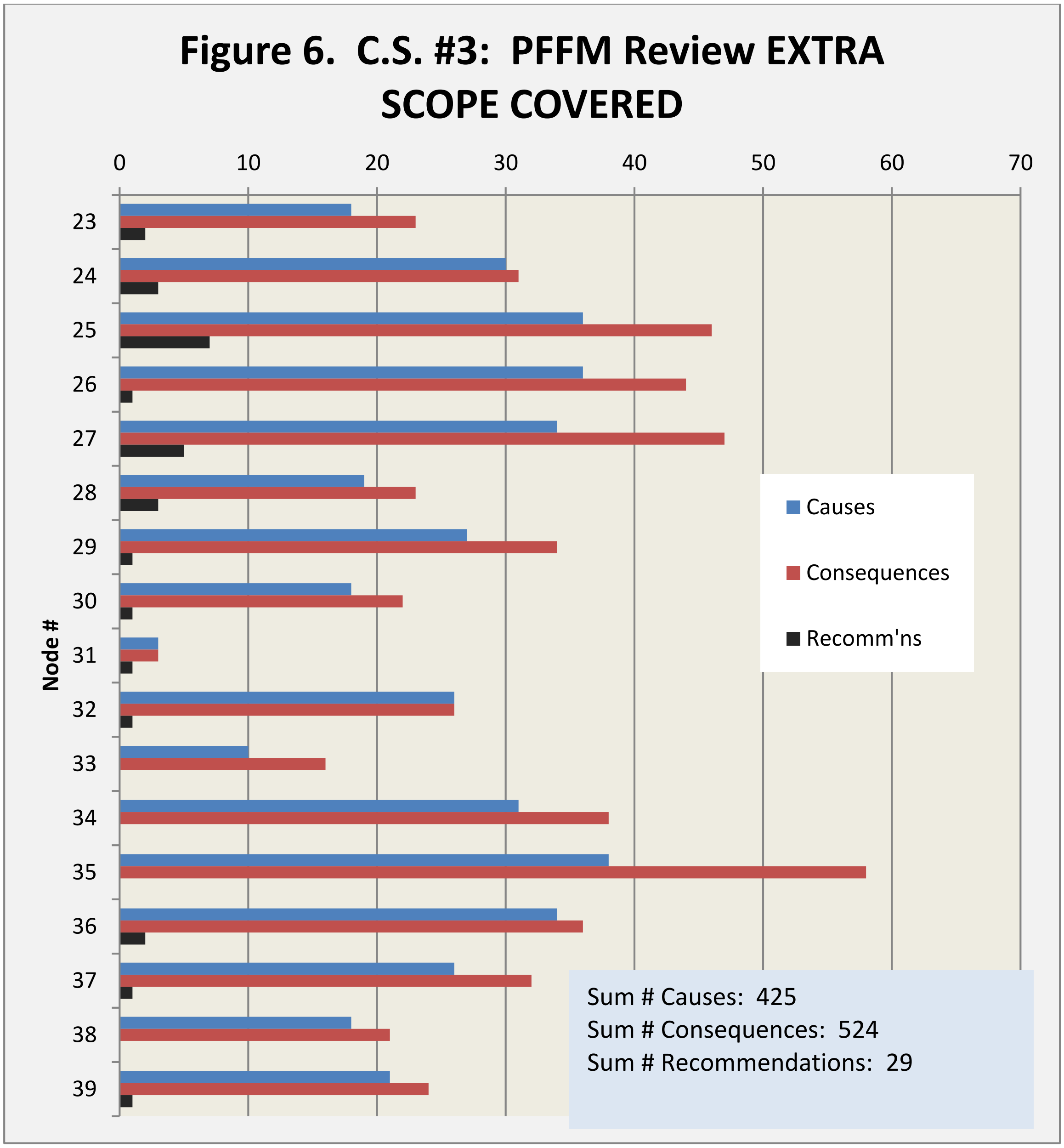
The PFFM review covered more scope, as mentioned above. Since HAZOP uses P&IDs, crowded or confusing layouts can result in overlooked scope. Field checked SFDs are generated for PFFM reviews of complex facilities, greatly reducing the likelihood of missed equipment. Additional scope covered in the PFFM review was:

- Two chemical injection packages + cutting oil (3 nodes)
- Steam superheaters in Coker Furnaces (2 nodes)
- Utilities sides of S&T Exchangers (2 nodes)
- Pump Steam Turbines (1 node + causes in 3 others)
- Steam Blowdown Drum & Pumps (2 nodes)
- Reboiler in Blowdown Tower (1 node)
- Start-up/Recirculation Piping (1 node + causes in 2 others)
- Coke handling facilities (1 node)
- Slop Oil header (1 node)

The results of the additional PFFM reviewed equipment are shown on Figure 6. A significant benefit includes the 29 recommendations that were made. To cover this additional scope took 1.9 more days, for a total of 13 review days for the PFFM review versus 12 for the HAZOP review. Some of the review recommendations from this additional scope included:

1. Access to the safety shower could become hazardous if antifoam has been spilled at the antifoam skid. Mitigate
2. Ensure proper set pressure of chemical skid PSVs to prevent backflow of oil to tote tanks, which could cause a flammable spill
3. Run dedicated flush oil line to antifoam line so that switching valve in flush oil header can function as needed to prevent escalation factors in unit (switching valve is part of unit emergency isolation system)
4. Deal with out-of-service steam superheater coils in fired heaters to eliminate associated hazards with current configuration
5. Two recommendations dealing with safe, reliable damper operation on fired heaters
6. Ensure functionality and correct sizing of PSV on cooling water side of a process exchanger
7. Address potential personnel burn hazard from current steam blowdown valve vent configuration
8. Several recommendations to address potential to cross-contaminate two separate slop systems, which could cause tank failure and LOC hot, flammable, sour fluid
9. Installation of start-up bypass around a high pressure steam isolation valve

None of these recommendations is superfluous, and their value is readily apparent. What is a concern is that they arose from equipment that was not even considered within the scope of the HAZOP review.



6. Summary

The data from the CSB paper (Kaszniak, 2009) makes it clear that the failure to identify credible failure scenarios can result in very serious consequences, and that credible failure scenarios are sometimes missed during PHA reviews. Failure scenarios are in the "Consequences" category, and to identify all potential failure scenarios, all potential causes must also be identified. This is where failures can be missed, and it is where the analysis of the case studies was focused.

The CSB paper (Kaszniak, 2009) examined serious incidents. Given the data shown above, and below in Table 5, the PHA reviews involved in the CSB paper incidents were not unusually deficient, and the typical HAZOP review done today not much more complete.

Table 5. Total Causes Comparison, All Three Case Studies

Case Study Number	HAZOP Total # Causes Listed	HAZOP Total # Unduplicated Causes Listed	PFFM Total # Causes Listed	PFFM Total # Unduplicated Causes Listed	% HAZOP Causes Identified, vs PFFM (Total)
1	62	58	93	93	67%
2	72	67	119	119	61%
3	688	n/a	1470	n/a	47%
TOTAL	822	n/a	1682	n/a	49%(weighted)

Why did the HAZOP reviews fail to identify all the causes—and, therefore, all of the potential hazards? Analysis of the differences in the case studies shows:

- Shortcutting of the HAZOP methodology—fire case is not considered at all in two of these reviews
- Shortcutting of the HAZOP methodology—feed stream hazards due to high/low pressure or high/low temperature were not included in one of the reviews
- Shortcutting of the HAZOP methodology—the assumption in the reviews is that, since the failure of rotating equipment and control/isolation valve failures have been individually considered, the power failure case (or instrument air case, as appropriate) has been covered. This is not so, because instrument air failure can cause multiple valves to fail, while power failures can cause multiple pumps, certain types of valves, and electric heat tracing to fail simultaneously
- Lack of systematic consideration of manual block valves being in the wrong position in even moderately complex piping arrangements—HAZOP methodology inherently makes these failure cases difficult to visualize, describe, and fit into a given deviation
- The assumption in HAZOP that all locked or car sealed valves and blinds will be in the positions indicated on the P&IDs causes some hazards to be missed. Operators in the HAZOP review may not raise the fact that the P&ID is incorrect in a given case because they are unsure themselves, or they have the impression that it is unimportant because other (possibly inadequate) safeguards exist, or because they are confused about which exact valve or blind the team is currently discussing
- Tendency to move the meeting on from the analysis of a given deviation or cause before all credible causes or consequences have been identified—this is worse for HAZOP because HAZOP teams get tired more quickly (common example: overheating of drums or cold sides of exchangers, once overpressure and blocked flow hazards identified)
- Following the deviation approach, the teams came up with complicated causes to fit the deviations. Simple failure scenarios (i.e. stuck open check valves, a single pump failure) are missed in the confusion.
- Use of complex P&IDs for noding and analysis, resulting in missed equipment & piping, missed high/low pressure interfaces, and in missed hazards

Table 6. Potential Serious Missed Causes (Annually, for One Facilitator)

Description	Value	Calculation	Result
# Causes in all reviews by one facilitator in one year	6379[5]	n/a	6379
Average Annual Causes Missed by HAZOP vs PFFM	51% (from Table 5 above)	0.51*6379	3253.3
Average Annual Missed Causes that Could Result in LOC (est.)	10% (estimated)	0.10*3253.3	325.3
Average Annual Missed LOC Causes Without Adequate Safeguards	10% (estimated)	0.10*325.3	**32.5**

Table 6 applies the results of the HAZOP/PFFM case study comparisons to one facilitator's year's reviews: 32.5 unidentified serious incidents could be lurking in these facilities, any one of which could occur while those facilities are in operation—for only one facilitator, for only one year. When the number of facilitators involved in HAZOP reviews, world-wide, every year, is considered, there is enormous potential for damage and loss of life. It is no wonder, therefore, that incidents continue to occur.

7. Conclusion

Findings from the examination of incidents and disasters in industry indicate that not all process hazards are recognized during PHA reviews—in fact, failure to recognise that a hazard existed was the most common cause of major incidents (Kazniak, 2009). This is a compelling case for change: we cannot manage a hazard if we don't know that it exists, and PHA review teams must make every reasonable effort to identify all process hazards—even those that are not easy to discern.

In these case studies, outcomes of three actual HAZOP reviews in the oil & gas industry have been compared with the results of Process Flow Failure Modes (PFFM), a "cold eyes" structured what-if examination method. For the same facilities, PFFM identified a weighted average of twice as many causes as the HAZOP review meetings did, and therefore was able to identify far more potential hazards. Case Study #3 was the most direct comparison between the two methods, and showed approximately 15% savings in review meeting duration when PFFM was used, while at the same time delivering better results. The more complex the facility, the more superior were the PFFM results. Surely, this is compelling evidence for incorporating the PFFM technique into all of our PHA reviews going forward.

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