

HORSES FOR COURSES: MATCHING THE APPROACH TO HAZARD ANALYSIS WITH PROJECT SCHEDULE AND DESIGN DEFINITION

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For many firms Hazard and Operability Analysis (HAZOP) has become a by-word for the "correct" approach to systematic hazard identification and analysis of process plants. But to be successful the technique requires sufficient design development, appropriate resources and sufficient time for implementation. Against a background of shortening schedules and pressure to reduce costs, there is the potential for HAZOP to be used under circumstances where it does not produce the best results.

This paper draws on our practical experience of implementing both HAZOP and alternative approaches matched to the stage of development of the project. In particular we review:

- The use of questionnaires for Process Hazards Analysis (PHA) at the early stages of a project during conceptual design.
- The use of Major Hazards Review (MHR) workshops for existing facilities which may have been in operation for some time and where potential hazards are well understood.

The aim of this paper is not to describe the PHA, HAZOP or MHR techniques but to give practical examples of their application, to demonstrate the effectiveness of alternative techniques and examine shortcomings when an inappropriate method is chosen for the stage of development of the project.

INTRODUCTION

All three techniques discussed in this paper can be said to have a common aim; identification of hazards in process plant. The identification step forms an integral part in overall process safety management which covers identification, assessment, and mitigation of risks in process plant.

The main point of the paper is to illustrate with practical examples circumstances under which each technique is most effective and the consequences which can occur if the identification techniques are applied inappropriately.

HAZARD AND OPERABILITY STUDY (HAZOP)

Many organizations have incorporated Hazard and Operability Study (HAZOP) as part of their process safety management procedures(1). These procedures typically use HAZOP as a method for evaluating, in a systematic way, the safety and operability of plants and auxiliary facilities. The approach is used by both Plant Operating Companies and the contractors working for them on process projects or re-vamps and the procedures for HAZOP may be incorporated into company standards or be part of the contractor's own approach to safety management.

The HAZOP Study involves a formal team review of Piping and Instrumentation diagrams (P&ID) under normal operation conditions and also under transient conditions such as catalyst activation, start-up or emergency shutdown to ensure the plant is in a safe condition during all these phases. The technique involves team assessment wherever deviations from the design intention can occur. Deviations are identified though systematic application of parameter-guideword combinations to nodes which are selected to break the plant down into different functional blocks.

Where credible deviations are found, the team reviews whether the situation could be hazardous or might make the plant difficult to operate. This review involves considering the consequences which might occur, the safeguards already in place to manage the risk and, in cases where the team feels improvement is desirable, recommendations aimed at further risk mitigation.

The discussions during the team review of each node are recorded using a HAZOP Worksheet which is typically projected to allow participants to keep pace with the findings. The facilitator will also annotate the P&ID to show progress and recommendations so that the mark-up and the HAZOP worksheet together provide a definitive record of each session which is reviewed and agreed by each participant on behalf of the function they represent.

The objective of the HAZOP study is to identify potential hazards and to assign actions to make good any shortfall in risk management rather than taking time to design solutions. However, if a solution is obvious to the team, a summary of the suggestion can be included in the worksheet recommendations.

The approach described for one node is repeated until all nodes on the set of P&IDs have been examined under normal operating conditions. Further review sessions focus on transitional phases of operation such as catalyst activation, start-up, shut down and regeneration. Particular attention is given to emergency shut down systems.

PROCESS HAZARDS ANALYSIS (PHA)

Some organizations have adopted Process Hazards Analysis (PHA) as a means to ensure safe plant design and to identify the required safeguarding devices to minimize the risk of design changes in the detailed engineering phase of a project. In the PHA study, a check list approach is used to evaluate the following issues associated with the plant.

- Hazardous plant equipment and materials (e.g. fuels, highly reactive chemicals, toxic substances, explosives, high pressure systems, and other energy storage systems).
- Safety-related interfaces between plant equipment items and materials (e.g. material interactions, fire/explosion initiation and propagation, and control/shutdown systems).
- Environmental factors that may influence the plant equipment and materials (e.g. earthquake, vibration, flooding, extreme temperatures, electrostatic discharge, and humidity).
- Operating, testing, maintenance, and emergency procedures (e.g. human error importance, operator functions to be accomplished, equipment layout/accessibility, and personnel safety protection).
- Facility support (e.g. storage, testing equipment, training, and utilities).
- Safety-related equipment (e.g. mitigating systems, redundancy, fire suppression, and personal protective equipment).

The PHA should identify major hazards and accident situations that could result in undesired consequences. It should also propose design features or alternatives that could eliminate or reduce those hazards. The study is conducted as a facilitated team investigation designed to inspire imaginative thinking by a group of experts. They focus on hazards and operational problems by examining the process units typically using a process flow diagram (PFD showing major equipment sub-systems) with team members referring to the P&ID and other available project documentation as needed.

This objective clearly overlaps with that of a HAZOP study, although the approach and the methods adopted are different. Both methods may be used on the same project with PHA used in the early stages of the plant design and HAZOP study using the parameter-guideword method performed in the subsequent detailed design phase.

MAJOR HAZARDS REVIEW (MHR)

Major Hazards Review is a workshop technique used to review the precautions on a particular plant to safeguard against the main generic hazards recognised on plants of the same general type[2]. The main working document is a risk register which covers each section of the plant listing the main hazards which have the potential to occur. The register is prepared before the workshop, drawing on all the hazards identified in previous HAZOP studies of the same type. Typically at least three previous studies are required, competently executed and with full recording, so that a thorough view of potential hazards is available. The register also includes a tabulation of accidents which have occurred on plants of the type under study drawn from the database we maintain. This tabulation can be especially helpful in the introductory phases of the workshop where it serves to give participants clear information (with a photographic record where possible) about the credibility and potential impact of incidents. The aim is not to be alarmist but to counter feelings that "we don't/won't have accidents" to encourage participants to focus on the rare but still credible chains of events which can lead to a major incident.

The workshop proceeds by reviewing each section of the risk register step by step. The team considers if each hazard listed in the register might occur on their particular plant, what the consequences might be and what safeguards are already in place. If the team feels the safeguarding could be improved, recommendations are made and added to the workshop record.

The second part of the workshop consists of a risk assessment by which team members give their views of the frequency and consequences of hazardous events before the recommendations are carried out and after they are implemented. The cost of the additional safeguard is also estimated. The assessments are made using calibrated ranking matrices, typically 5 point scales calibrated against hazard frequency for the industry and loss history. The assessments are made independently by individual experts and if time permits the individual scores are compared and discussion facilitated between team members who have expressed widely differing views. The aim of the discussion is to reach a common consensus on the risk evaluation.

In the final part of the analysis for each recommendation two items are compared:

- The loss aversion expected from the additional safeguard (the difference between the risk before and the risk after implementation).
- The cost of implementation.

From these inputs a benefit cost ratio can be determined allowing recommendations to be classified either in terms of the risk reduction they achieve or the benefit cost ratio they offer as a return on safety investment.

The quality of the workshop hinges on the thoroughness with which the risk registers are prepared and hence the quality of the previous HAZOP studies on which they are based. Provided these are points are acceptable, the approach provides an effective way of identifying the major safety performance improvement measures which can be justified for a particular plant.

STRENGTHS AND WEAKNESSES OF THE THREE METHODS

All three techniques can deliver good hazard identification given an expert team, a skillful facilitator and a well prepared design basis. Where these conditions do not prevail some undesired outcomes may result.

LACK OF TEAM EXPERTISE

If those participating in the study lack experience of the unit under study the quality of the work is likely to be seriously impaired. In essence either a HAZOP, PHA or MHR study is only as good as the team which carries it out. It might seem as if these meetings could be a good training for a new engineer but in practice this is often a frustrating experience both for the new recruit as well as other members of the team who quickly recognize a "passenger". Those crucial experts assigned to the study team can often be busy people with many demands on their time. It is very disruptive to proceedings if the attention of such individuals is diverted by phone calls or their attendance interrupted by the need to participate in other meetings.

INEXPERIENCED FACILITATOR

If the facilitator lacks confidence or experience this can slow the progress of the study and unsettle the team. Facilitators need to gain experience of course but this is best done on the foundation of a good training course and supportive initial assignments involving short studies with familiar technology to allow the fledgling facilitator to gain confidence.

It is important to recognize that different types of facilitation skills are required by the three methods. For PHA the facilitator needs to have strong interpretation skills so that team members can be guided to appreciate the relevance of a general question to a particular design feature of the plant in question. For MHR the technique is very practical but requires facilitation with a strong appreciation both of the operation of the plant in question and the safeguards used elsewhere. HAZOP is by comparison the most methodologically structured approach and can be successful even in the hands of a facilitator who does not know the particular plant, provided there is a strong grounding in and a willingness to apply thoroughly the HAZOP methodology.

TOO LITTLE TIME FOR SCOPE TO BE COVERED

It is essential that whoever commissions a HAZOP, PHA or MHR study understands the time required and makes an adequate provision. Figure 1 shows the relationship in our recent studies between the number of drawings for review and the time taken for study.

It is immediately apparent that the PHA approach (purple line) allows more drawings to be progressed in a given time. However it is important to realize that the analysis achieved by PHA is not as deep as that obtained by HAZOP. Only a single point is available for MHR but we suggest the analysis achieved by MHR corresponds to that of HAZOP because the study items are drawn from previous HAZOP studies.

Analysis shows that the larger number of drawings which can be processed by PHA is not because the work rate in terms of numbers of items discussed is greater. Figure 2 suggests there is little difference in this respect between all three techniques, MHR, PHA and HAZOP in the hands of the same facilitator. A note of caution is needed because relatively few points are available for MHR and PHA and there is a wide scatter between the HAZOP studies. Those who have facilitated HAZOP will recognize the different rates of progress achieved by different teams and the "bedding down" which occurs as team members become used to working with each and can accelerate discussions without feeling they are skipping important points.

The linear correlation for items per day shows more scatter than Drawings per day in Figure 1 (compare R^2 values) indicating that some groups move at different speeds to the average. For example this occurs where one or more team members are unfamiliar with the principles behind hazard identification and take up too much discussion time with procedural irrelevances or "hobby-horses". By contrast small groups of experts who are familiar with the process and with working together can progress at a rate which is above average.

A similar analysis can be conducted for the number of recommendations generated in a day's work. The following graph shows data for HAZOP, PHA and MRH with the linear trend line for the HAZOP data.

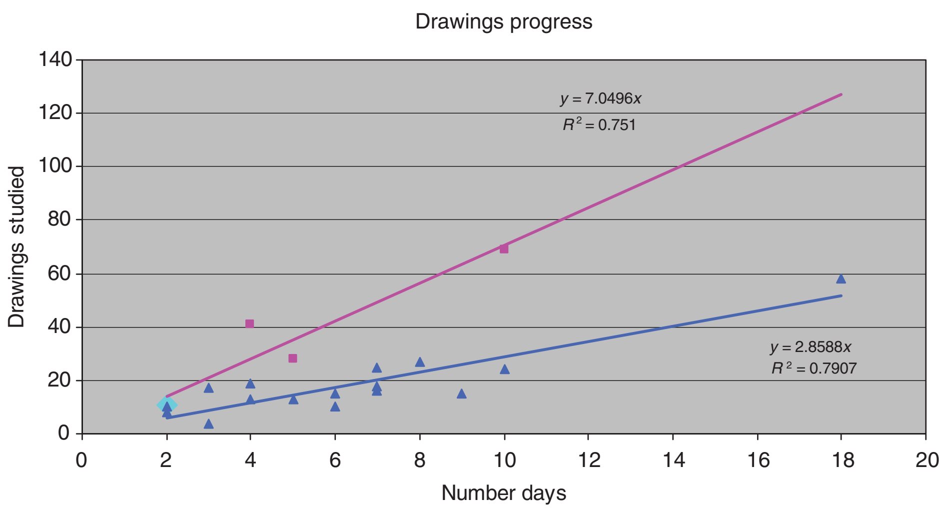

Figure 1. Drawings per day of study. *Source:* Arthur D Little PHA Purple, HAZOP: Blue MHR Turquoise

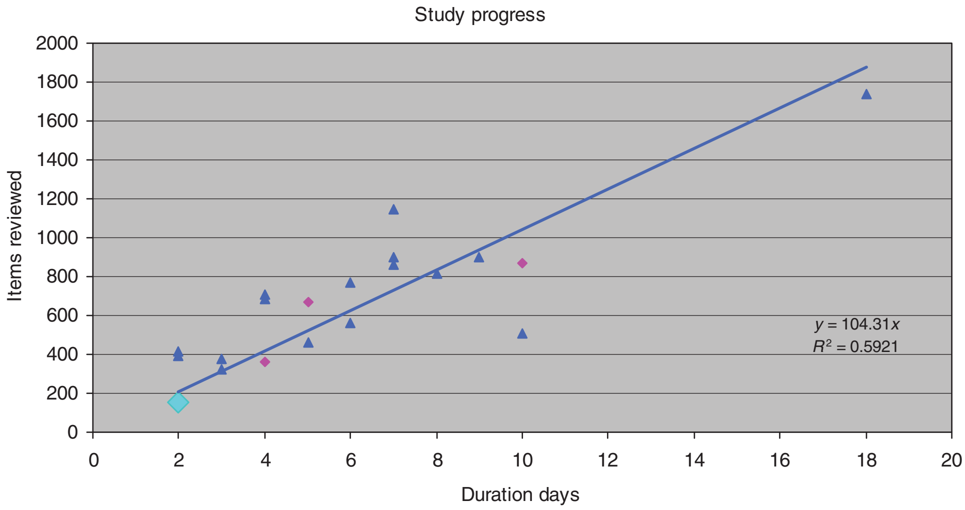

Figure 2. Items studied per team day. *Source:* Arthur D Little PHA Purple, HAZOP: Blue, MHR Turquoise

This provides the closest correlation of the three analyses indicating a relationship between the number of recommendations generated and the time available for study. Although few points are available for PHA and MHR they appear to fall within the range of deviation of the HAZOP data.

There is an important implication from this finding. It shows that the PHA approach, while apparently covering more ground in terms of drawings does so in a shallower manner (fewer recommendations per drawing, about four per drawing for PHA, 14 per drawing for HAZOP). This is an important characteristic which needs to be recognized when choosing between PHA and HAZOP.

MHR on the other hand generated a higher than expected rate of recommendations in the single study for which we have data. This might occur because the team meetings are focused on only hazardous issues drawn from precursor HAZOP studies on the same type of plant as the one under study.

HAZOP WITH "SHORT CUTS"

While the merits of the HAZOP technique are often recognized, project staff may be tempted to shorten the study time by setting "rules" designed to limit debate. Examples of such guidelines include:

1. *Mechanical protection devices (PSVs, rupture discs) are expected to work.*
   Any equipment has a failure rate even though it may be quite small. For Pressure Safety Valves the expected failure rate may be small and this can be an independent layer of protection which needs to be considered during SIL assignment. However there are other failure modes (unintended isolation on inlet, blockage of discharge piping, lifting and then failing to properly reseat) so without a discussion on such issues there may for example be inconsistent approaches to PSV mechanical arrangements and sparing philosophy.
2. *No quantitative analysis to be performed during HAZOP meeting.*
   This often limits discussion on the size of potential consequences with the result that different team members may have different mental models of the potential outcome should a particular hazard occur. Information based on QRA nomograms giving approximate effect distances can be helpful for team members to appreciate the magnitude of some consequences and a matrix ranking exercise (see discussion from page 9 "Risk assessment following hazard identification") can be a useful added value exercise with the team once the HAZOP is completed.
3. *If there is more than one train or pass, only one will be reviewed, considering they are identical.*
   It is often advisable to do a line check to verify this is in fact the case otherwise a topic which could be missed is flow distributions between parallel heat exchanger or furnace passes. There can be safety implications for uneven flow distribution in such equipment.
4. *Single check valve is adequate for contamination protection or excessive temperature unless special circumstances exist.*
   Operating plant experience shows numerous accidents have occurred through failure of non return valves. This is a potentially important topic which needs to be discussed in relation to the service, particularly for dirty service or multi-phase service for example oil/hydrogen mixtures under pressure.
5. *Impact on environment (e.g., dispersion) will not be analyzed.*
   This may appear to be a simplifying assumption but short consideration will bring to mind major accidents with huge consequences for the operator arising from environmental liability.

6. *No design work will be done*.
   While agreeing that a HAZOP is not a design session it is an opportunity to review the proposed plant design and particularly if the licensor's representative is present, it makes sense to allow discussion to draw on team experience to illustrate approaches to problem solving adopted on other plants. An experienced facilitator is expected to judge how far and how deep such discussions offer value.
7. *Simultaneous occurrence of two unrelated incidents not considered*.
   This "rule" so called double jeopardy is often used to curtail discussions. However recognizing what is truly unrelated is worth discussion in the light of actual accident experience where major consequences have resulted from "coincidence" of superficially unrelated occurrences. An experienced facilitator will also bear in mind special operations or plant status when normal protections may not be applied allowing hazardous situations to arise for a single failure.
8. Occurrences such as *Natural calamity*, (e.g., flood, earthquake), *Dropped objects* on live line are sometimes excluded yet have been the cause of major loss in isolated instances.
9. *Interlock/shutdown system/trip is deemed as protection/safeguard*.
   Obviously the sufficiency of an interlock is the subject of a SIL assessment requiring understanding of the frequency of occurrence and consequences which might occur were the SIS to fail on demand.
10. *Alarm system for operator action or operating instruction/operating manual is deemed as protection/safeguard*.
    Many accidents have occurred because operators failed to respond correctly to alarms in time.
11. *Assume that the design basis is correct*.
    In a number of projects, random checks have shown design weaknesses such as inappropriate PSV design cases, control valve capacities, equipment design temperatures, and material selection. It is our experience that such issues can be missed in "P&ID/design review" or assumptions made in design which do not stand up to challenge in subsequent HAZOP studies.

All the above restrictions have been proposed for HAZOP and PHA studies at one time or another. In our experience such arbitrary limitations fail to curtail discussion (practical engineers understand the potential risks in these situations). An experienced facilitator is expected to be able to allow such topics to be raised but to manage the discussion to a quick and fruitful conclusion which satisfies team members that the issues have been sufficiently aired rather than "brushed under the carpet".

WHEN PHA IS PREFERRED TO HAZOP

Once the project has advanced beyond the concept stage and the extensive work involved in Front End Engineering (FEED) is completed it makes little sense to conduct a PHA on the PFD's. However, at earlier stages of the project if an owner becomes concerned that the project safety culture is weak, PHA can serve as a useful technique to establish a clear Design Philosophy based on Safety Management considerations (rather than based on constraints of cost or schedule). For example basic issues such as locating pumps in flammable service directly underneath pipe-racks and fin-fan banks (design practice which went out decades ago) needs to be addressed at the early stages of the project and not left to the later stages of FEED.

To achieve this objective using PHA requires a consistent checklist appropriate to the stage of the project at which it will be applied. As an example of an early design issue:

> "*Is it possible to reduce potential safety and environmental hazards by minimizing leak sources such as pumps or tanks?"*

Such a question may be appropriate to a PHA checklist to be applied at the conceptual stage. Consider a checklist item such as:

> "*Loss of utility failsafe position of valves*"

Such an item may be an issue for later design when reviewing the P&IDs and considering the safe status of the plant in emergency conditions such as loss of instrument air.

Other questions may be included in checklists such as:

> "*Should there be reliance on instrumented trip functions", rather than "inherent safe design*".

The issue may need early consideration even though this may appear to require detailed understanding of the control and safeguarding philosophy. The scope of enquiry should be open to the team so that arbitrary limitations are not imposed. For example in our HAZOP practice we carry out checks for the consistency of the design basis, for example the application of an appropriate design factor between the low pressure and high pressure side of a heat exchanger. Some object to this practice arguing that this is a design matter or an issue which should be dealt with in P&ID review. We introduce such questioning when we can and find quite often inconsistencies in approach between different licensor packages in the same facility.

A different issue concerns the investigation of potential hazards across interfaces. It is sometimes argued for example that flare capacity issues lie outside the plant battery limit and should not be discussed. However in the expansion of an existing site, increasing the capacity of the flare system or sizing for adequate liquids handling can become issues to be investigated. If "rules" exclude such discussions, the outcome could be unacceptably high SIL requirements for instrumented trips to limit flaring. We feel this issue is best anticipated earlier rather than later when it may come to a head during detailed design.

A consistent checklist appropriate to the stage of design development avoids frustrating members of the team with different expectations which exclude "looking in too much detail" for example at consistency of instrumentation on comparable items of equipment.

In our opinion, owners would have been far better to conduct:

- PHA on the PFDs at an early stage of the project for example during conceptual design.
- HAZOP on the P&IDs depending on the project contract structure.

At the Front End Engineering stage of the project this implies HAZOP in good time to allow the findings to be included in the final FEED documentation. Later in the project schedule when the focus is on detailed engineering and build ie during the Engineer, Procure and Construction (EPC) phase, this implies conducting HAZOP prior to giving 'approval for construction'. In this latter case the work comes late in the day so that weak FEED stage studies (by PHA or HAZOP) that do not challenge project philosophies, design basis or assumptions are likely to lead to a troublesome EPC study HAZOP. Significant delays/difficulty can be experienced if the design has not undertaken sufficient rigorous review during the FEED stage especially if the EPC stage is by fixed lump sum contract. Not only does the project risk significant delay, it also opens the door to claims/variation orders if the EPC contractor can show the FEED design basis to be inappropriate.

We notice a trend to postpone design decisions to the EPC contract in an attempt to reduce the cost and duration of FEED. It is desirable for both Client and Contractor to have an agreed design before commencing review and not postpone difficult discussions to the detailed design HAZOP to see whether the issues are identified. Last minute changes leading to issue of revised P&IDs to client on day of the HAZOP or process redesign once the unit HAZOP has commenced are not best practice and lead to difficult and inefficient HAZOP studies.

Two of the approaches discussed, HAZOP and PHA may not be suitable for the examination of plants which have been in service for some time, where the hazards are well known and safeguards are in place. Nevertheless a formal process is required for example to manage changes such as revamp or debottlenecking. Under these circumstances a Major Hazards Review (MHR) could be considered.

WHEN MAJOR HAZARDS REVIEW IS MORE EFFECTIVE

Major Hazards Review benefits from previous systematic study but avoids taking time to generate this tried and trusted material afresh in another HAZOP for the plant in question. The technique therefore offers considerable saving in time and resource provided the necessary conditions apply.

The data in Figure 1, Figure 2 and Figure 3 includes a point for a Major Hazards Review study we recently conducted. Comparing the relationship between the turquoise point (MHR) to the HAZOP trend line in Figure 2 and Figure 3 suggests that MHR produces more recommendations per item discussed. The average ratios from these studies are:

- for HAZOP 5.3 items discussed per recommendation,
- for PHA 3.6 items discussed per recommendation
- for MHR just 1.6 items discussed per recommendation.

It means that by comparison with the HAZOP and PHA technique, MHR workshops appear more productive in terms of recommendations made in comparison to the number of issues covered.

This ability of MHR to focus team time is a reflection of the depth of analysis in the HAZOP studies on which the review is based. The higher ratio of recommendations

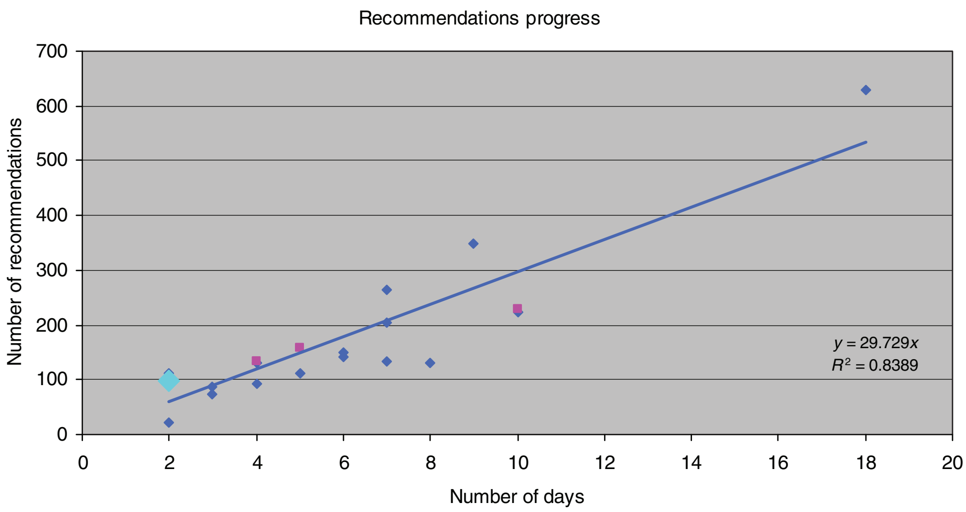

Figure 3. Recommendations proposed per day. *Source:* Arthur D Little PHA Purple, HAZOP: Blue MHR Turquoise

to issues discussed in MHR is achieved by careful preparation during which previous HAZOP studies are collated and the main hazards extracted. Team time is thereby focused to hazardous issues making more efficient use of company resources.

RISK ASSESSMENT AS PART OF HAZARD IDENTIFICATION

Some of our clients ask us to risk assess as part of hazard identification in HAZOP, PHA or MHR studies. There are two ways to tackle this requirement:

- Evaluate risk for each hazard at the time of identification to determine whether a recommendation is required.
- Assess the risk reduction on offer for each recommendation as a separate exercise once the hazard identification is complete.

We have shown previously that reliable risk assessment can be achieved using calibrated ranking matrices [(3)]. Our experience has been that attempting such assessment at the time each hazard is identified is very time consuming. Such timing interrupts the momentum of hazard identification in a particular process plant section by requiring a separate comparative task needing broad knowledge of failure rates and potential losses in different contexts. In previous work we have shown[(4)] that risk assessment after hazard identification can be a powerful tool for improvement of investment returns in existing assets. Where procedure requires "all recommendations have to be implemented" assessment is less beneficial.

As part of our MHR practice we include matrix assessment of the risk before and after implementation of each recommendation[(2)]. In principle such an approach could be also applicable to HAZOP or to PHA but due to the greater number of days typically and the greater number of recommendations typically, such matrix assessments could add many days additional to what has already been a long procedure. Because of the much shorter time, and hence typically fewer recommendations in MHR (see Figure 3) the matrix assessment technique can be built into the MHR procedure in a quite time effective manner.

Once sufficient time has been spent in the workshop to understand the principal involved, these assessments can be done individually and collated separately after the workshop is completed. This might at first seem a weak process open to manipulation but in practice we find teams produce a good degree of consistency where the safety benefit of a recommendation offers a clear safety improvement.

Of the 98 recommendations in the MHR study example we report here, two categories were recognised from the matrix assessment:

- A group of nine recommendations assessed with positive values of benefit cost offering loss aversion of over $4 million were they to be implemented.
- A group of 23 recommendations assessed with breakeven benefit cost ratios offering loss aversion of over $ 1 million.

The first group of recommendations were characterised by close agreement between the assessments of the participants. Separate assessments were made for:

- The frequency with which the potential hazard might occur.
- The probability of a loss resulting from the occurrence.
- The size of loss if one occurred.

By contrast the degree of unanimity for the assessment of the group of 23 assessments was much less. It seems a good consensus forms around recommendations which clearly offer safety performance improvement. Where on the other hand the rankings are breakeven, implying that the benefits are less clear cut, there is a wider range of variation in the team assessment.

We checked the stability of our findings by removing one extreme value ie the assessments were either "topped" or "tailed" to remove the assessment with the greatest divergence from the others. The result for the group of nine recommendations is illustrated in Figure 4.

The result shows no change whatever in the assessment of five of the recommendations which remain stable when extreme results are removed whereas for four of the recommendations the safety benefit was reduced because the exceptional assessment was on the optimistic side. The average loss aversion benefit moved from just over $4 million to $2.7 million. The result gives confidence that a substantial loss aversion can be achieved by focusing improvement budgets on just a few recommendations where there is close consensus in the review team.

This test was carried out with the assessments for the group of 23 recommendations with breakeven benefit cost (see Figure 5). Removal of extreme results allowed only one of the recommendations to show a greatly improved benefit cost ratio. Six of the recommendations showed diminished benefit cost and the remaining 16 assessments were substantially unaffected. With all assessments included, a loss aversion of $1.04 million was estimated and this rose to $1.29 million after "topping and tailing" reflecting the significantly improved benefit expected from one recommendation.

These results build on our previous finding that matrix assessment carried out by independent experts can be a reliable method to assess risk[(4)]. The implication is that time spent trying to resolve differences in individual assessment may not be well spent. The findings suggest that where there is a positive benefit cost ratio, this is recognised clearly by all participants who independently achieve good consensus with their assessments. Where the benefit cost ratios are breakeven, wider disagreement in assessment is expected, which may take time in team discussion to resolve but rarely leads to identification of worthwhile recommendations making a significant impact on safety performance. This finding offers a justification for speeding

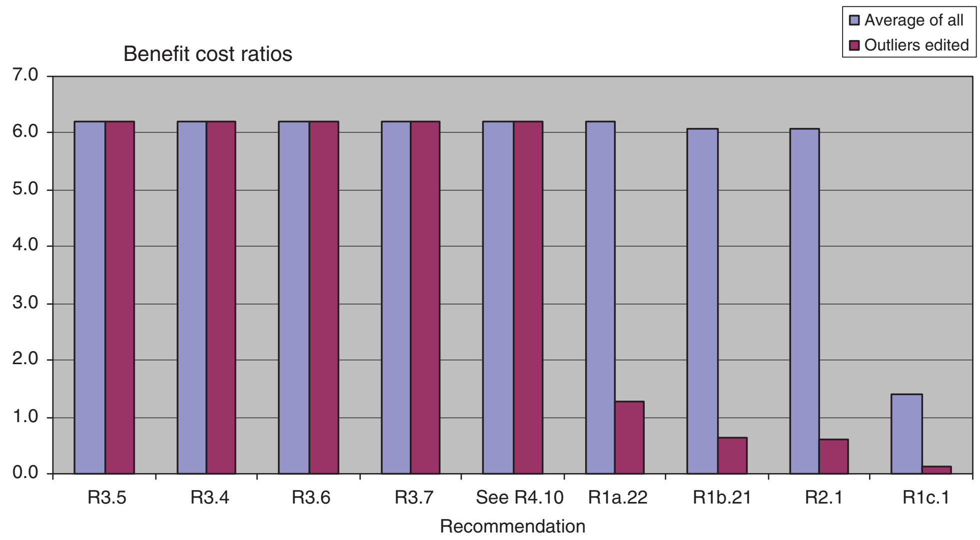

Figure 4. Removal of extreme values from group of nine recommendations with positive benefit cost ratio. *Source:* Arthur D Little After removal of outlier Purple, Full assessment set: Blue

up the matrix assessment so that it is carried out on an independent basis without taking time for lengthy consensus seeking efforts.

CONCLUSIONS

All of the three techniques reviewed (HAZOP, PHA and MHR) can deliver good hazard identification given an expert team, a skillful facilitator and a well prepared design basis. Data from our studies shows that the PHA approach allows more drawings to be progressed in a given time but the analysis achieved by PHA is not as deep as that possible with HAZOP. The closest correlation in our analysis was found between the number of recommendations generated and the time available for study. We discuss a number of "short cuts" we have seen which attempt to limit discussion in HAZOP to shorten the study time. We also review the benefits of risk assessment

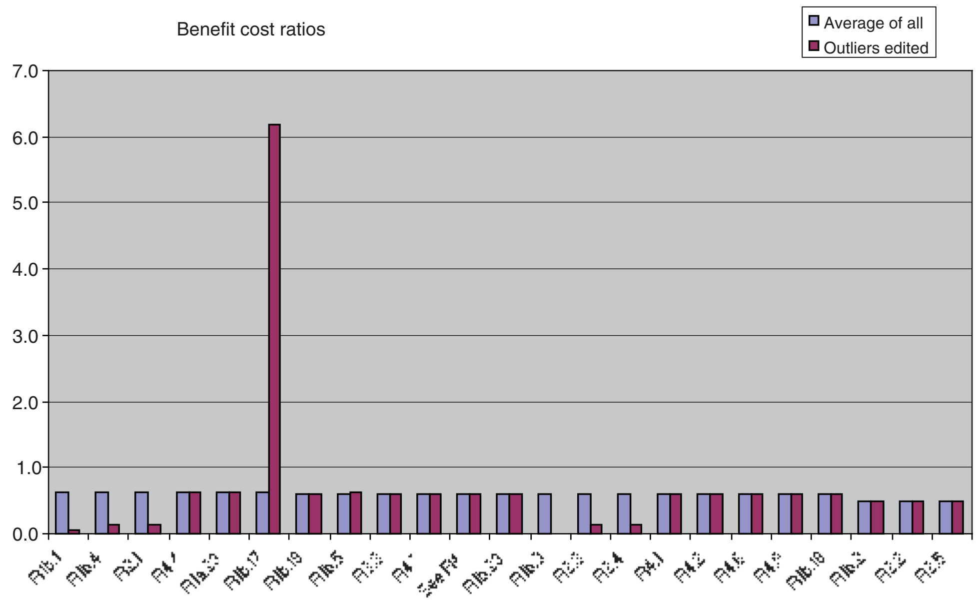

Figure 5. Removal of extreme values from group of 23 recommendations with breakeven benefit cost ratio. *Source:* Arthur D Little After removal of outlier Purple, Full assessment set: Blue

during the study and show this can be effective particularly during MHR if the focus is on recommendations which the entire team recognizes as offering safety benefit.

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