Putting the "OP" Back in "HAZOP"

Dennis C. Hendershot
Robert L. Post
Paul F. Valerio

Rohm and Haas Company
PO Box 584
Bristol, PA 19007

James W. Vinson

Rohm and Haas Texas, Inc.
6519 LaPorte Freeway
Deer Park, TX 77536

Donald K. Lorenzo
David A. Walker

JBF Associates, Inc.
1000 Technology Drive
Knoxville, TN 37932

Prepared for Presentation at the
MAINTECH South '98 Conference and Exhibition
Houston, Texas
December 2-3, 1998

Putting “OP” Back in “HAZOP”

Dennis C. Hendershot
Robert L. Post
Paul F. Valerio
Rohm and Haas Company
Bristol, PA

James W. Vinson
Rohm and Haas Texas, Inc.
Deer Park, TX

Donald K. Lorenzo
David A. Walker
JBF Associates, Inc.
Knoxville, TN

ABSTRACT

Hazard and operability (HAZOP) analysis has a well-deserved reputation for systematic and thorough evaluation, and it has become the tool of choice in the chemical and hydrocarbon processing industries for performing qualitative hazard/risk evaluations of processes. In principle, both operability and reliability considerations have been a part of the HAZOP methodology from its inception. Initially, many companies easily justified process hazard analyses on the basis that the economic benefits of finding and correcting process weaknesses through HAZOP far outweighed the cost of the analysis. Unfortunately, in recent practice, regulatory compliance obligations and increased concern with major incident prevention have resulted in a de-emphasis of the operability aspects of HAZOP in many organizations. At the same time, the maintenance and reliability groups in many companies have recognized the economic benefits of organized approaches to establishing maintenance programs. Techniques such as reliability centered maintenance (RCM), based on failure modes and effects analysis (FMEA), have been implemented to improve plant reliability and maintenance cost-effectiveness. This has resulted in a duplication of effort by different groups in the same organization, arising from separate RCM and HAZOP studies. Rohm and Haas has successfully combined HAZOP studies with RCM studies to increase efficiency and improve the quality of both reviews.

Introduction

In the last 20 years, process hazard analysis (PHA) techniques, particularly hazard and operability (HAZOP) studies, and formal maintenance and reliability methods, such as reliability centered maintenance (RCM) based on failure modes and effects analysis (FMEA), have developed in the chemical process industries. Often these techniques have been developed and promoted by different organizations within a company, and the studies are often done independently. In practice, HAZOP and FMEA techniques have much in common, and a combined study offers opportunities for greater efficiency and higher quality from both the process safety and reliability/maintenance point of view. In this paper, we will review the development of HAZOP and RCM methodologies at Rohm and Haas, and in the chemical process industry in general, and offer suggestions on how to integrate the two types of studies.

HAZOP in the Chemical Industry

In the 1960s, an improved form of what-if analysis emerged within Imperial Chemical Industries (ICI), and its application first became known as operability and hazard studies. Later, to emphasize the importance of process safety, the name HAZOP (<u>HAZ</u>ard and <u>Op</u>erability) was coined. From the literature (CIA, 1977) and discussions with ICI, Rohm and Haas discovered the HAZOP technique and decided to run a pilot study on an agricultural chemical manufacturing plant. The pilot study was a great success, with the HAZOP logic process re-discovering the mechanism of several incidents that had actually occurred, as well as identifying other credible incident scenarios that had not yet happened. The pilot study also identified many process, equipment, and procedural improvements, which benefitted safety, product quality, and plant operations.

The word got out quickly, and there was an increasing demand from some managers of operating plants for assistance in performing these new studies. Members of the pilot HAZOP team were called on to train teams and lead other studies. In 1979, a Process Hazard Analysis Department was formed in the Engineering Division. It served as a resource for conducting studies, and coordinated assignment of experienced HAZOP team members to train new study teams. Within a few years, demand resulted in the group growing to four full-time people, and a number of other people in plants and the Engineering Division were spending a significant amount of time doing HAZOP studies.

This growth in process safety capability in the late 1970s and early 1980s was almost entirely driven by internal customer demand. What was it that created this demand? Did we observe a significant reduction in the number of major fires and explosions? While we certainly believe that the HAZOP studies have reduced the risk of such major events, the chemical industry, even using its traditional safety review techniques, had achieved an excellent safety record and major events were already rare. Over the 5 or 6 year period when HAZOP studies became common at Rohm and Haas, there were insufficient data to statistically demonstrate a reduction of risk of fire or explosion. While the HAZOP teams did identify and correct potential incident scenarios which were disturbing to management once they were recognized, the HAZOP process was really sold to customers by the “OP” (operability). Managers universally believed that they learned a lot about their plants, and that the plants ran better after a HAZOP study. In the early days of HAZOP, Rohm and Haas collected data categorizing the types of concerns that the HAZOP recommendations were intended to address. For most studies, 50-60% of the recommendations were intended to address product quality or plant operability issues, and did not arise from any safety or environmental concern.

While we never attempted to quantify the benefits, HAZOP customers strongly believed that the operability benefits “paid for” the HAZOP study, and that the improvements in process safety were a welcome bonus. Similarly, engineering design teams believed that HAZOP was helping them to identify potential problems on paper during design, rather than in the field during startup. HAZOP reports were useful in writing operating procedures and troubleshooting guides for plant operators. Some comments from HAZOP customers and team members from that time provide anecdotal evidence for the perceived benefits of HAZOP:

- “My product is extremely valuable. While it seems like we are spending a lot of time in the HAZOP study, all it has to do is prevent one bad batch and it will pay for itself.” — Technical manager of a speciality chemicals plant
- “Just writing down the HAZOP intentions showed several inconsistencies in how different shifts were operating the process.” — Operator in a continuous process
- “Great way to learn the process.” — Trainee operator who sat in on several HAZOP sessions (Note: A nearly identical comment was made by a new production manager who had little previous experience with the plant, in a different HAZOP)
- “I’ve learned more about how this process works in the last week than I did in twenty years of repairing pumps and fixing equipment.” — Maintenance foreman in a batch polymer plant

Other companies reaped similar benefits from their HAZOP studies. One study of a thermal oxidizer discovered a way to save $40,000 per year in fuel costs. Another study of a gas plant incidentally found ways to increase the yield of natural gas liquids by 50%. Others found that after HAZOP studies, the average time from startup of a new unit to full production dropped from 6-8 weeks to 2-3 weeks. The time and cost of a unit’s first maintenance outage (when companies traditionally fix all the problems found during startup) also plummeted because the unit was designed and built “right from the start.”

The advent of the OSHA PSM regulation in May 1992 (OSHA, 1992) introduced a new consideration — possible audit of the HAZOP results by a potentially hostile government agency. Since OSHA’s authority only covers safety hazards to workers, companies naturally limited the mandated PHAs to the mandated consequences of interest — hazards that posed a “serious danger” to workers. Employers were afraid to document nonsafety issues (and their resulting action items), fearing that an OSHA inspector might mistakenly demand the same prompt, documented resolution of those items as required for safety-related issues.

Other factors also pushed companies to focus on “HAZ” studies. One factor was simply the finite limits of resources. At a time when many companies were reducing staff, the added burden of implementing a PSM program and performing the required PHAs meant that other activities, such as operability improvements, had to be delayed or abandoned. Also, because the OSHA regulation did not explicitly require maintenance participation on PHA teams, key input on ways to improve quality and minimize downtime was often missing from PHA teams.

Some companies chose to outsource PHA leadership, but, even then, competitive pressure to submit the low bid pushed consultants to propose only “bare bones” PHAs to meet minimum regulatory requirements. Consideration of operability issues, if included in the bid at all, was typically mentioned as an optional additional expense that few companies were willing to undertake.

Reliability-centered Maintenance

The aircraft industry began to develop concepts in the early 1960s that eventually blossomed into MSG-3 (from Maintenance Steering Group - 3 Task Force of the Air Transport Association of America) in the aviation industry, or RCM as it is known in other industries (Moubray, 1991). A task force, called the FAA/Industry Reliability Program, was established in 1960 to study the reasons behind the failure of traditional maintenance programs to improve the reliability of aircraft components. The primary method of maintaining equipment at that time was through scheduled overhauls, regardless of the condition of the equipment. Today’s RCM approach is to focus on a defined system using a multidisciplinary team of people including a facilitator, manufacturing engineer, operator, craftsman, and other specialists as required. The team:

- Defines the operating context of the system, including a description of what the system does and a list of the equipment within the system
- Defines all the functions of the system including primary functions, secondary functions (e.g., containment, support, appearance, environment), and protective features (e.g., alarms, interlocks, relieving abnormal conditions)
- Lists all the failure modes and effects for each function
- Uses a decision diagram to help make decisions on how to maintain the function of the equipment in the most sensible manner

Maintenance tasks depend not only on the type of component, but on the consequences of its failure in terms of cost, safety, and environmental impact, and whether the failure of a component is immediately evident or hidden. Some failures of components are hidden — you do not know that the component has failed until something calls upon the component to perform the desired function. Examples of hidden failures include:

- A relief valve that has an internal fault such that it will stick open when activated
- A high-high level switch (the process normally never reaches the high-high level, so there is not way to tell if the switch works without testing it)
- A low oil pressure trip (oil pressure is not normally low, so you must test the switch to confirm that it works)

The results of an RCM analysis could be that identical components in the same system are maintained differently if the failure effects of the components are different.

Rohm and Haas began to employ RCM in 1994. The first RCM studies analyzed several systems within a new chemical plant using a team of engineers, operators, craftsmen, and technicians who were going to be working in the plant. The analyses identified all the maintenance tasks, the need for new procedures, and also opportunities to use the control system to trend performance of various components. Since then, RCM has been used in many Rohm and Haas plants worldwide. Some of the more significant lessons the RCM studies are:

- RCM provides a means to determine a maintenance schedule in a complete and logical manner. The thorough process and a well-rounded team promote high quality results

- The team learns an incredible amount about the system that is being analyzed. Therefore, RCM has been found to be especially helpful for complex systems that are difficult to understand
- The multidisciplinary team unites operations, maintenance, and engineering. The RCM meetings develop an understanding of the role of each other group in the overall maintenance effort
- Sometimes plants have difficulty implementing the recommendations from an RCM analysis. The thoroughness of the process results in quite an extensive list of tasks and procedures that may be perceived as overwhelming; but the results are the whole point of the process. Successful implementation relies on delegation of action points from the meetings and support by management

Recently, other companies have begun to incorporate RCM in their PHAs. For example, Alley, et al. (1998) describe several ways in which the two techniques were integrated. Two factors appear to drive companies in this direction:

- The realization that the cheapest way to increase plant capacity is to reduce unplanned outages of the existing equipment
- The realization that the OSHA-mandated mechanical integrity program can be easily expanded to encompass process-critical equipment as well as safety-critical equipment

Thus, when a pharmaceutical manufacturer was faced with an overwhelming demand for its product, it revised its PHAs to consider production delays and off-specification batches as consequences of interest. The pharmaceutical manufacturer then used the PHA results for risk-based prioritization of preventive and predictive maintenance tasks.

HAZROP — A Proposed Methodology to Incorporate Reliability into PHA Studies

As more people have become familiar with both HAZOP and RCM, awareness of the similarities between the two activities has grown. Both RCM and HAZOP are analyses conducted by multidisciplinary teams, including engineers, operators, and technical specialists. Both analyses start with a description of the functional requirements of the system and stress evaluation of those functional requirements. In RCM, operating context is defined, and functions are identified. This activity in HAZOP is frequently referred to as process description and intentions. In the search for potential operational problems in a system, HAZOP terms can be translated into comparable FMEA terms used in RCM, with intentions as functions, deviations as functional failures, causes as failure modes, and consequences as effects. Unlike a conventional FMEA, HAZOP uses guide words such as no/low flow or higher pressure to suggest functional failures. This improves the likelihood that less visible functional failures will be missed. An RCM analysis based on the FMEA technique can be considered acceptable as a PHA as long as the proper consideration of safety, health, and environmental functions is ensured, because FMEA is listed as an acceptable PHA technique in the OSHA PSM standard (OSHA, 1992).

There are also differences between HAZOP and RCM in practice. HAZOP's use of guide words ensures that consideration will be given to a comprehensive range of deviations from intended operation at the system level; RCM's guidance of functional definition and analysis is fairly broad-brushed. HAZOP requires documentation of recommendations, but is generally free-form in how the team is allowed to generate those recommendations. RCM, on the other hand, offers a fairly rigid protocol for determining what maintenance tasks are appropriate given the failure modes identified. Also, the makeup of the teams generally reflects the differing intents of the two types of studies. HAZOP teams always include hazard and risk analysis specialists, operating managers, process engineers and operators. Maintenance personnel are not always represented, and the mechanical engineering perspective is often missing. RCM teams include operators and operations management, and, of course, reliability engineers, maintenance engineers, and mechanics, but may lack the broader process design perspective.

There is also a difference in the results. HAZOP’s guide word approach, developed in the process industry, ensures that the analysis maintains the system perspective necessary to identify hazard and operability problems in a complex process unit. On the other hand, HAZOP has had limited focus at the component level. RCM, being conducted generally with an intent to determine maintenance needs of a system of components, does well at analyzing potential failures down to the subsystem and component level. But the results at the process system level have not always been as good. Also, for a new project, HAZOP is often done before final detailed design. RCM has most commonly been practiced on existing systems. As a result, the Maintenance Task Analysis Decision Diagram, used to develop RCM recommendations for maintenance practices, suggests redesign as a last resort. Yet, the ideal is to identify potential reliability problems before substantial investments are made.

Finally, both HAZOP and RCM consume significant personnel resources. While the delivered benefits are very attractive, making HAZOP resources available during early engineering is very painful to project management. But, waiting until after design frequently means that some of the benefits of these analyses may only be realized as design changes — also very painful to project management. Doing a complete, separate RCM at the same time would be extremely taxing from a resource standpoint.

In light of the similarities between the two analyses, it is proposed to merge these two analyses into a single activity, which we have been referring to as “HAZOP” — HAZard, Reliability, and OPerability (Post, 1998). A HAZROP is a HAZOP with an additional focus on reliability. To add the benefits of RCM, several minor changes are made to the HAZOP protocol:

- Maintenance, reliability and mechanical engineering perspectives must be fully represented on the HAZROP team
- Pertinent background reliability information must be presented during the system description. This includes results of reliability simulations highlighting key reasons for loss of availability; typical Mean Time Between Failure (MTBF) data for equipment in similar services; typical maintenance procedures including activities required before and after actual repair procedures, as well as typical preventative and predictive tasks
- Additional guide words that focus on reliability and maintenance issues are used
- As safeguards are identified, the team determines whether their failure would be apparent to the operator or hidden, requiring a failure-finding task
- Risk is qualitatively estimated for all but minor consequences, for example, by using a risk matrix (CCPS, 1992)
- Generic FMEAs are provided for common subsystem or component failures. (ad hoc FMEAs can also be recommended for critical high-risk subsystems — this is not really a change from classic HAZOP procedure)

- Task analysis can be done by a smaller group of the team members using the failure modes identified during the HAZROP analysis. These can be causes identified in HAZOP, component-level consequences (e.g., consequential failures) or failure modes from the generic FMEAs. Existing preventative and predictive tasks can be evaluated against the system-level failure mode and effect information now available

Experience to date with this approach shows several benefits. The mechanical viewpoint, frequently underrepresented in HAZOPs, often allows identification of failure modes and consequential problems that might otherwise be missed. At the same time, maintenance people develop a much better understanding of how the process system works. Availability of relevant reliability data allows better understanding of risk. Examples have included:

- Understanding the effects of concentration cycling on equipment
- Recognition of potential overpressure situations within a vacuum pump subsystem
- Identification of opportunities to improve process unit availability
- Recognition that installed spare equipment may not significantly affect process unit availability in some cases
- Identification of existing operating procedures that reduce pump reliability

Of course, in addition to such benefits of an “improved HAZOP” as described above, HAZROP provides an indication of specific maintenance requirements much earlier than would be provided by a conventional, separate RCM conducted later. It is possible to provide a summary of maintenance tasks required to the designers to ensure that the layout and detail design facilitate such activities.

In the industry, a few leaders have tried approaches like this. Ashland Petroleum, working with JBF Associates, Inc., reported success with this approach (King, et al., 1997). Eastman Chemical reported success in performing an operability and maintainability analysis very early in preliminary engineering, and then doing a PHA later (Chastain and Jensen, 1997). Another company, working with a consultant, has included maintenance and reliability professionals in their PHAs, and used generic fault trees for common systems and subsystems. Rohm and Haas is trying both HAZROP, as described above, and HAZOP with subsequent FMEAs led by reliability engineers.

In many cases there has been a concern expressed about the size of the team and the total time required. The experience at Rohm and Haas is that the man-hours used in preparation for HAZOP are about the same as preparation for RCM; likewise, resource requirements for doing the FMEA part of either HAZOP or RCM are about the same, and about the same time as is required for preparation. Doing a combined HAZROP FMEA does not appear to take more than 25% additional time versus conventional HAZOP. The task analysis of RCM (which should be similar for HAZROP) requires about the same amount of time as the FMEA activity. In summary, it appears that a complete HAZROP requires only about 60% of the man-hour resources that would be required from separate HAZOP and RCM activities.

HAZROP Example

The following simple, abbreviated example illustrates the HAZROP process applied to the simple process system presented in Figure 1.

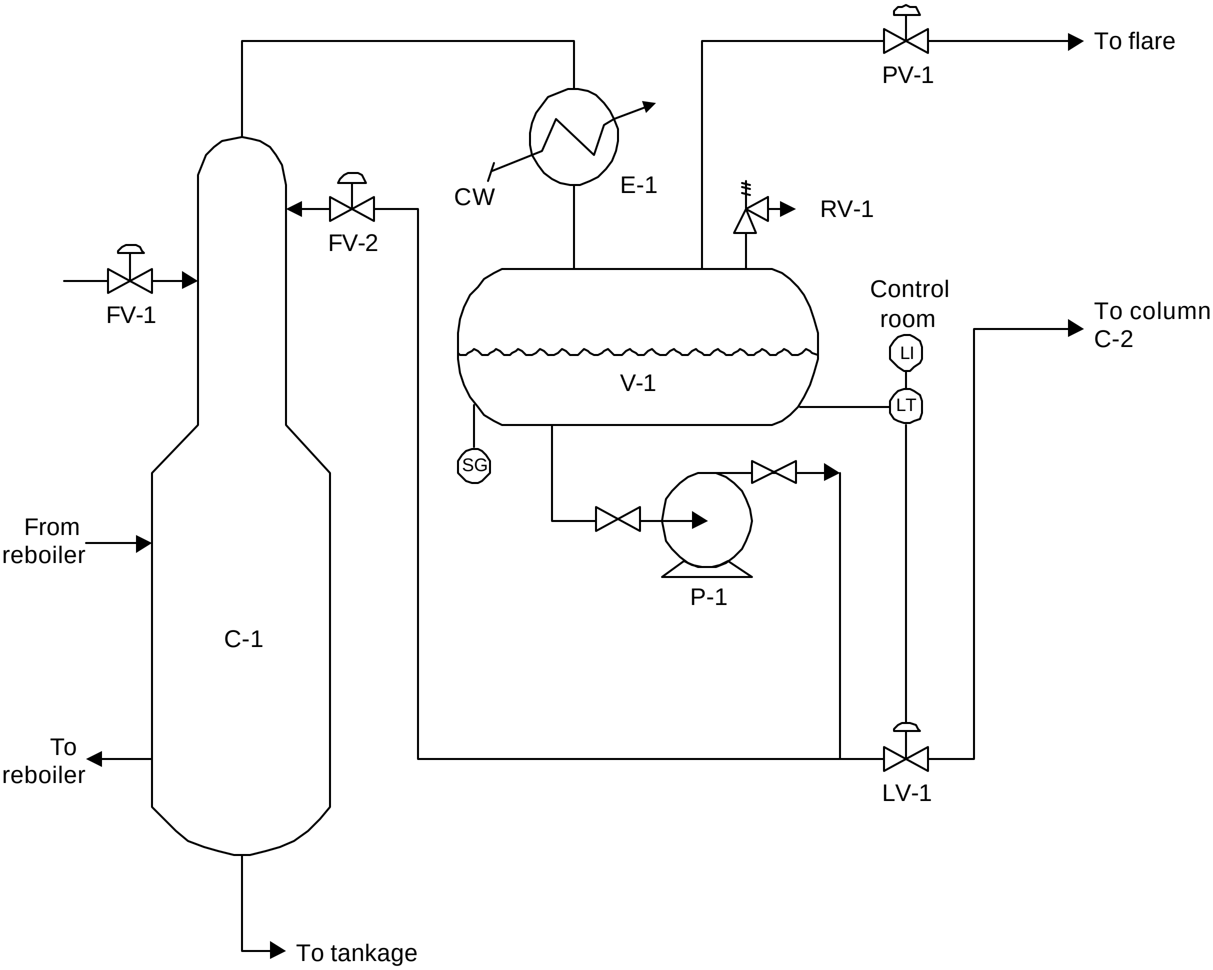

Figure 1 Example System for HAZROP Analysis

HAZOP Portion of the HAZROP

Table 1 summarizes a section of a HAZOP analysis for the system shown in Figure 1.

<table>
<tr><th colspan="6">Section 5: Accumulator V-1</th></tr>
<tr><th>Deviation</th><th>Causes</th><th>Consequences</th><th>Safeguards</th><th>Risk</th><th>Recommendations</th></tr>
<tr><td>High level</td><td>Insufficient flow from P-1 (See the generic FMEA for centrifugal pumps)
Operator fails to start or inadvertently stops P-1
•
•
•</td><td>Overflow of V-1, possibly causing a major upset at the flare and/or in other systems connected to the flare header
High pressure in C-1 (see the high pressure deviation for C-1)</td><td>Field checks of the sightglass on V-1 (See the generic FMEA for sightglasses)
Control room indication from LT-1 (See the generic FMEA for level control loops)</td><td>Medium</td><td>Add independent high level switch/alarm to V-1 (Engineering)</td></tr>
<tr><td>•
•
•</td><td>•
•
•</td><td>•
•
•</td><td>•
•
•</td><td></td><td>•
•
•</td></tr>
</table>

Table 1: HAZOP analysis table used in conjunction with a HAZROP

Note how the HAZOP portion of the analysis does the following:

- Focuses on both equipment failures and potential human errors leading to consequences of interest
- Accounts for safeguards against incidents
- Uses risk as the basis for prioritizing issues
- Encourages development of recommendations other than just maintenance task planning
- Links to generic FMEAs that have already been performed for various classes of equipment

Generic FMEA Portion of the HAZROP

Rather than expanding the analysis of insufficient flow from P-1 in Table 1, the HAZOP analysis team would have consulted (or might have developed) a generic FMEA for centrifugal pumps. This generic FMEA would provide the HAZROP analysis team with better insights into the specific failure modes that could cause insufficient flow from P-1. This would equip the HAZROP analysis team to (1) more thoroughly understand the safety, economic, and environmental risks and (2) more reliably characterize the level of risk.

An experienced group would have participated in defining generic functions of centrifugal pumps. The group would include:

- A rotating equipment specialist
- Reliability engineers
- Operator
- Mechanics
- Process engineer
- Pump vendor technical representatives
- Seal vendor technical representatives

In addition, the group would develop lists of functional failures. Once the process begins, functional failures could be developed easily from the definitions for the function. The group would draw from its experience to identify modes that could cause functional failures. From these definitions, specific failure effects and mean time to repair (MTTR) can be added during the operational analysis. System level failure effects are identified as part of the HAZROP, where they are referred to as consequences. MTBF and MTTR data are needed, in addition to consequence severity, to assess risk.

Centrifugal pumps have two generic functions. First, they must move fluids under specific conditions. This description is stated in Function 1 (Table 2). The movement of a fluid is described by specific characteristics that define a moving fluid. Each characteristic has a range required for proper operation. Values outside the required operating range produce a functional failure. Functional failures for the "rate of flow" function are listed in Table 3.

The failure mode is the basis of the functional failure. Each of the functional failures has a set of failure modes associated with it. For the functional failure that is described as insufficient flow, 16 failure modes, listed in Table 4, were identified. Clearly not every mode will be present in one specific pump, but in appropriate modes can be eliminated when the gFMEA is reviewed for each application.

The second generic function is that the pump must "contain all fluids under all pertinent design conditions." This function has four functional failures related to leaking process fluid, barrier fluid, heat transfer fluids, or lubricants. Each of these functional failures has a set of associated failure modes.

Values for specific requirements can be added to the gFMEA to make it specific for the equipment that is being evaluated. The intent is to generate an "overly comprehensive" list of failure modes for the gFMEA. Then, for each specific application, the nonapplicable failure modes are removed from the list (e.g., eliminate modes involving buffer fluid problems when the pump in question has a single mechanical seal with no flush, or eliminate "stage missing" in single stage pumps). Unique applications may require additional failure modes. They can be added where appropriate.

Centrifugal Pump Function 1:

Move ___ gpm of ______ against ______ discharge pressure, with a suction pressure _______ and NPSHa of ______ without adversely affecting fluid under a _______ duty cycle.
Operating conditions should include all normal and off-normal operating modes (e.g., boilouts, water runs, shutdown, startup, system clearing, pickling, etc.)

Table 2: Generic description of centrifugal pump function "move process fluids"

Functional Failure	Description
A	Insufficient flow
B	No flow
C	Too much flow
D	Intermittent flow
E	Adversely affect fluid
F	Cannot operate at required duty cycle

Table 3: Functional failures for "rate of flow" for a centrifugal pump

Rohm and Haas has generated a number of generic FMEAs for use in the HAZROP process. gFMEAs have been prepared for control valves and induction motor/starter systems. There are also some "generic instrument loop HAZOPs" developed in the past that are expected to be applicable as a basis for gFMEAs. In all cases, the gFMEAs must provide the detailed focus on failure modes needed for maintenance task analysis. They will also provide technical depth that has not always been available in the past to the HAZROP team, and should provide additional detail without seriously adding to the time required for the PHA.

Failure Mode	Description
1A1	Pump not primed
1A2	External system not setup properly (e.g., valves closed, lines clogged)
1A3	Low RPM
1A4	Impeller clogged
1A5	Impeller worn, deformed, broken, or corroded
1A6	Impeller clearances incorrect (front or back)
1A7	Incorrect impeller diameter
1A8	Worn or clogged bowl or casing
1A9	Missing 1 stage impeller (multistage pump)
1A10	Excessive seal buffer leakage from seal into pump
1A11	Internal pressure relief leaking
1A12	Seal or bearing flushes...excessive flow due to improper design
1A13	Same as 1A12 except due to wear
1A14	Reverse motor rotation
1A15	Improper pump assembly
1A16	Process fluid solidifies (e.g., salts up, polymerizes, or freezes) when allowed to become stagnant in pump

Table 4: Identified failure modes for a centrifugal pump for the functional failure "insufficient flow"

Consistency in Task Assignments

A key issue in maintenance task planning is promoting consistency across a unit, plant, division, or corporation. Many organizations are increasingly finding substantial variability in how analysis teams are assigning maintenance tasks and associated frequencies. Of course, some variability should be expected because of unique applications/situations. However, much variability is due to inconsistent maintenance task planning choices caused by factors such as the following:

- Lack of awareness of advanced maintenance technologies
- Lack of knowledge about appropriateness of maintenance tasks for certain situations
- Differences in risk acceptance paradigms among various teams
- Uncertainty about how ITPM task frequencies affect loss exposure

One tool for combating these issues is to have maintenance/reliability experts develop task selection guides for various classes of equipment. An example section of a task selection guide is shown in Table 5. Because this guide is prepared by experts, it contains the best guidance available to teams for allocating maintenance resources appropriately to control the company's loss exposure. This allows analysis teams to focus on prioritizing risks and generates effective maintenance plans even if maintenance/reliability experts are not actively involved in each analysis.

<table>
<tr><th colspan="6">Component: Level Indicating Control Loops</th></tr>
<tr><th colspan="6">Failure Mode: Sensing Error</th></tr>
<tr><th rowspan="2">ITPM Task</th><th rowspan="2">Type of ITPM Task</th><th rowspan="2">Responsibility</th><th colspan="3">Suggested Task Frequencies for Various Risk Levels</th></tr>
<tr><th>High</th><th>Medium</th><th>Low</th></tr>
<tr><td>Check accuracy of reading compared with sightglass readings</td><td>Condition monitoring</td><td>Operations</td><td>At least once each shift</td><td>Daily</td><td>Monthly</td></tr>
<tr><td>Calibrate</td><td>Preventive maintenance</td><td>Maintenance (instruments)</td><td>Monthly</td><td>Quarterly</td><td>Annually</td></tr>
<tr><td>⋮</td><td>⋮</td><td>⋮</td><td>⋮</td><td>⋮</td><td>⋮</td></tr>
</table>

Table 5: Example task selection guide for level indicating control loops

Summary

In the original HAZOP concept, the study of plant operations, product quality, and maintenance and reliability was an important part of the HAZOP process — that is why the "OP" is in the acronym. However, over the years there has tended to be more emphasis on the "HAZ" part of HAZOP, as the technique became viewed as a major component of many PHA programs, and HAZOP or similar studies on many units were required by regulations. There was a de-emphasis on the "OP," and a concentration on the "HAZ." At the same time, many companies recognized the value of an organized and systematic approach to understanding the factors that determine plant reliability, and in understanding how to define cost effective maintenance programs. The result was the application of systematic tools such as RCM and FMEA to chemical process units.

HAZOP and RCM study methodologies have much in common, and a combination of the two types of reviews offers the potential for both increasing the efficiency of the study teams and improving the quality of both studies. Combining the studies avoids much rework resulting from two different teams reviewing the same system independently in separate meeting sessions, perhaps with each team unaware of the activities of the other. The broader spectrum of knowledge and expertise present on the team for a combined study will also result in a better quality study, bringing a broader range of experience into the team discussions. We have described suggested techniques for combining reliability studies and PHAs, and are currently evaluating the effectiveness of these techniques. Preliminary results indicate a potential for significant time savings with a combined study. This can be viewed as a return to the original concept of the HAZOP study — let's put the "OP" back into "HAZOP." And, to emphasize the importance of reliable plant operation, let's add an "R" to get "HAZROP" — Hazard, Reliability, and Operability.

References

Alley, M., M. Long, D. Walker, and R. Montgomery (1998). "Integrating Reliability-centered Maintenance Studies with Process Hazard Analyses." *International Conference and Workshop on Reliability and Risk Management*. September 15-19, 1998, San Antonio, Texas. New York: American Institute of Chemical Engineers.

American Petroleum Institute (API) (1990). *Management of Process Hazards*. RP 750. Washington, DC: American Petroleum Institute.

Center for Chemical Process Safety (CCPS) (1985). *Guidelines for Hazard Evaluation Procedures*. New York: American Institute of Chemical Engineers.

Center for Chemical Process Safety (CCPS) (1992). *Guidelines for Hazard Evaluation Procedures, Second Edition with Worked Examples*. New York: American Institute of Chemical Engineers.

Chemical Industries Association (CIA) (1977). *A Guide to Hazard and Operability Studies*. Alembric House, London: Chemical Industries Association.

Chemical Manufacturers Association (CMA) (1985). *Process Safety Management*. Washington, DC: Chemical Manufacturers Association.

Chastain, J. W., and J. H. S. Jensen (1997). "Conduct Better Maintenance and Operability Studies." *Chemical Engineering Progress 93:2* (February), 49-53.

King, C. S., D. A. Walker, and M. P. Long (1997). "Lessons Learned from an RCM at Ashland Petroleum." *5th Annual Conference of the Society of Maintenance and Reliability Professionals*. October 5-8, 1997, Pittsburgh, PA.

Moubray, J. (1991). *Reliability-centered Maintenance*. Oxford, U. K.: Butterworth-Heinemann.

Occupational Safety and Health Administration (OSHA) (1992). "29 CFR Part 1910 Process Safety Management of Highly Hazardous Chemicals; Explosives and Blasting Agents; Final Rule." *Federal Register 57, 36* (February 24), 6356-6417.

Post, R. L. (1998). "Combining Process Hazard and Reliability Analyses." *TCC/ACIT 1998 Safety Seminar*, June 9, 1998, The Woodlands, Texas, Session IV: Mechanical Integrity.