A Preliminary Analysis of Key Issues in Chemical Industry Accident Reports

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Abstract:

Chemical industry accident reports provide a wealth of information that can be used to develop lessons learned to improve safety and efficiency of operations at chemical industry facilities. The United States Chemical Safety Board (CSB) is one source of these accident reports. As a part of an investigation and causal analysis process, CSB investigators identify “Key Issues” for each chemical accident. This research evaluated trends in those Key Issues by applying two distinct analyses of these issues. The first analysis assessed the Key Issues naturalistically, as reported by the expert investigation team; however, this result was problematic, as about 2/3 of all Key Issues, as described in the chemical industry accident reports, occurred only once. In the second analysis, the Key Issues were sorted thematically to capture insights from the many single-occurrence issues. This thematic analysis, using categories drawn from the Occupational Safety and Health Administration’s (OSHA’s) Process Safety Management (PSM) guidance, allowed for a more comprehensive understanding and grouping of the issues behind the chemical accidents studied. The findings of this research identified several accident themes that can be used to develop a better understanding of chemical industry accidents and potentially improve safety and efficiency of operations at chemical facilities.

Key Words:

Chemical Industry, Accident Investigation, Process Safety, Semi-quantitative Analysis

1. Introduction:

Regardless of the industry of origin of hazardous chemicals, a lack of proper control can result in an accident with serious consequences to workers, the environment and the public. Maintaining worker and public safety, along with protecting the environment, is a key priority in the chemical industry. Even prior to the advent of groups such as the Occupational Safety and Health Administration (OSHA) and industry groups such as the Center for Chemical Process Safety (CCPS), unexpected releases of toxic, reactive or flammable liquids were reported, yet remained a recurring problem. The introduction of OSHA’s Process Safety Management (PSM) Guidelines played a large role in helping to lower the incidence of unexpected releases and other accidents at chemical facilities [1]. Meanwhile, industry groups, such as the CCPS and others, have also focused on improving safety internally, by sharing lessons learned from accidents and promoting safety management. Due to this focus on safety, the chemical industry is relatively safe compared to other high hazard industries, considering the materials handled by these facilities on a daily basis [2].

However, the overall relative safety of the chemical industry does not preclude the occurrence of accidents. Review of the recent accident records reveals that there have been accidents in the chemical industry ranging from combustible dust explosions, plant explosions and fires to chemical releases and asphyxiation. The chemical industry accident report database used in this analysis contains 60 accident reports issued between 1998 and 2012. These accidents represent 120 fatalities and 895 injuries, including chemical workers, first responders, and the public at large. At first glance, 60 accidents in 14

years may appear to be an acceptable rate (about 4 per year in a \$769 billion industry in the U.S.); however, not all accidents involving injury are investigated by external groups and, consistent with the concept of continuous improvement, this research attempted to derive new insights from looking at this group of accidents as a whole.

Studying accidents to determine their causes is fairly common in high hazard industries. There are several accident databases available for study, with varying degrees of information available. Studies have shown that analyzing these accidents and applying lessons learned from them helps to avoid future accidents and reduce risk [3]. The Environmental Protection Agency has a Risk Management Program that requires each facility under their purview submit a five-year accident history when they submit a Risk Management Plan [4]. This database has been studied to find trends in the accidents at these facilities, including plant demographics, chemical inventories, and others [4]. Some studies, such as Kahn and Abbasi, use several accident databases, worldwide to analyze the common causes which led to accidents at fixed chemical facilities [5]. Khan and Abbasi performed a statistical survey of a selection of chemical industry accidents over a 70 year period (1928 – 1997); as part of that analysis they assessed what they called ‘major factors’ that led to accidents at fixed chemical installations, such as those reviewed by the CSB. They did not use the PSM categories to sort the data, but basically found that mechanical integrity issues, operating and maintenance process issues, design concerns and ineffective hazard evaluation were leading causes [5].

One common form of analyzing individual accidents is a causal analysis, or the determination of the problem, without which the accident would not have occurred. The lessons learned through such causal analysis can be collected and shared through regulatory and industry groups to raise awareness of certain types of events with the hope of preventing similar events from occurring in the future. The U.S. Chemical Safety Board (CSB) is an advisory group that performs a causal analysis and drafts a thorough accident report, sharing recommendations with regulators and industry and tracking the implementation of these recommendations [6]. These chemical industry accident reports compose the database that the present work evaluated.

As a part of each accident report, and consistent with the CSB’s congressional tasking to “identify contributing causes,” each investigation team defines “Key Issues” which contributed to the accident. As such, the identified Key Issues are an expert summary of the major factors contributing to the accident; they can include procedural issues ranging from the permitting of hot work to specific maintenance problems, or management issues such as a lack of organizational learning. These Key Issues are identified through a causal analysis (formal or informal), and represent factors that contributed significantly to the accident [11]. The Key Issues act as a snapshot of the analysis from the investigation team concerning the contributing factors to each accident; as such, they provide information which can be used by chemical facilities to identify accident reports that may be applicable to their facilities, to help to improve process safety. The catalogue of Key Issues, or contributing factors, that has accumulated over the years 1998-2012 can be analyzed to identify areas of vulnerability and to develop improvement actions to enhance safety and efficiency of operations at chemical facilities.

2. Methodology:

The objectives for this work were: to analyze the Key Issues based on their qualitative characteristics, quantify the number of occurrences of Key Issues, and search for common Key Issues in chemical industry accident reports in order to potentially identify lines of inquiry to improve safety and efficiency of operations at chemical facilities. In order to accomplish these objectives, this research involved two separate analyses of the Key Issues identified in chemical industry accident reports: naturalistic and thematic. The naturalistic analysis involved a qualitative categorization of the chemical industry accident report Key Issues, verbatim. In the present study, the naturalistic analysis served as a precursor to the thematic analysis, and only the results of the thematic analysis were carried forward. In the second analysis, a thematic analysis was performed to determine common themes that branch across several Key Issues and bring to bear more explanatory power than those developed during the first analysis.

The methodology for this study used a qualitative analysis technique to initially gain insight into the causes of accidents in the chemical industry. Similar qualitative analyses have been performed on accident documentation, i.e., Gephart 1993; Roberts, 1990; Vaughan, 1990, and provided valuable insight. Gephart uses qualitative data analysis facilitated by a computer to develop key word lists for study, a similar methodology to the Key Issues analysis described herein [7]. Another study, Genserik, 2015, used qualitative data available through interviews from the chemical industry security field to provide recommendations to consider for security improvements [8]. The results of these studies provided trends that can be used to recommend improvements, similar to the analysis described herein.

2.1 The Naturalistic Analysis:

In the naturalistic analysis, the Key Issues were studied as they occurred in the chemical industry accident reports; that is, exactly as they were described by the investigation team. The number of occurrences of each individual Key Issue was tallied in an attempt to identify Key Issues that were potentially common across several incident reports. It was anticipated that these commonly occurring Key Issues have the potential to offer clear and significant targets to address in working to prevent future accidents.

This first analysis involved using a naturalistic qualitative method in which the unit of analysis was one chemical industry accident report. Data collection consisted of the identification of Key Issues for each document, dividing the Key Issues into related concepts and then further subdividing the identified concepts into categories. For this approach, the words in the Key Issues were used verbatim, without making any changes or assumptions. This naturalistic approach to data analysis is further described in Patton [9]. The main objective was to refrain from manipulating the data in any way during this initial evaluation, but rather to allow the data to fall into natural groupings based on similarities in wording.

Performing the Key Issues analysis with a naturalistic approach was intended to capture slight differences in terminology and phrasing resulting from differences in accident circumstances. This naturalistic method is often used for the analysis of expert opinions [10].

A preliminary assessment of frequently occurring Key Issues was accomplished (see Table 1 below). Unfortunately, the Key Issues from the chemical industry accident reports contain inconsistent terminology and phrasing; the naturalistic approach to the Key Issues analysis yielded over 60 single occurrence Key Issues. In other words, from the reports evaluated in this research, there are 92 total identified Key Issues, 65% of which occurred only once. Examination of many single occurrence issues illustrated that numerous variations in description complicated analysis; however, similarity in concepts addressed indicated that more detailed evaluation of the data could produce valuable trends.

2.2 The Thematic Analysis:

In response to the high number of single occurrence Key Issues, a second analysis was performed in which the Key Issues were analyzed using thematic grouping. This secondary analysis smoothed out major variations in wording, and evaluated the context of the Key Issues in the reports, which allowed single occurrence Key Issues to be grouped into appropriately themed categories. By combining these categories into logical groups based on similar wording and contextual clues, clearer trend information could be extracted concerning the major foci of accidents in the chemical industry.

The focus of the thematic analysis was to develop categories based on similar wording, and then group these categories into clearly related, higher-level themes. This phase involved the development of categories that were both appropriate and meaningful. The Process Safety Management (PSM) guidelines were suggested to the authors as a logical source for themes in this methodology [11]. As the chemical industry is required to adhere to these OSHA guidelines, which have been in place since 2000, the PSM major headings lent themselves well to a sorting approach for the Key Issues identified in the final accident reports.

In addition, several Key Issues suggested some additional themes, derived from PSM themes and refined through interviews with several industry experts. These additional themes were developed by grouping together similar issues and discussing the common themes among the groups with several industry experts. The theme of hazard recognition was derived from the naturalistic analysis as a combination of hazard recognition and hazard awareness key issues that appeared in the text. Standards issues were grouped together as a combination of standards implementation, recognition, oversight, and others. Design and engineering contemplated both engineering controls and safety systems, not covered by PSM, but a Key Issue in many accidents from the naturalistic analysis. Maintenance issues were separated from the PSM theme of Mechanical Integrity and include Key Issues of housekeeping, less than adequate maintenance, and planning of maintenance activities based on industry expert input. The themes of human factors and management oversight were developed after the naturalistic analysis as well, and determined to be themes of their own. The thematic analysis structure is illustrated in Figure 1, and each theme is attributed to either the PSM guidelines (identified by (PSM)) or created based on naturalistic analysis with refinement from industry experts (identified by (NA)).

Figure 1. Thematic Analysis Structure

Once the set of themes was developed, the Key Issues data from the chemical industry accident reports were sorted into the appropriate theme. This sorting process was iterative and the placement of each topic within a theme was determined by the use of wording or phrasing similar to Key Issues in the PSM guide under the section of the rule from which the thematic heading was derived. The next step in this process involved looking for “convergence” of Key Issues; that is, those topics that could be logically grouped based on a final analysis of the Key Issue, its context in the report, and related concepts and topics identified [10].

3. Results:

The results for both the Naturalistic Analysis and the Thematic Analysis of the chemical industry accident report Key Issues are described below. The two analyses of Key Issues shared some similar results. The more detailed results achieved in Thematic Analysis suggested that the more frequently occurring themes could be used as lines of inquiry for potential improvement actions.

3.1 Results for Naturalistic Analysis:

Sorting the Key Issues in the first naturalistic approach yielded 93 distinct issues, 60 of which (or roughly 2/3) were represented by only one occurrence throughout the 60 reports. The results for Key Issues with a frequency of 6 or more (10%) are presented in Table 1.

Table 1. Naturalistic Key Issue Frequencies

Key Issue	Number of Occurrences in CSB Reports	Percentage of Reports Containing Key Issue (%)
Emergency Planning, Response, and Notification	15	25.0
Equipment (or Process) Design and Scale Up	15	25.0
Regulatory Oversight	7	11.7
Process Hazards Analysis	7	11.7
Reactive Hazards and Safeguards	7	11.7
Operating Procedures	6	10.0
Accident Investigation and Lessons Learned	6	10.0

Table 1 illustrates the distribution of the most frequently occurring Key Issues and the relatively low number of occurrences of similarly worded Key Issues. Emergency planning, response and notification, along with equipment or process design and scale up, were both represented in the reports with a frequency of 15, meaning that these topics were considered to be Key Issues in the accident in approximately 25% of the accidents reported in the database. The next tier, with only 7 occurrences, included regulatory oversight, process hazards analysis and reactive hazards and safeguards. With 7 occurrences, these issues were prevalent in approximately 12% of the accidents reported. Other issues of note included accident investigation and lessons learned, and operating procedures in 10% of the accidents.

It is also important to note, as mentioned above, that there were 60 Key Issues with only one occurrence which led to the desire to more closely analyze this very large group of Key Issues. Many of these Key Issues appeared to share common ideas; either with more frequently encountered Key Issues or among others in this “once only” group, based on similar wording. Thus it was determined that more detailed analysis was needed, so that clearer trend information could be extracted.

3.2 Results for Thematic Analysis:

In an initial, revised thematic sorting of the Key Issues, the data was placed into themes based on textual clues, and several themes were created to sort the Key Issues; the preliminary results of this thematic analysis have been presented at a conference [12]. These findings have since been refined, based on feedback received at that conference, using the PSM guidelines as the primary source of categories and combining these with several themes developed through industry experience [11].

As discussed previously, the Key Issues were then sorted into each of these new themes. The results from this analysis are presented in Table 2. Results presented include themes with greater than 6 occurrences (10%) in the chemical industry accident reports (as in the naturalistic analysis, above). It should be noted that twice as many themes (14) reached this frequency of occurrence in this revised analysis.

Table 2. Thematic Key Issues Frequencies

Theme	Total Number of Key Issue Occurrences	Percentage of Reports Containing Key Issue (%)
Design and Engineering	27	45.0
Standards	24	40.0
Process Hazard Analysis	23	38.3
Emergency Planning and Response	22	36.7
Hazard Recognition	21	35.0
Operating Procedures	14	23.3
Maintenance	12	20.0
Management of Change	11	18.3
Mechanical Integrity	9	15.0
Process Safety Information	8	13.3
Employee Participation	7	11.7
Accident Investigation	7	11.7
Training	6	10.0
Human Factors/Management Oversight	6	10.0

As illustrated by the data in Table 2, the results from the thematic placement of the Key Issues differ from the previous naturalistic analysis. Design and engineering, as well as emergency planning and response, still represented two of the most frequently occurring issues; however, standards, hazard recognition, and process hazard analysis emerged as among the five (5) most frequently occurring

themes in the chemical industry accident reports – each occurring in more than one-third (33%) of the reports analyzed.

Once the most common themes were identified, a closer examination of the phenomena represented in each of the Key Issues that fall under each theme was used to identify particular focus areas in which changes in process safety management could be considered. The following five (5) Key Issue themes with more than 20 occurrences, appeared in around 33% of all final accident reports in the database, and are examined more closely as follows.

The most common theme, with occurrences in nearly half of all final accident reports studied was design and engineering. Topics in the design and engineering theme can be further divided into several phenomena. One of the typical topics in the chemical industry accident reports under this theme was a lack of a layered protection system; for instance, the existence of a single alarm system which could be compromised in an accident scenario, or a fence with no warning signs or locks. Other design and engineering topics included not incorporating accident analysis insights into design (e.g., no relief valves on pressurized tanks, no secondary alarm system), specific problems with equipment design, and scale up concerns with processes.

The standards theme was also determined to be a common theme in the chemical industry accident reports. In this theme, topics addressed were typically split between: insufficient or nonexistent regulations (with instances of enforcement issues) and a lack of oversight to ensure the standards are being followed.

Topics identified under the process hazard analysis theme related to the OSHA-prescribed process hazard assessment (PHA) which each facility is required to undergo at a minimum of every 5 years. In general, phenomena relating to the PHA were subdivided as follows: the PHA was incomplete or lacked required information, the PHA was out of date, or the PHA was not performed by an appropriate team of knowledgeable employees. The most common of these topics was the lack of information in the PHA.

In the emergency planning and response theme, the most common topics identified were related to the responsibilities of the on-site staff/management and emergency crews responding to the accident. On site, the most common topics included a lack of planning or guidance for employees and managers on proper management of emergency situations, along with instances in which the planning and guidance were in place but employees and management were not familiar with or did not adhere to the plan. Problems associated with emergency crews typically centered on a lack of understanding of reactive chemical management, a lack of preparation, or a lack of knowledge about the accident unfolding at the plant.

Hazard recognition was the final theme with more than 20 (33%) occurrences in the reports. This particular theme involved instances in which the staff and management were unable to recognize and properly respond to potential hazards at the facility. Some of the most common occurrences of this include the lack of recognition of combustible dust hazards, boiling liquid expanding vapor explosion (BLEVE) hazards, and hot work hazards.

4. Discussion:

4.1 Overview of Results

Some of the Key Issues addressed in the chemical industry accident reports are addressed in more detail in CSB Safety Bulletins, such as combustible dust hazards [13]. Safety Bulletins are another type of document produced by the CSB, designed to draw attention to a particular focus area. These safety bulletins are a synthesis of accident reports, and therefore were not included in this analysis to avoid double-counting.

Other commonly identified issues may warrant further evaluation to improve process safety at chemical facilities. Regulators and safety oversight organizations (e.g. OSHA, the CSB) use formal recommendations and regulatory revisions to achieve improvements in process safety; however, facilities, companies, or industry groups can also use the insights available from analyses of Key Issues from the chemical industry accident reports, such as this one, to improve process safety. Use of the insights available from the analysis of Key Issues can support organizational learning, taking advantage of the experience gained in the many branches of the chemical industry (e.g., agriculture, chemical manufacturing, and oil and gas).

In analyzing these chemical industry accident reports, several themes emerged as potential focus or improvement areas for chemical facilities, as described in Section 3, above. The five (5) major themes were design and engineering, standards, process hazard analysis, emergency planning and response, and hazard recognition. As these themes each occurred as Key Issues in over 33% of the chemical industry accident reports, a closer analysis of their effect on safety and efficiency of operations may be warranted.

Participants in OSHA's PSM program are required to update and/or review compliance every five (5) years with special updates encouraged as changes occur [11]. These updates and reviews would be an ideal time to apply organizational learning from accident reports to facility operations. The five (5) major themes highlighted in this analysis may be used as a guide to determine areas of process safety that might need review at a given facility during the aforementioned routine or special PSM updates.

4.2. Recommendations and Potential Improvement Actions

Each of the five themes that occurred with a high frequency in the chemical industry accident reports were reviewed in detail to develop ideas for areas of potential focus during routine or special Process Safety Management updates in the chemical industry. The following questions should be considered when evaluating updates to Process Safety Management at your facility. These ideas can be tailored to the specific operations of the given industry.

If the answer to any of the questions is "no," it may be an important step to consider the rationale for that answer and if there are any steps that should be taken to improve process safety in that particular area. Considering that the source of the data for these suggestions was an exhaustive database of

accident reports, focusing in on the addressed areas may reduce the likelihood of a similar occurrence at your facility.

If the answer to these questions is “yes,” that suggestion has been considered at your facility, it is important to continue on and evaluate actions you are taking to address this consideration. If your facility is not currently addressing the issues raised in the questions, evaluate the improvement to your PSM program that could be achieved by implementing the industry ‘best practices’ that form the bases for the questions.

4.2.1. Design and Engineering

- Are designs consistent with current industry standards (for instance, pressure vessel design should contemplate the most updated pressure vessel code of the American Society of Mechanical Engineers [14])?
- Do you enlist the assistance of a qualified team of people to perform peer review of engineering and design calculations for a new system or when making changes to an existing system.
- Does your engineering process evaluate scaling effects on the system when increasing the capacity or throughput of the processes?
- Do your safety-related systems implement the “multiple layers of protection” concept using both active (e.g. monitoring systems and alarms) and passive (e.g. containment) safety systems, as appropriate?

4.2.2. Standards

- Do you regularly monitor the issuance and modification of technical and safety standards applicable to your facility?
- When compliance audits are performed, do you develop corrective actions and work to implement changes where they are deemed necessary?
- Do you participate in community planning; e.g., zoning laws and local emergency response plans can benefit from participation and information sharing by the chemical facilities in the community?

4.2.3. Process Hazard Analysis

- Is your Process Hazard Analysis updated regularly, especially when changes are made to a process or facility (at a minimum, the PHA should be updated every 5 years, as required by OSHA)?
- Have you enlisted the assistance of a diverse team of experts when performing or updating the PHA to maximize the recognition of potentially hazardous scenarios?

4.2.4. Emergency Planning and Response

- Has your facility recently reached out to emergency responders in the community to maximize effectiveness and communication?

- Does your facility have a means to ensure that adequate information about hazards present at the facility is available to emergency response teams?
- Have you developed and do you regularly update your facility's plan for emergency response, and run drills that involve the facility employees?

4.2.5. Hazard Recognition

- Are your employees thoroughly familiar with the process hazard documentation, as well as process safety information for the facility through formal and informal training programs?
- Are hazards clearly identified on operating procedures (for example, if a particular hazardous chemical is used in a process, include an attachment of the MSDS)?
- Do your procedure revision and design change processes encourage employees to participate in work planning and controls and use their operating and/or maintenance expertise to identify additional hazards and improve the process?

1.2.6 General Familiarity with the PSM Standard

- Are you familiar with the other topics addressed in the PSM standard [11] that do not occur as frequently in the chemical industry accident reports [15] (note: not all industries are the same, the topics that did not occur frequently in this study may have particular relevance to a specific facility, company, or industry group, and therefore, can be used as organizational learning tools through which to improve safety and efficiency of operations at those entities)?

4.3. Additional Observations for Regulators and Safety Oversight Organizations

In the process of completing this analysis, a few additional observations were made which could potentially improve safety in the chemical industry, and could also be applicable to other industries. These are ideas for regulators and safety oversight organizations to evaluate for implementation as they continuously improve their processes:

- Does your organization develop and release safety bulletin-type information regarding accidents or groups of accidents under your purview?
- Do your incident reporting procedures and accident analysis processes use a consistent set of Key Issues (like the major PSM topics) to facilitate monitoring of trends in these accidents?
- Do you revise your standards/processes, as necessary, when new guidance that could improve safety is released by industry groups, or when new technology or information becomes available through other sources, such as lessons learned from accidents?
- Do your oversight processes ensure standards are being implemented and followed at the required facilities and follow up as necessary on issues discovered during this process?

5. Conclusions:

The rich database available in the chemical industry accident reports contains valuable organizational learning information that can be used to help improve the safety and efficiency of operations at chemical facilities. The work presented herein illustrates the usefulness of these reports through the analysis of identified Key Issues. The results from this analysis, and subsequent ideas presented for improvement actions, can be used by facilities, companies, and industry groups—coupled with their own specific trend information—to evaluate and prioritize process safety management program initiatives and thus improve process safety and efficiency of operations.

The results of analyzing Key Issues contained in the chemical industry accident reports identified several themes that can be used to develop a better understanding of chemical industry accidents and aid in continuous improvement of Process Safety Management programs; thus, potentially preventing future accidents from occurring or reducing their impacts. From the results of this analysis, the themes which may be useful to emphasize in improving safety and efficiency of operations at chemical facilities include: design and engineering, standards, process hazard analysis, emergency planning and response, and hazard recognition; detailed discussion of each of these themes or categories can be found in Section 4, above.

Finally, it is noted that the above analysis evaluated experience from a broad spectrum of facilities in the chemical industry. Facilities, companies and industry groups may be more interested in experience specific to their portions of the chemical industry. The categorization scheme in this study, which uses industry-standard terminology derived from the OSHA PSM Guide, and the facility-specific CSB accident database, can be used as a starting point, or example, for future industry-specific studies.

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