Contents lists available at ScienceDirect

Process Safety and Environmental Protection

journal homepage: www.elsevier.com/locate/psep

Learning from the Bhopal disaster to improve process safety management in Singapore

Yang Miang Goh[a,b,*], Sherry Tan[b], Kean Chung Lai[a]

[a] Department of Building, School of Design and Environment, National University of Singapore, 4 Architecture Drive, Singapore 117566, Singapore

[b] Workplace Safety and Health Institute, 1500 Bendemeer Road #04-01, Ministry of Manpower Services Centre, Singapore 339946, Singapore

ARTICLE INFO

Article history:
Received 3 October 2014
Received in revised form 9 December 2014
Accepted 4 February 2015
Available online 12 February 2015

Keywords:
Process safety
Bhopal disaster
Lessons learnt
Singapore
Expert interviews
Qualitative study

ABSTRACT

The Singapore process industry is mainly made up of chemical and energy companies such as Mitsui Chemicals, Clariant, Exxon Mobil, Shell, Sumitomo, Petrochemical Corporation of Singapore and Infineum. Majority of these companies are located on Jurong Island, southwest of Singapore. Jurong Island houses nearly 100 leading petroleum, petrochemicals and specialty chemicals companies and the total investment is about S$42 billion in total. With a land surface area of only 716 km^2 and a high concentration of process plants, the Singapore government places strong emphasis on safety and risk management. In this paper, four process industry veterans from the government, academic and private sectors were interviewed. Through the interviews, the authors sought to understand the veterans' perspectives on lessons that the Singapore process industry should learn from the Bhopal disaster. The veterans expanded their thoughts beyond the Bhopal disaster and provided many insights and suggestions critical to process safety management in Singapore and other countries. A systemic model of process safety management was derived from the interviews and key elements of operational process safety management were identified. In addition, a research agenda was identified based on the inputs from the veterans.

1. Introduction

The Bhopal disaster, which happened on the night of 2–3 December 1984, is the worst industrial accident in recent history (Abbasi and Abbasi, 2005), resulting in thousands of deaths and hundreds of thousands of ill-health. The disaster was a result of complex socio-technological factors which had been studied by many (e.g. Casey and Casey, 1993; Meshkati, 1991; Peterson, 2009) and the process industry in many countries responded with new safety initiatives and regulations.

In response to global trends in process safety management, the recommended practice on process safety management was established in Singapore in 1993 by the former Ministry of Labour (Go, 2010). The recommended practice was heavily influenced by the United State OSHA's 29 CFR part 1910.119 and API RP 750, with the aim to "eliminate or mitigate the consequences of large accidental releases involving hazardous substances" (Go, 2010). Subsequently, the recommended practice was developed into the Code of Practice on Safety Management System for the Chemical industry (2001). With the enactment of the Workplace Safety and Health Act (2005) in 2006, a new Singapore Standard, SS506 Occupational Safety and Health (OSH) Management System – Part 3: requirements for the chemical industry was established. Currently, quantitative risk analysis of new process plants is required by regulatory agencies such as the National Environment Agency (NEA), Ministry of Manpower (MOM),

* *Corresponding author at*: Department of Building, School of Design and Environment, National University of Singapore, 4 Architecture Drive, Singapore 117566, Singapore. Tel.: +65 66012663; fax: +65 67755502.
E-mail address: bdggym@nus.edu.sg (Y.M. Goh).
http://dx.doi.org/10.1016/j.psep.2015.02.004
0957-5820/

Singapore Civil Defence Force (SCDF) and Singapore Police Force (SPF).

While the Singapore government and the process industry have implemented many measures to prevent major process accidents, the 30th anniversary of the Bhopal disaster is a timely reminder of the potential severity of process incidents. Thus, this paper aims to use the Bhopal disaster as a platform to identify the key factors affecting process safety and suggest a research agenda to improve process safety in Singapore. It is likely that the identified factors and the proposed research agenda will also be useful to the process industry in other countries.

2. Process industry in Singapore

The process industry in Singapore makes up one-third of the manufacturing sector with high growth potential (Ministry of Manpower, 2010). From 2000 to 2009, there was an increase from 61 to 95 chemical companies and the total assets grew from US$17 billion to US$25 billion. The sector accounts for a workforce of more than 100,000 workers. It is a cornerstone of Singapore's economic strategy, with at least another S$5 billion worth of investment over the next few years in Jurong Island and Tuas. The Singapore process industry comprises mainly multi-national chemical and energy companies. Many of the companies are located on the Jurong Island, home to nearly 100 leading petroleum, petrochemicals and specialty chemicals companies, amounting to a total investment of S$42 billion. With a land surface area of only 716 km^2 and a high concentration of process plants, there is a strong emphasis on safety and risk management on the Jurong Island.

3. Summary of causes of Bhopal disaster

Factors leading to the Bhopal disaster have been discussed extensively elsewhere, such as by Shrivastava (1987), Meshkati (1989) and Peterson (2009). These factors include corporate negligence, such that corrective actions were not taken to address earlier accidents. In addition, there were also operational lapses, such as the failure to follow safety and operational procedures in the flushing of the MIC line and faulty, inadequate, or non-operational process equipment. Manpower was also cut due to economic reasons, a problem exacerbated by the replacement of experienced staff with less-skilled employees. In terms of responding to the accident and mitigating its impact, the plant's safety systems, such as the flare tower and the water curtain, were either not operational or did not have sufficient capacity. Emergency response planning and public health infrastructure in the vicinity of the densely populated Bhopal area were also lacking, which could have otherwise minimized the number of people in the community affected by the disaster.

4. Research method

This study taps into the expert knowledge and experience of four process and safety veterans in Singapore so as to identify the critical learning points that Singapore should learn from the Bhopal disaster. All of them have more than 25 years of experience in process safety-related work with varied backgrounds in academia, industry, regulatory and training and consultancy services. The brief profiles of the four experts are summarized in Table 1.

Table 1 – Brief profile of experts interviewed.

Interviewee no.	Years of relevant experience	Selected experience
1	>33	• Currently the Technical advisor to private equity managers, investment banks and fund managers, where he assesses technical, operational, safety and environmental protection issues. • Significant experience in operations, safety and project management at a multi-national oil and gas refinery, involved in the development and implementation of safety programmes and processes, in both line and support functions.
2	>25	• Currently the Health, Safety and Environment Manager of a major oil and gas company in Singapore. • Heavily involved in process industry associations and national level workplace safety and health committees. • Significant experience in areas of process technology and operations, health and safety programme development and implementation, including driving process safety management programme
3	>35	• Currently an academia with a focus on safety, health and environment research and teaching. • Significant experience as an auditor and consultant in a wide range of industries, including the chemical industry. • Heavily involved in workplace safety and health standards setting in Singapore.
4	About 40	• Currently the CEO of a safety and health consultancy in Singapore. • Heavily involved in a national level safety association. • Worked in a range of senior management positions in a safety and health regulatory agency in Singapore; was responsible for enforcement, training and promotion of safety and health.

Prior to each interview, the expert was given a summary of the causes and lessons learnt from the Bhopal disaster that the authors have prepared. In addition, they also received a summary sheet that spells out the aim of the study and

Semi-structure Interview Questions

a. Please elaborate your experience in the process industry. How many years have you worked in the industry? What are the types of company that you have worked for? What are the different appointments that you have had?
b. What are the regulatory and industry interventions that would prevent a major process accident, such as Bhopal disaster, in Singapore? (Rank the top 3 interventions, if possible)
c. What are the lessons of Bhopal that are important to the Singapore process industry? (Rank the key lessons, if possible)
d. In view of the current interventions in Singapore, what are the residual risks for a major process accident? What more should be done?

Fig. 1 – Research protocol.

the key research questions that the researchers will be asking them. Out of the four interviews, three were conducted at the workplace of the expert. One of the experts came to the lead author's office for the interview. The interviews were conducted in a semi-structured format (Silverman, 2010) where the interviewers used the prepared questions as guides (see Fig. 1), and follow-up questions were posed in response to the answers provided by the interviewees. The in-depth interviews were conducted in a conversational style so that the experts can express their opinions freely and the interviewers can have opportunities to dwell into their vast knowledge and experience. During each interview, the interviewers would seek permission from the experts to audio record the interview. All the four experts agreed to be audio recorded and each interview lasted about 1–2 h. To ensure consistency in the interview process, all three interviewers were present in the first interview. Subsequent interviews were conducted by one or two interviewers. After each interview, the audio record, together with handwritten notes of the interview, were compiled into electronic interview notes for analysis. A total of 15,152 words were recorded in the interview notes.

Subsequently, the four sets of interview notes were imported into qualitative research Nvivo 10 (QSR International, 2014). Word frequency analyses were conducted to identify the key themes that the interviewees have highlighted. The key themes were then used as general guides when the interview notes were coded into "nodes" or sets of quotes. The set of initial codes were then evaluated, clustered and re-organized to reflect the key themes that were raised by the four experts. The intent of the coding was to condense the contents of the interviews into a set of factors (in relation to the lesson learnt from of the Bhopal disaster) that are significant to process safety management in Singapore. However, it was noted the experts often went beyond the scope of the Bhopal disaster and highlighted issues and factors important to process safety management (PSM) in Singapore. These deviations were not discouraged because they provide valuable insights which are still in line with the aim of this paper. Even though the interviews were focused on lessons relevant to Singapore, the information shared by the experts would also apply to other countries as well.

5. Overview of results and findings

As highlighted earlier, word frequency analyses of each interview note were first conducted to explore the key themes highlighted by the four experts. A series of word clouds were developed to facilitate the evaluation. The analysis showed that Interviewee 1 focused more on management systems and operational controls. Interviewee 2 highlighted many facts relating to the lesson learnt from accidents and incidents. Interviewee 3 suggested strongly that financial issues drive effectiveness of process safety management in the industry. Interviewee 4 mentioned many times the importance of industry-led efforts in safety and goal-setting, and the importance of safety culture and management commitment to safety. Similar points were highlighted across the interviews, but each expert provided a different focus and angle to the interview questions.

The subsequent detailed coding and re-organizing of the nodes produced Figs. 2 and 3. Fig. 2 provides an overview of all the factors identified and these factors were classified into government, industry and plant levels. The experts had shared significant amount of information on the elements of effective operational safety management, thus Fig. 3 is used to summarize the details provided. Each of the terms in Figs. 2 and 3 is established with reference to at least one quote from the interview notes. Both models will be discussed in the following sections.

6. Plant safety

The experts felt that a safe plant is dependent on four interacting areas: inherently safe design, financial well-being of the company, safety culture and operational safety management.

6.1. *Inherently safe design*

In terms of inherently safe design, the experts felt that there must be "rigorous process risk analysis" by designers. Unintended mixing of substances (e.g. water and MIC) should also be looked into during design stage. Furthermore, fail–safe designs should be provided. For example, when a component fails, the sub-system will shut down to prevent any accident from occurring. A safe design is critical to the plant safety because humans are expected to make mistakes and there must be deliberate attempt to reduce the reliance on humans.

6.2. *Financial well-being*

Interviewee 3 was particularly convinced that financial well-being is the true underlying cause of the Bhopal disaster. He felt that the plant was generally safe and people were able to perform their tasks, but poor financial well-being triggered off a series of decisions that neglected the maintenance and critical safety equipment to be ineffective. Interviewee 3 opined that (note that all quotes cited herein are taken directly from the interview notes and may not reflect the actual phrase used by the interviewees)

> "*The basic issue pertaining to maintenance is the financial issue. The plant is not doing well, probably the products are not selling well and so whatever they do, they have to save money. When income is low, maintenance will be low. . . . It is a financial issue that they do not want to spend on it.*"

He felt that it was the financial concerns, i.e. the commercial benefits the plant provided to the community, which caused the Bhopal local government to fail to take actions before the accident. Interestingly, financial concerns were also the key reason why the process industry is known to be more safety conscious. This is because Interviewee 3 felt that the process plant owners were very concerned that major accidents like Bhopal disaster will wipe out their investments.

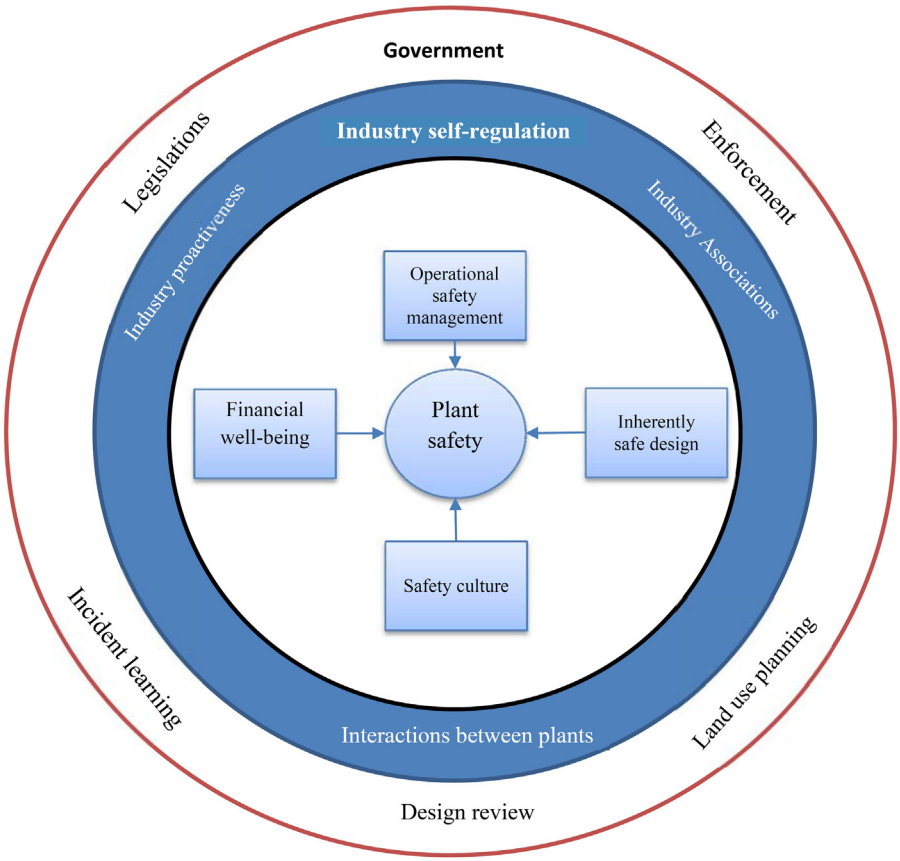

Fig. 2 – Critical success factors of process safety in Singapore.

Interviewee 2 felt that "[c]ost should not be the top or only priority and *[sic]* must be weighed against effectiveness". He gave an example of the contractor selection, where the evaluation process must take price, capabilities, available resources and alignment to the company's systems into account. Interviewee 1 highlighted the danger of being overly focused on financial or cost aspects with reference to the 2004 Nicoll highway collapse (Goh and Soon, 2014). Prior to the major accident, which killed four persons and caused a highway to collapse, the Singapore Land Transport Authority (LTA) appointed a contractor who bid S$60 million below the next higher bidder. Interviewee 1 provided an example of how to prevent financial woes from impacting maintenance and purchases critical to safety. In his former company, "non-discretionary"

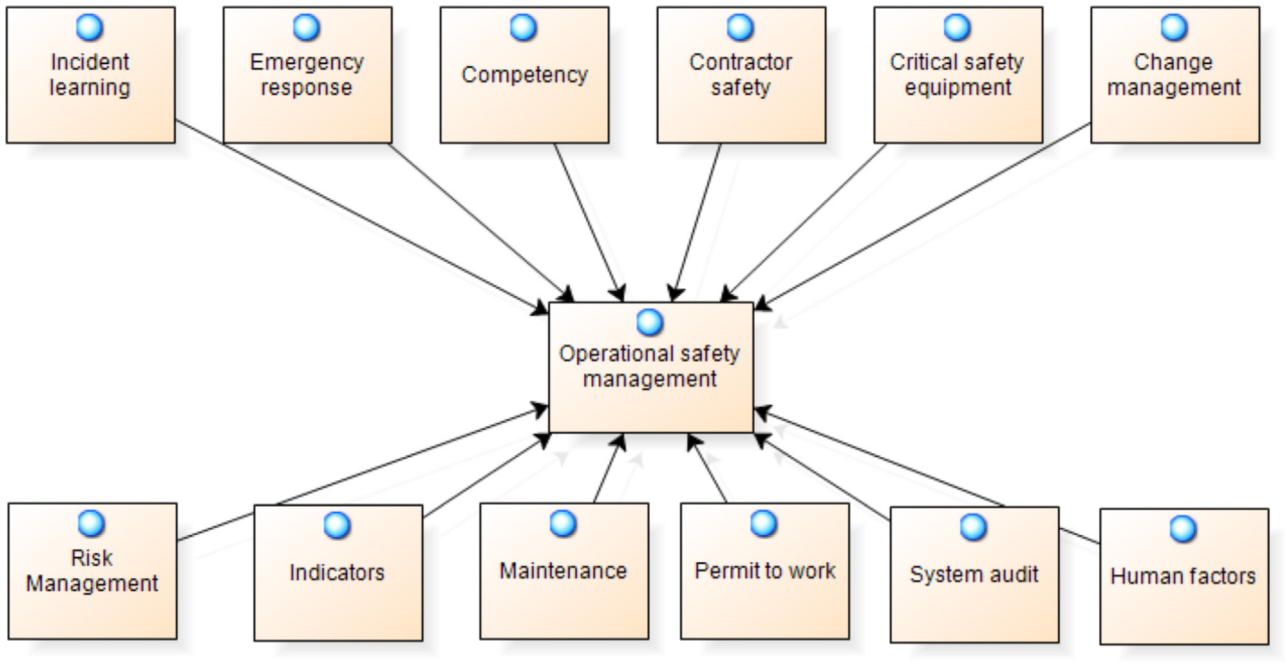

Fig. 3 – Key elements of operational safety management.

budget items are identified early on. These items are non-negotiable and will have to be purchased or implemented with no discussion.

6.3. Safety culture

Safety culture was highlighted as an "overarching element that impacts ... each aspect of process safety". Interviewee 4 opined that as in the case of Bhopal, a lack of top management attention would result the operational safety management system to deteriorate across time. Interviewee 1 highlighted that an effective safety management system requires clear accountability from every employee. This includes workers being convinced of their right to stop unsafe work without any repercussion and presence of communication channels for employees to provide feedback to the top management. This is supported by Interviewee 4, who shared that management could "[leverage] on employee innovation for safety improvements" through initiatives like Safety Improvement Teams. Furthermore, contractors must also be involved and closely supervised because safety culture should be pervasive.

Interviewee 4 hypothesized that for incidents like Bhopal and the Spyros fire in 1978 (a major accident in Singapore), organizations involved could have held the shared belief that "accidents were bound to happen". Such reactive culture can easily lead to major accidents. Furthermore, Interviewee 3 observed that poor safety culture can defeat safety management systems through surface compliance or "paper play" (Goh and Soon, 2014). This is where the paperwork does not reflect the true implementation of safety procedures. Interviewee 4 was also concerned with the setting of safety targets based on fatality rates. He opined that this equates to "giving [companies] a license to have a fatality...". However, he noted the current drive by the Ministry of Manpower with "Vision Zero" is on the right track.

6.4. Operational safety management

As can be seen from Fig. 3, the experts mentioned numerous operational safety management elements. The following discussion covers the elements that are more relevant to the Bhopal disaster.

Learning from past incidents is especially prominent because it is related to the theme of this study. The Bhopal plant had many incidents of leaks before the disaster in December 1984 (Peterson, 2009), but the plant management failed to learn from these incidents and make improvements to their practices. An example is the fatal phosgene leak accident on 24 December 1981 where plant management blamed the worker for removing his gas mask during operation. The experts opined that learning from other incidents would involve understanding the details of the incident, assessing the relevance of the incident to the plant and internalizing key learning points. Senior managers of sister plants could lead the accident investigation to provide certain level of authority and independence, and their knowledge of the operations will facilitate the derivation of lessons learned. Furthermore, incident investigation should result in concrete actions, which are tracked and reported to management. The information provided by the experts reflected the views of many in the process industry, who had identified the importance of learning and remembering major accidents (e.g. Meshkati, 1989; Murphy and Conner, 2014; Singh and Bhadoria, 2013; Wright, 2012). However, Interviewee 3 was skeptical because he emphasized the difficulties in convincing people of the risk of major accidents during normal operations. He stated:

> "*Safety is learnt ... and paid by life [sic]. ... Before any accident happens, it is difficult to tell people ... the risk.*"

Management of change is an important concept that was neglected in the Bhopal plant. Interviewee 1 identified the 1974 Flixborough disaster in the U.K., the 1986 Hotel New World collapse in Singapore and the 1995 Sampoong Department Store Collapse in South Korea as other accident cases that highlighted the importance of management of change. It was emphasized that changes must be carefully studied by personnel with the relevant expertise before implementation. In addition, Interviewee 1 also emphasized the importance of clearly identifying safety critical equipment. In the case of Bhopal, the plant should not have been operating when the safety equipment (the flare) was not functioning. Similarly, a permit-to-work could have been required for all work conducted on safety-critical equipment.

The Bhopal disaster demonstrated that the lack of emergency preparedness could lead to repercussions of far greater magnitude. Interviewees 1 and 2 felt that the Singapore Civil Defence Force (SCDF) is commendable in this aspect. Interviewee 2 commented that keeping emergency response capability up-to-date and competent is very important.

Another important element highlighted in the interviews was system audit. Prior to the Bhopal disaster, several inspections and audits raised many shortcomings related to the disaster (Peterson, 2009). The experts generally felt that independence and competency of auditors are critical to ensure the effectiveness of the local audit requirements, which is based on the Singapore Standard SS506 part 3 (Spring Singapore, 2013).

7. Government regulation and self-regulation

The experts identified that the requirement for biannual system audit by a third party is an important lever to facilitate self-regulation of the industry. However, the requirement only covers larger plants. There were concerns that smaller plants would be less prepared and less resourced to address process safety.

Due to the proximity between plants on Jurong Island, an incident at a single plant could affect the nearby plants. However, the experts were generally confident of the land use planning in Singapore, Interviewee 2 opined that:

> "*Singapore has done a good job with land use planning in phasing hazardous installations away from the community. Despite the [possibility of a] domino effect should an accident occur on [the] Jurong Island, this is the lesser of 2 evils compared to the siting of hazardous installations in the vicinity of a densely populated area.*"

Interviewee 2 suggested that there should be a single coordinating body to review the risk of a process plant during design stage. The current review process involves many agencies such as the Ministry of Manpower (MOM), Singapore Civil Defence Force (SCDF), National Environment Agency (NEA) and the Singapore Police Force (SPF). These agencies focus on different aspects of the design. It was felt that such a process "makes it difficult to focus on important issues or ... details". A single design review body can help to facilitate sharing of

information within the community where the new plant is residing in and the neighbouring plants can also make necessary adjustments in their emergency response plans. Such an approach will help to prevent incidents in one plant to cascade to neighbouring plants.

Another suggestion by Interviewee 2 and Interviewee 3 is the creation of an independent investigation board led by an influential person with sufficient political power to make strong recommendations. The investigation board can be modelled after the Chemical Safety Board in the U.S. with the aim to

> "*investigate incidents and develop recommendations, including those addressing deficiencies in management systems and local regulations. Findings and recommendations from the investigation of various accidents could then be shared with others in the process industry for learning and preventing similar incident purposes.*"

On the other hand, Interviewee 3 highlighted the importance of having strict enforcement of process safety legislations and standards. Regulators can use financial well-being of companies as an indicator of potential neglect of maintenance. There were also concerns about the process safety competency among the regulators (at least in the past) and fresh graduates. The universities and industry associations are encouraged to do more to improve process safety competency.

8. Research agenda

The opinions of the four experts provided much food for thought. Using the Bhopal disaster as a trigger, the experts shared a wide range of process safety issues that should be looked into. Figs. 2 and 3 provide a useful summary of the key points raised by the experts. Drawing from the inputs of the four experts, the following research agenda is proposed:

1. Explore the use of financial indicators as leading indicators of process safety risk.
2. Define the current level of safety culture in the Singapore process industry using a suitable psychometric scale.
3. Define the current process safety competency gaps among smaller process companies and devise strategies to close the gap.
4. Compare and contrast the identified operational safety management elements in Fig. 3 with existing frameworks used in the process industry and develop best practice guidance for the industry.
5. Develop an incident learning database for the Singapore process industry. This can be based on the framework of case-based reasoning (Goh and Chua, 2009, 2010) consisting of case representation, retrieval, adaptation and retain.
6. Study the investigation analysis techniques used in the Singapore process industry and propose a range of suitable techniques for different types of incidents.

9. Conclusions

The Bhopal disaster remains the worst industrial accident in recent history. The Singapore process industry needs to learn from the disaster and improve its process safety performance proactively. There has been many initiatives to prevent process incidents in Singapore, but much more can be done. This study used the Bhopal disaster as a platform to discuss what the local process industry can learn from the devastating accident. Four process safety veterans were interviewed and many relevant factors were identified and summarized in this paper. Even though the experts raised many similar points, each expert was focused on different aspects of process safety.

The key points raised can be broadly classified into three levels: plant, industry and government. At the plant level, four key aspects affected process safety, these are inherently safe design, financial well-being of the plant, safety culture and operational safety management. A wide range of process safety elements was identified under operational safety management. At the industry level, self-regulation is important and can be achieved if the industry is proactive and carefully manages the close proximity between plants. It was also identified that the industry associations played an important role in improving the competency of the industry. Lastly, at the government level, it was felt that the safety legislations must be strictly enforced to ensure compliance. In addition, suggestions were made to streamline and focus the design review process. An independent investigation board was also proposed to help the industry learn from past incidents. It was felt that land use planning had been systematically implemented in Singapore so far.

Based on the inputs of the four experts, six possible research topics were identified. The proposed research will help the Singapore process industry improve process safety management. The suggested research topics can also be implemented in other countries.

Acknowledgements

The authors would like to acknowledge the valuable inputs provided by Mr Ameerali Abdeali, Mr Bernard Leong, and Mr Min Fook Seow.

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