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Three-Stage ISD Matrix (TIM) Tool to Review the Impact of Inherently Safer Design Implementation

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ABSTRACT

Inherently safer and friendlier plant design offers a simpler, cheaper, safer solution that consumes less energy, requires less maintenance, and produces less waste and pollution. It is a solution that the chemical industry needs to continually adopt in the years ahead. Nevertheless, obtaining an inherently safer process/technology with respect to all potential hazards is quite unfeasible and may lead to conflicts in the alternative process selection. To resolve safety conflicts, thorough understandings of all the hazards associated with the process options are vital. This paper presents a systematic screening procedure for reviewing inherently safer design alternatives using a combination of three-stage ISD matrix tool and guide word approach. The proposed methodology was applied to the ammonia supply system with the objective to understand the trade-off of inherent safety toward the overall process. The results show that the proposed tool is capable of helping users understand the impact of modification toward the safety and implementation cost.

1. Introduction

In 1970, Kletz introduced a theory of inherently safer design (ISD), which intends to eliminate or reduce hazards. The theory is based on four principles: eliminate/substitute, minimize, moderate, and simplify. Historically, the "missed ISD opportunities" in chemical process industries (CPI) have led to major accidents such as the Bhopal and Flixborough explosion, where the consequences were devastating. The Flixborough explosion in 1974 was among the most notable cases that have spurred the needs for ISD in CPI. The accidental release of flammable and combustible liquids from a reactor piping system led to the occurrence of vapor cloud explosion and fire (Mannan, 2004; Sanders, 2003). In this case, high-inventory processes can be avoided by increasing the reaction and conversion rate via a mixing process as well as by properly sizing the piping system (Kletz, 2001). Another dreadful disaster in CPI is the Bhopal accident, which happened due to the release of a large amount of methyl isocyanate (MIC) from a storage tank. This accident has been repeatedly cited as an accident that could have been prevented through the implementation of ISD (Edwards, 2005; Etowa et al., 2002; Khan and Abbasi, 1999). There were few reports that showed the Bhopal facilities were heavily dependent on engineered and procedural systems that were not maintained properly, thus the system were inefficient to prevent accidents from happening (Gupta, 2002; Wiley et al., 2006). Learning from these past accidents, and in light of the incident at Bayer Corp Science facilities involving MIC in 2008, the Chemical Safety and Hazard Investigation Board (CBS) requested a committee of

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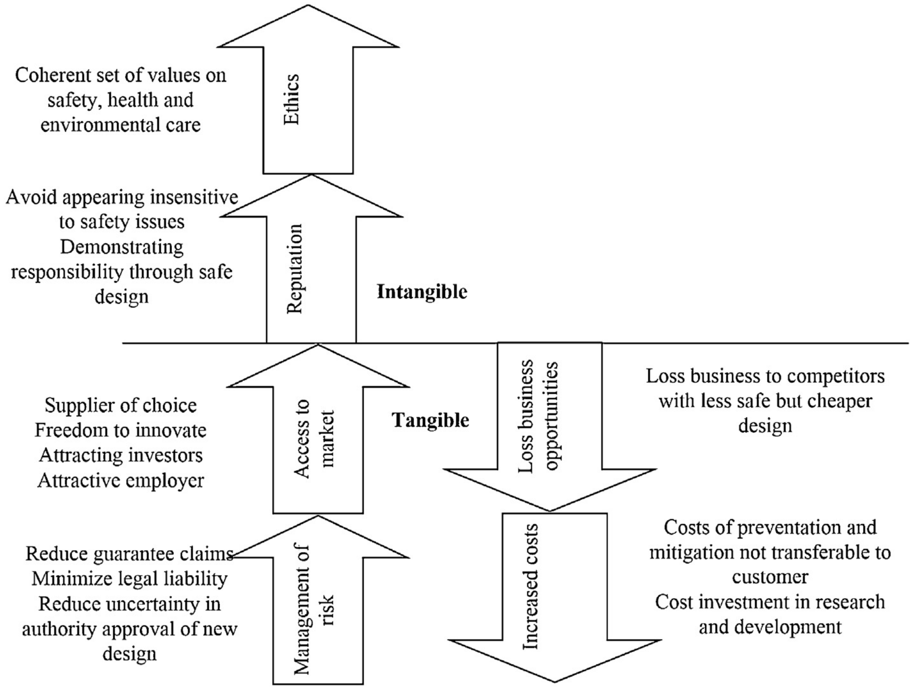

Fig. 1 – The business case for safety by design (Hale et al., 2007).

independent experts to re-evaluate the carbamate pesticides production process using MIC that led to the implementation of ISD via a minimization concept in 2010 (Bayer Crop Science, 2012). Nowadays, companies such as Bayer, Dow, and Exxon Chemicals recognize the importance of ISD and have incorporated these strategies into their safety management programs (Srinivasan and Natarajan, 2012).

1.1. *Overview on ISD conflict*

The implementation of ISD should be done in a hierarchical manner where the first-order inherent safety involves the step to avoid or eliminate hazard, and when the first order of the inherent safety is not applicable, the second-order inherent safety will be considered. The implementation of the second-order inherent safety consists of two steps: severity reduction and likelihood reduction (Moore et al., 2008). Although the concept of ISD seem to be simple, many factors need to be considered during ISD selection such as the trade-off issues from ISD implementations, e.g., performance, environment, the conflict between inherent safety principles, the conflict between hazardous properties, and business and economic factors (Khan and Amyotte, 2003). It should also be noted that making a facility inherently safer does not automatically reduce the risk. If such measure involves reducing the chemical or physical hazards of an operation, this usually translates into a lower severity of consequences if a loss event occurs. Since the risk is a function of both severity of consequences and likelihood, any changes that increase the likelihood of a loss event more than it reduces its potential severity event would actually increase the overall risk (Center for Chemical Process Safety, 2011).

The conflict between ISD principles has been discussed extensively in literature. For example, certain minimization technologies for ISD can also steer to other potential problems such as operating with higher energy inputs, higher temperatures, the requirement of more complex process/control system, and instability issues (Etchells, 2005). An example of minimization principle given by the Center for Chemical Process Safety (2010) shows that although a continuous reactor is a safer choice compared with batch reactor by reducing the impact of accidents, it relies heavily on controller instrumentation, thus it should be considered inherently less safer. Another work by Luyben and Hendershot (2004) provides an example of a situation in which minimizing the reactor size will lead to a more aggressive response and cause instability problems for the controller. A large deviation in process variables can push the process into unsafe regions of operation and affect the product quality, thus the requirement for controllers and safety measures of the process will be higher than the original one. Other examples of an ISD conflict including selection between volatile and toxic solvent, and selection of ammonia-based and chlorofluorocarbon refrigerant (Hendershot, 2011, 2006, 1995). Based on the above discussion, it is concluded that selecting the best ISD option is a challenging task. A broad perspective is required and an overly narrowed focus on one or two high visibility concerns may result in selecting a technology that does not represent the best overall inherent safety balance.

More than that, economic and business factors should be considered in selecting an ISD alternative. While the objective of ISD is to strive toward a safer and cheaper design, there is a crucial balance between tangible and intangible costs and benefits that shape the company's decisions (Fig. 1) (Hale et al., 2007). Sometimes, striving toward a safe design requires additional costs. Whereas inherently safer and friendlier plants are often cheaper than hostile ones, considering the former lifetime costs of a process and its operation, this is not true for all cases (Table 1). In the case of reactor intensification that was discussed, conflicts will arise due to ISD implementation via minimization with a simplification concept, and this will give a direct impact toward the cost. While implementing the reactor intensification concept will reduce capital and accident costs, the cost for added safety equipment will be higher in order to ensure a smooth process. It is important to highlight that costs-added safety equipment do not solely come from