Accident causes involving pressure vessels: A case study analysis with STAMP model

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Abstract. Although most companies comply with laws and regulations and use the latest technologies, tragic accidents involving pressure vessels and piping still occur, particularly in Canada (Journey Energy pipeline, Edmonton, 2017) and the United States (ExxonMobil refinery, Baton Rouge, 2016). The storage of a fluid under pressure can represent a serious risk of dangerousness, not only to the employees, but also to the emergency services, the population in the vicinity and the environment. Currently, technical aspects are the main concern of the regulatory authorities (TSSA O. Reg. 220/01, RBQ B-1.1, r. 6.1, US National Board of Boiler and Pressure Vessel Inspectors (NBBI)) and the scientific community with a particular focus on risk assessment related to structural integrity and leak tightness. The present paper explores the non-compliance of standards (API and ASME) in 50 accidents cases that occurred in Canada and the United States from 1997 to 2017 and related to pressure vessels and piping in the petrochemical and nuclear industry. Moreover, it also presents an analysis of these accidents using a risk ranking network and Venn diagram. The analysis indicates that the main cause of two-thirds of the documented accidents is an organisational issue that includes non-compliance with standards, health and safety management violation or its absence, training deficiency, non-compliance with work procedures, and absence of clear and detailed maintenance procedures. However, in most cases, if a good safety management and clearer operation procedures existed and were respected the majority of the accidents could have been prevented. From this standpoint, the Systems-Theoretic Accident Model and Processes (STAMP) method is used to analyse the causes of one particular accident as a case study.

Keywords: safety, risk ranking, pressure vessels, accident analysis, STAMP

1. Introduction

Accidents involving boilers, pressure vessels and piping systems are generally caused by technical and organizational errors. The consequences of these accidents on the environment and human health can be devastating. In addition, the loss of revenue and the cost of maintenance are of major economic concern as a result of such incidents (Steinhauser et al. 2014). Indeed, the explosions of boilers, pressure vessels and piping systems have been the cause of many catastrophic accidents in the industry. Although manufacturers are under the obligation to follow strict regulations and standards such as ASME, API, CSA and ASTM and the availability of high technological equipment, accidents still occur (Leamington, Canada and Louisiana, United States 2017). Most researchers concluded that the causes of failures of pressure vessels are related to technical issues based on the investigation of (Helmreich 2000). The study of Wyckaert (2017) shows that accidents related to pressure vessels are caused by two major technical failures; the first one is related to fluid leakage and the second one is related to equipment structural integrity. However, the same study also points to other causes related to organizational issues such as poor maintenance management, non-compliance with operating procedures, poor safety management and nonconformity with standards and regulations.

Boilers, pressure vessels and piping do generally operate in sophisticated and complex systems under severe working conditions. Characterizing the socio-technical system of pressure vessels operations involves the analysis of many factors. These factors include: operational constraints, limited maintenance deadlines, extreme operating conditions, high temperature and high pressure (ASME 2015).

This work is to investigate and analyze accidents related to pressure vessels and piping systems, by implementing qualitative analyses to identify their main causes and factors. The qualitative analyses are implemented to 50 accidents that occurred in United States and Canada and listed in authority comprehensive databases. Furthermore, scrutinizing the pertinence of systemic approaches was conducted through STAMP (Leveson et al. 2003) for on case. This particular method was selected to evaluate the context of non-compliance with Canadian and American standards and regulations on safety management. The study demonstrates the applicability and advantages of STAMP. Indeed, the explosion of a miniature steam generator manufactured in Quebec was used as the case study. The main point that distinguishes this accident and makes it interesting is that it occurred despite all the efforts of Quebec authorities to reinforce law and regulations of pressure vessels and piping operations (RBQ B-1.1, r. 6.1, CSA, 2013). It presents a typical case that demonstrates the consequence of the non-compliance of standards and regulation. The application of STAMP requires an understanding of the company safety regulations (e.g. standards, rules and procedures of design, installation and operation).

2. Methods

The data of the considered 50 industrial accidents in this work was collected from reports published by government institutions in Canada and U.S.A (OSHA, USCSB, CNESST and BST) in their open access databases. The study period concerns accidents that happened from 1997 to 2017. This 20-year period was selected to have a significant number of accidents to analyze and thus to have relevant statistics. On the other hand, the choice of the oil and gas sector was made to emphasize the importance of compliance of regulations, standards and best practices to reduce the occurrence of accidents. The first phase of the analysis was to identify the reports of accidents involving pressure vessels and piping components that occurred in this sector. The analysis presents quantitative and qualitative results of accidents in both Canada and the United States; two countries that use similar standards and regulations. Venn diagram was used to obtain the qualitative results while the distribution of the facts and causes of the analyzed accidents were used to get the quantitative results. The analysis is conducted in the results section. The analysis of these 50 accidents include basically all kinds of industries operating pressure vessels and piping systems with the exception of the transport industry which uses hazardous materials stored under pressure, which is out of the scope of this study. Information about such studies can be found in (Peignier et al. 2011).

As mentioned earlier, STAMP method was used to analyze the special case study. STAMP analyzes complex systems in nine steps: 1) identify the system information; 2) identify the security constraints of the system; 3) document the loss of the security control structure; 4) determine the immediate events leading to the loss; 5) analyze the loss at the physical system level; 6) analyze how each higher level of the system contributed to inadequate control at a lower level; 7) review overall coordination and communication between elements of the system; 8) determine dynamics and changes in the security control system and structure; 9) generate recommendations or solutions (Leveson et al. 2003). The analysis will be limited to the non-compliance of equipment to CSA B51-5 -03 and the ASME boiler and pressure vessel code.

3. Results

The accidents analysis shows a phase difference between the concerns of researchers on one side and those of industrials on the other side. While researchers are in general more interested in technical issues, the results point to the importance of organizational issues.

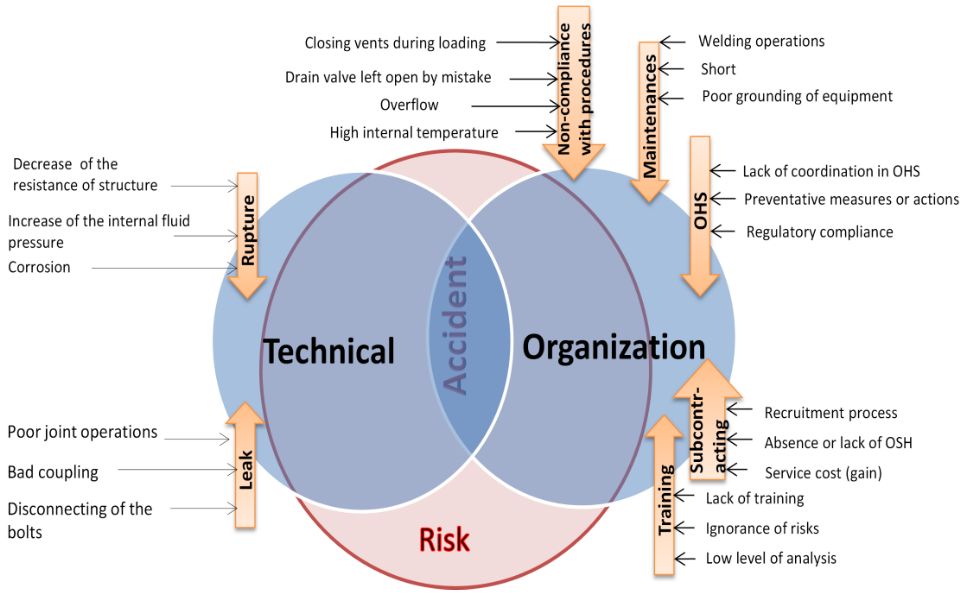

Figure 1. *Venn diagram of facts leading to accidents (involving pressure vessels)*

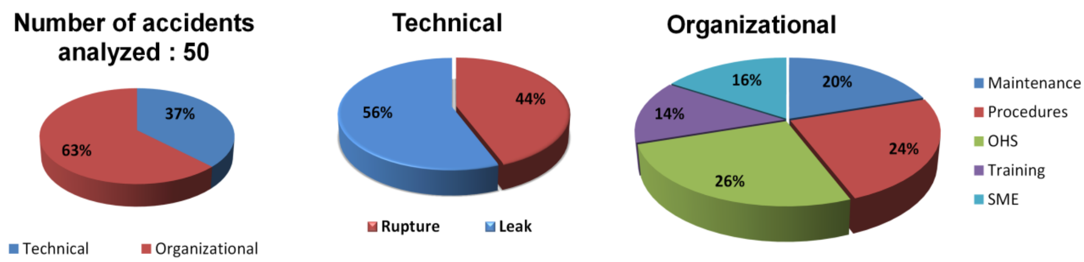

Figure 2*. Facts distributions and causes of accidents analyzed*

These results are displayed in Figures 1 and 2. The accidents of purely technical origin represent only 37% of the total accidents studied. This category is divided into two main causes: 67% are due to structural failure and 33% are due to leakage failure. The organizational causes account for 63% of accidents. This category is divided into five sub-categories: 26% due to OHS failure, 24% due to non-compliance, 20% due to maintenance errors, 16% due to subcontracting to small and medium enterprises (SMEs) and 14% due to lack of training.

STAMP was used to investigate the non-compliance of the miniature steam generator to the Quebec Laws and Regulations respecting pressure installations (RBQ B-1.1, r. 6.1,). Moreover, the considered boiler does not comply with the CSA B-51-F03 code.

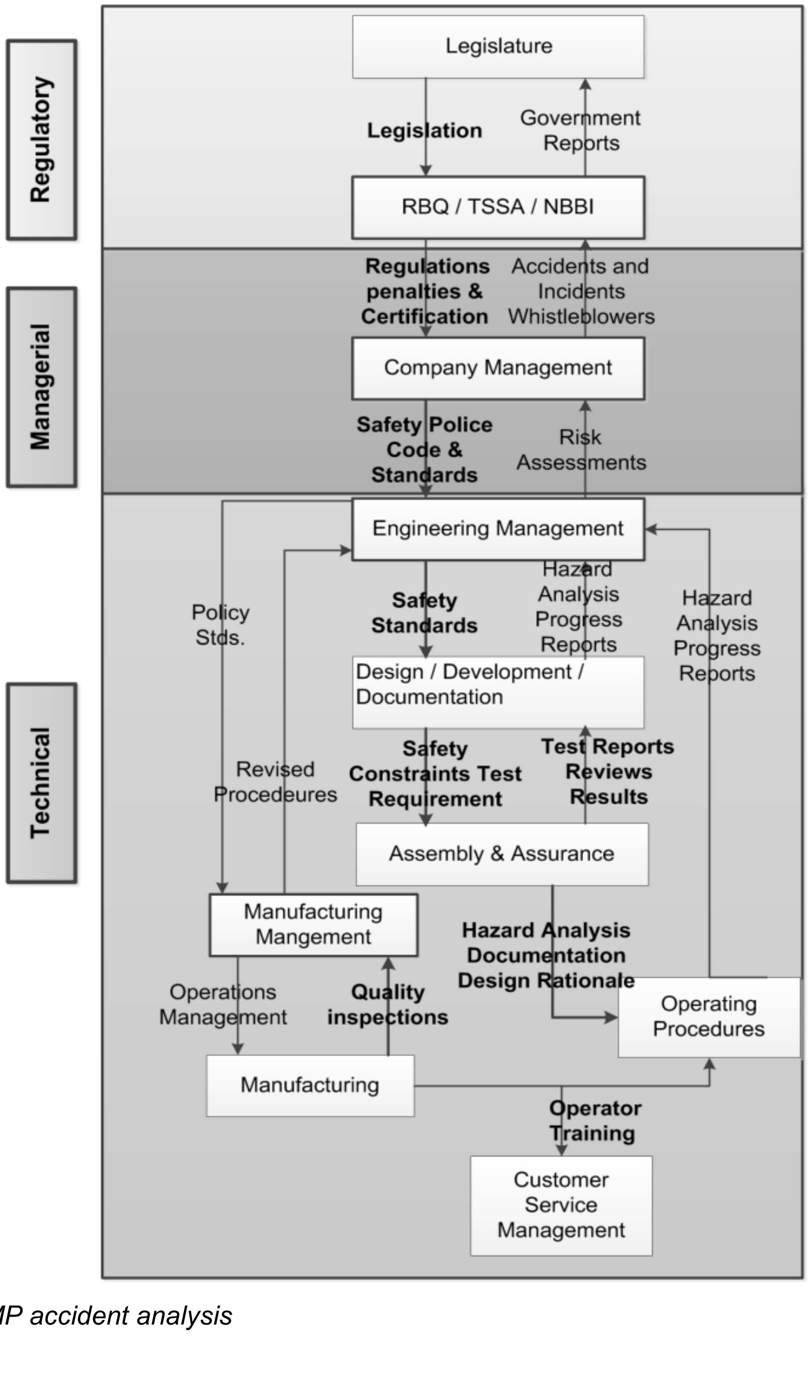

***Figure 3**. STAMP accident analysis*

4. Discussion and conclusion

The absence or failure of the health and safety management system is in general the main cause of accidents. The none systematic implementation of OHS in companies in most sectors is a reality because it is most often considered as a secondary support service to the company (Nenonen 2010). Unfortunately, accident prevention is most often considered as an added cost, not an added value and an option not an obligation. In fact, more than 80% of accidents have as their main or secondary cause non-compliance with OHS regulations. Non-compliance with procedures or even worse their complete absence implies a violation to OHS regulations. Overflow of stored product following pipe disconnections is the most frequent cause in this category, causing fires and explosions. While technical causes are not always the main reason of accidents, the consequences of maintenance subcontracting are often the root cause. In general, SMEs have a more unfavourable record of fatal accidents at work than large companies due to their limited perception of OHS. Their budgetary scale and lack of investment of resources in OHS are often to blame. Maintenance also presents a significant risk. Effective management and maintenance planning can prevent unsafe situations in industry. Adequate upstream coordination between maintenance and OHS services, as well as proper training can significantly reduce accident frequency. Inadequate training has an influence on other organizational causes. Indeed, lack or poor training can lead to dangerous actions by staffs that are not aware of the seriousness of their actions. Therefore, proper training has an essential role in accident prevention.

Technical causes have been divided into structural integrity and leakage failures. Ruptures are caused by cracks initiated in different components (shells, connections, pipes, joints, openings, welds) causing not just leaks and spills of the confined fluids but also fires and explosions. The main causes of these ruptures and damages are due to the extreme operating conditions such as high temperatures and high pressures. The consequences of pressure vessel bursts are numerous and various in nature. Pressure wave emissions, sudden expansion of confined fluid, explosion, fire and fragment projection are to name a few. Leaks represent a recurring problem in pressurized equipment. Operating accessories (pipes, valves, fittings, seals, etc.) constitute the most sensitive parts of pressure vessels. The slightest defect (improper installation, improper tightening, degraded material, etc.) can cause a leak, leading to serious consequences. These can be a creation of a pool of flammable or toxic products, dangerous vapours, a cloud of gas, etc. This situations can ultimately result in fires, explosions or even asphyxiations or poisoning of workers (Hetrick et al. 2018).

The results of the Systemic Approach Analysis (STAMP) for the case studied help understand the main contributing causes. This in turn led to clarify the weakness of the company's safety management systems (represented principally in the quality and design). In addition, the results of the accident analysis clearly show that the causes are related to each other. This case study just focused on non-compliance with the standards and procedure. Our future work will have a wider perspective.

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