

Accidents and Near-Misses in the History of a High-Risk Chemical Installation: Analysis of the Human Component

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In European industrial plants at risk of major accidents, which are subject to Directive 2012/18/EU (Seveso III), the occurrence of an accident can have devastating effects on both plant and surrounding environment. However, high impact accidents are rare and difficult to predict, so they cannot be adopted as primary or univocal indicators of the effectiveness of a company safety program nor of its general level of safety.

The present work analyses the succession of near-misses and minor accidents that occurred over the years in a polyurethane systems production plant of a high-risk chemical company, starting from the analysis of its historical accident database and paying particular attention to the specific role played by the human component in the occurrence of undesired events, potentially leading to malfunctions, anomalies and accidents.

The study aims to provide useful instruments for identifying and classifying events – and in particular related incorrect human behaviors - which can be considered precursors of major accidents in such critical and complex industrial plants. At the same time, it is thought as an occasion to contribute to the ongoing behavioral interventions in the analysed industrial site.

1. Introduction

Industries with major accident hazards, as chemical and nuclear plants, are potentially very prone to serious accidents since they deal with significant amounts of hazardous materials, to be used at high temperatures and/or high pressures. Problems can derive from a combination of different factors (human, organizational, technical ones) due to the high level of complexity of such systems (Mackenzie and Holmstrom, 2009). They can also bring to “atypical scenarios”, that is, unexpected situations that cannot be treated through a conventional hazard identification procedure (Paltrinieri et al., 2011).

High impact accidents are generally rare and it can be therefore convenient to highlight low-impact events or quasi-accidental events (the so-called near-misses), as well as unexpected circumstances or human behaviors. They could represent possible precursors of catastrophic events throughout the working lifetime of the plant (Paté-Cornell, 2012). Near-misses can be thought in fact as unintended events not resulting in significant injuries but eventually producing injuries, property damages or loss of process in slightly different circumstances.

International literature reports various proposals of early indicators of risk, as the abnormal event frequency (AEF), which is defined as the number of abnormal events in a time interval (Lv et al., 2014). Previous researches have also shown that correct precursor-based methodologies and frameworks, as Bayesian approaches, can help to carry out reliable estimations of rare events frequency (Yang et al., 2013). Moreover, Bayesian inference models appear as good instruments to realize risk assessment with a dynamical methodology (Folch-Calvo et al., 2019), as generally required in such complex industrial systems (Di Nardo et al., 2020). Causal Loop Diagrams can be also added in order to dynamically model the relationships between causal factors influencing near-misses in complex systems (Bugalia et al., 2021).

The specific industrial sector of chemical plants has always been object of deep investigations, since it represents a widespread and well-known complex high-risk working context. Vairo et al. (2019) applied Bayesian belief networks on a petrochemical coastal storage as an example of industrial site with major accidents hazard. Similarly, Chen et al. (2020) outlined a new method based on Bayesian theory for a chemical process of styrene, with a particular attention paid to near-misses. Some authors proposed a self-learning method ("DyPASI") to manipulate early warning data, that is, near-misses, past accidents and inherent studies: they have to be systematically reviewed (Paltrinieri et al., 2011) in order to preview possible critical scenarios. Safety can be guaranteed only if precursor signals are promptly followed by appropriate reactions, with a resilient approach. Some authors observed, a few years ago, that the same promptness of reaction is somehow required to healthcare facilities all over the world in the event of an epidemic or pandemic (Paté-Cornell, 2012). It is clear how this concept is still current today, in light of the Covid-19 worldwide diffusion and its recurrent peak waves. Historical accident data collection and analysis represent the basis for being able to anticipate and prevent major disasters, thanks to the dependency between precursors and undesired events. Such approach is valid in process plants but also in other categories of high-risk working contexts, as constructions, where historical data can be supported by additional information coming from prior knowledge of selected experts (Jin et al., 2020). Some studies tried to identify which categories could be used in order to classify and analyse such basic data. Fabiano and Currò (2012) tried to identify factors related to plant/process (e.g. failure to equipment), environment (e.g. natural event) and organization (e.g. maintenance or worker error) through a review of the story of oil industry. They also distinguished between types and severity of accidents and near-misses and tried to schematize causes, as well as consequences, of each event. The final goal was the identification of trends related to possible occurrence of unwanted catastrophic events.

The Human Factors Analysis and Classification System (HFACS) taxonomy (Shappell and Wiegmann, 2003) has been recently used by Baldissone et al. (2019), in the manufacturing field: it represents an useful instrument to classify unsafe acts (related to human behaviour), preconditions for the unsafe acts (related to working conditions and organisation), unsafe supervision and organizational influences.

In recent years, deep historical data analyses have been used also in the field of constructions (Raviv et al., 2017), where unexpected events were classified through a rising scale from near-misses to fatalities.

The scientific community has gradually proposed and refined the approach consisting in deeply analysing the historical sequence of accidents and potentially dangerous events. It can be potentially applied to many process plants with risk of high-impact low-probability disasters, but also to manufacturing, constructions (characterized by a huge quantity of low-impact undesired events) and health care services.

Near-misses management systems are emerging and they represent, together with inspections and online monitoring, one of the actual pillars of the so-called "Observability-in-Depth" (Gnoni and Saleh, 2017). It consists in the ability to observe emerging hazardous conditions and latent failures before they produce direct effects on the system's behaviour, in order to carry out a dynamical prioritization and a correct allocation of resources for targeted safety interventions. Researchers also started to investigate the importance of leadership and company top management: possible deficiencies in company safety culture and Health, Safety and Environment (HSE) management system could have an impact on insidious near-misses and low-impact accidents (Fabiano and Currò, 2012). Even behavioral interventions are often applied in order to improve safety and can be targeted on the identified human shortcomings, as recently proposed in literature for complex systems (Carra et al., 2020). The present work analyses the succession of near-misses and minor accidents that occurred in a polyurethane systems production plant of an Italian high-risk chemical company, namely Dow Italia s.r.l., in the period 1986-2020. The analysis is based on technical documents and reports, as extracted from the company accidents database in the form of operative experience sheets for Seveso audits.

Technological, organizational and - especially - human factors, involved in accidents or quasi-accidents, are identified and reworked through a general spreadsheet, also in the wake of the HFACS methodology. Interdependences and possible common analysis criteria are proposed.

The present study aims to carry out a decades-long analysis of historical accidents data in a real case of a chemical plant. With respect to previous international research works, attention is concentrated on the human component, whose role in the chain connecting near-misses, low-impact accidents and eventual catastrophic events will be represented through graphs and detailed in tables, before being finally discussed.

2. Data collection and analysis

Two types of main chemical processes take place in Dow Italia production plant in Correggio:

1) process of simple mixing of polyols with various additives (catalysts, blowing agents, glycols, etc.) without the presence of any chemical reaction. This process takes place in special mixers equipped with agitators.

2) pre-polymerization process, which consists in the partial reaction of isocyanate with polyols and/or glycols. The product obtained is defined as a prepolymer. The prepolymerization process takes place in a mixer equipped with an agitator and a heating and cooling unit (the “reactor”), through the following phases:

- i. the addition of the amount of isocyanate necessary for the preparation of the prepolymer into the reactor;
- ii. eventual addition of benzoyl chloride, in order to improve the stability of the final product over time;
- iii. the addition of polyols and/or glycols in the required quantity to the reactor, to react with the isocyanate;
- iv. when the reaction is over, product discharge into drums, intermediate bulk containers (IBC) or trucks, according to customer's request.

Both processes are controlled by process controllers and a supervision system for field monitoring. They are supported by the necessary processes of plant cleaning and materials storage.

The present work analyses 21 unwanted events (near-misses and minor accidents) that touched the plant along the years, by taking data from the company database, in particular from operative sheets for Seveso audits and internal reports. Minor accidents do not produce severe injuries or severe material damages, nor catastrophic consequences on the surrounding environment. Near-misses can turn into accidents only if compounded with additional adverse conditions. Only one event also involved the surrounding environment (a nearby company), but with very light consequences for people, so it was included in the analysis as a minor accident as well.

2.1 Analysis criteria and methodology

The selected events were inserted into a general spreadsheet, in which each of them has been analyzed by referring to specific attributes, in the wake of the creation of a “feature vector” as proposed by Raviv et al. (2017), as detailed in Table 1.

Table 1: Attributes for classification of unwanted events

Attribute	Description
Event severity	Severity type according to the outcome of the event (damages on property or equipment, losses of dangerous products, injuries, effects on the surrounding environment)
Year	Year of event occurrence
Brief event description	Short title used to quickly identify and understand the event
Critical anomaly triggering the event	The anomaly that firstly appeared, giving rise to a possible chain of events up to the accident
Classification of the critical anomaly	Distractions and oversights of the operator, e.g. in tightening (operational error); Wrong assessments by the operator (decisional error); Wrong system/plant settings; Wear, losses, deficiencies in maintenance and testing; Installation errors; Technical design deficiencies
First-order consequences	Events resulting in a chain from the initial anomaly
Second-order consequences	Other events eventually resulting in a chain from first-order consequences
Damage to people, injuries	Eventual physical consequences on people (injuries)
Human component contributing to the unwanted event	Behaviors of workers that can be considered the cause (or one of the causes) of the unwanted event
Technological component contributing to the unwanted event	Characteristics of the plant or of the work environment that can be considered the cause (or one of the causes) of the unwanted event
Organizational component contributing to the unwanted event	Organizational procedures and regulations that can be considered the cause (or one of the causes) of the unwanted event
Accident prevention interventions (organizational aspects)	Recovering and prevention actions based on organization of work and processes (e.g. workers' training, control procedures).
Accident prevention interventions (technical aspects)	Recovering and prevention actions based on improved technical systems (e.g. selection of more suitable equipment, changes in process)
Interventions aimed at managing the event in case of recurrence	Solutions to stem the negative effects of a major accident already in progress
Working phase	Process phase involving the unexpected event

Human components and organizational components contributing to each unwanted event can be thought as connected. In the four levels of HFACS, individual factors (violations or errors, e.g. decision errors, skill-based errors, perceptual errors), environmental factors (preconditions for unsafe acts, e.g. adverse physiological

states), supervision factors and organizational factors (e.g. organizational climate, resources management) are related. Organizational interventions for accident prevention are thought of as applicable to both human and organizational issues, by acting at different levels of the hierarchical structure.

The main accident causes in the plant, also including technological aspects, have been firstly identified. The possible interconnections between human and organizational factors have been further investigated through an analysis of each unwanted event. Results are reported in the following subsections.

2.2 Analysis results

Almost 42.8% of the events presents damage on property/equipment or losses of dangerous products, but without workers' injuries, while 42.9% shows a just potentially dangerous situation. The remaining 14.3% of the events has produced (minor) injuries in workers.

Based on the identified criteria for classifying unwanted events (Table 1), it has been found out that accidents and near-misses were mainly triggered by workers distractions and oversights, technical design deficiencies and losses related to maintenance problems, as shown in Figure 1.

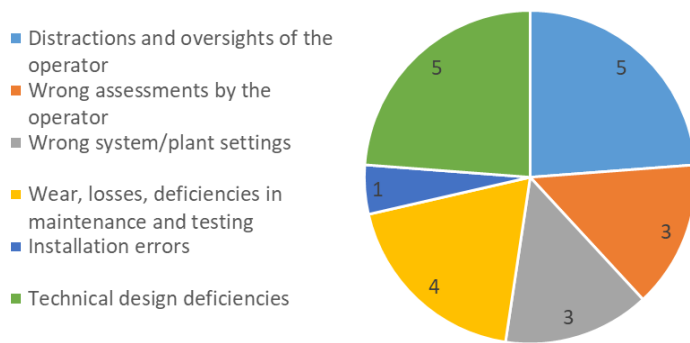


Figure 1: Number of identified unwanted events for each typology of triggering critical anomaly

Each one of such initial anomalies has produced consequents events in a chain and turned out to be correlated to different concomitant aspects (technical, human and organizational ones). More specifically, in relation to the human factor alone, Table 2 reports the main emerged issues of the human component (related to the behaviour of front-line operators) and of the organizational component (related to behaviours at higher levels of the hierarchical scale) in accidents. Some of such issues are in common between the two categories, even if declined in a different way.

Table 2: Issues in human and organizational components

Issues	Human component (front-line operators)	Organizational component (higher levels of the company hierarchy)
Communication errors	between workers (different contractors)	along the hierarchical scale
Individual errors	forgetting open valves, insufficient tightening; poor accuracy in work; wrong assessments; overconfidence with processes	
Incorrect confirmations of previous interventions or checks	error in confirming interventions (even made by other workers) that never really took place	failure to organize direct and visual additional checks on compliance with the checklists
Deficiencies in maintenance organization		underestimation of importance of maintenance of some components
Information about procedures	failure to comply with procedures due to lack of information	insufficiently detailed procedures and checklists

Starting from such classifications, for each event a different score was given to human, organizational and technological components respectively. It was calculated, for each component, by summing the number of aspects presumably contributing to causing the event and the number of consequently applied accident prevention interventions, as extracted from company reports. Results are shown in Figure 2, where the year of occurrence of each event is also specified. Organizational factors seem to have a more evident impact on recent

events, with respect to front-line workers' errors. Technological components have maintained an important role over time, especially in the last decade.

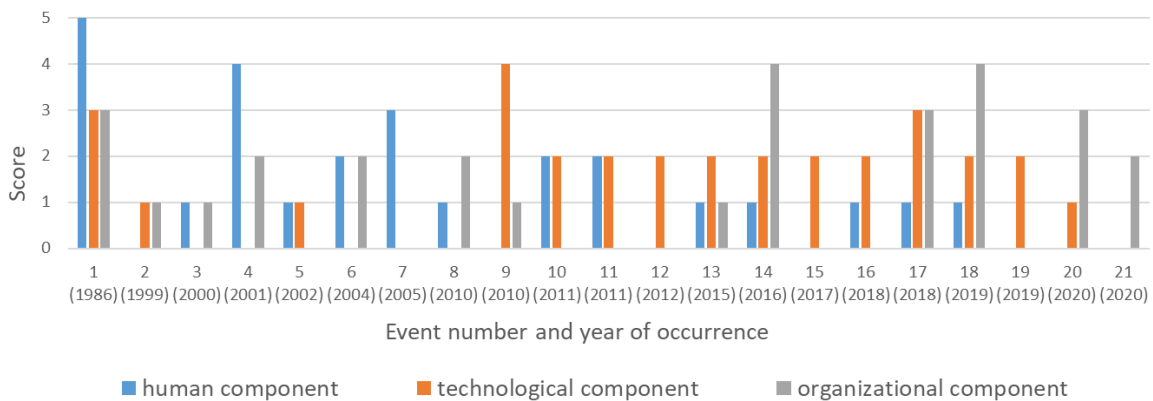


Figure 2: Score attributed to each unwanted event for human, organizational and technological components

3. Results interpretation and discussion

Based on the aforementioned criteria for classifying unwanted events through specific attributes, it has been observed that distractions and oversights of operators and technical design deficiencies have the most important role in producing triggering anomalies in the plant (24% each). They are immediately followed by wear and material leaks (related to maintenance and periodic inspections) at 19%. Wrong assessment by operators and wrong settings of plant parameters follow at 14% each, while installation errors just cover 5% of cases.

When trying to group such attributes into wider categories, it is not easy to understand how many unwanted events are related to human factors (individual workers' behaviors at front-line level) or to organizational factors (human behavior at managerial level). Every anomalous triggering event produces multiple consequences and it is related to both them inside a complex chain. Organizational aspects include actions carried out by managerial roles in the corporate hierarchy (e.g. supervisors, production managers), who represent another "human factor". Even some technical aspects, e.g. plant settings, are influenced by human decisions at different levels. Moreover, middle and higher management can operate in order to increase the global corporate safety culture, whose development is a necessary condition to reach good effectiveness of behavioural interventions in complex systems (Carra et al., 2020), which have been applied since many years even in the studied plant.

This partial overlap between human and organizational factors has been confirmed by results shown in Table 2: many lacks in workers' behavior correspond directly to lacks in company procedures. Typically, for example, workers' errors are due to a too poor knowledge, so the necessity of improving training and information activity arises immediately. Other organizational interventions, at higher level, can include the introduction of new control procedures, more frequent inspections and more detailed checklists. They coexist with technological interventions, consisting in adoption of new mechanical solutions, substitution of obsolete equipment and updating of control systems.

Organizational factors had a role in most analyzed events, as shown by Figure 2, and they seem to have acquired more importance in most recent years, with respect to individual operators' behaviors. The increasing complexity of 4.0 industrial systems has probably highlighted the importance of decisions taken at higher level, since they allow to create the right connections between behaviors and technologies.

A limit of the present study is the absence of a characterization of the stochastic occurrences of precursor events over time. This is mainly due to the limited number of analysed events; it could be overcome, for example, by the addition of similar events occurred in other plants of the same company.

4. Conclusions

Near-misses and minor accidents which occurred in a polyurethane systems production plant have been retraced historically. They have been classified through a defined set of attributes, with the purpose of finding out common features and recurring factors leading to possible precursor events of catastrophic accidents.

In almost 86% of cases, no worker was injured and only in half of them accidents really produced damage on property or equipment or losses of dangerous products. Distractions and oversights of operators, technical

design deficiencies and maintenance problems represent the more common primary causes of anomalies in the plant.

Human, organizational and technical factors appeared to have a significant impact on such events. This means that they all have to be taken into account when trying to identify risk factors for more catastrophic events. The data analysis has shown that organizational factors at managerial level seem to have acquired a more and more important role over the years with respect to individual errors. Technological drawbacks keep giving a quite constant contribution. It has been observed that human factors are strictly related to organizational ones, which can produce, if well managed all along the hierarchical scale, solutions to compensate human errors and to support technological troubleshooting.

Future work could include the addition of new data coming from opinions of plant workers, managers and Seveso inspectors, as well as data directly coming from observations in current behavioural interventions. A deeper analysis of human and not-human factors influencing the occurrences of precursor events could also represent a possible first step for the creation of a dynamical complex safety model of the plant.

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