Learning from creeping changes

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Creeping changes are the accumulation of minor changes which often are ignored or accepted as the new norm, but which over time can add up to a big change and ultimately lead to a major incident. For example, the well-known phenomenon, "normalization of deviance" fits into this category too. It means "that people within the organization become so much accustomed to a deviant behaviour that they don't consider it as deviant, despite the fact that they far exceed their own rules for the elementary safety". Past tragic events such as the fatal explosion and crash of Nimrod XV230, Space Shuttle Challenger or Columbia disasters, SHELL Moerdijk explosion, Herald of Free Enterprise, Kings Cross fire, and Texas City refinery explosion occurred in entirely different areas or industry sectors. There is, however, an aspect which is common in these cases, namely creeping changes. The theory behind creeping changes is that no industrial sites are static, there are changes made to the original design or there are changes due to ageing and degradation of equipment over time, together with organizational changes that can affect plant integrity. The IChemE Safety Centre has recently addressed this topic, presenting a case study in its quarterly publication, the Safety Lore. They also provided practical tips to managers, process safety engineers, supervisors, and operators of industrial sites to learn how such major incidents involving creeping changes can be avoided. This paper demonstrates the phenomenon of creeping changes via two case studies from two different sectors. In addition, it suggests lead metrics associated with these events to help monitor the changes applying the ISC process safety lead metrics guidance document. Finally, it provides ideas to managers, supervisors, process engineers, and operators of how to address those changes in their work.

Keywords: creeping changes, major incidents, lead process safety metrics

Introduction

Creeping changes are the accumulation of minor changes which often are ignored or accepted as the new norm, but which over time can add up to a big change and ultimately lead to a major incident (Goff, 2017). For example, the well-known phenomenon, "normalization of deviance" fits into this category too. It means "that people within the organization become so much accustomed to a deviant behaviour that they don't consider it as deviant, despite the fact that they far exceed their own rules for the elementary safety" (Vaughan, 2008). Past events, such as fatal explosion and crash of Nimrod XV230 (Cave, 2009), Space Shuttle Challenger and Columbia disasters, SHELL Moerdijk explosion (Dutch Safety Board, 2015; Leveson, 2017), Herald of Free Enterprise or Kings Cross fire (Fennel, 1998) suggest that creeping changes occur with a disturbing frequency. The theory behind creeping changes is that that no industrial sites are static, there are changes made to the original design or there are changes due to ageing and degradation of equipment over time, together with organizational changes that can affect plant integrity. Creeping change was noticed as an issue at the UK Health and Safety Executive's Key Programme 4 (HSE, 2014) on ageing and life extension in the offshore oil and gas industry. The Energy Institute also published its report on creeping changes and a modified hazard identification method called CCHAZID to support better understanding how these creeping changes can be recognized during the hazard identification phase.

The IChemE Safety Centre has recently analysed creeping changes through a case study in its quarterly publication, the Safety Lore. It also provided practical tips to managers, process safety engineers, supervisors and operators of industrial sites to learn how such major incidents involving creeping changes can be avoided. This paper presents two cases to identify aspects of creeping changes. Then it discusses leading metrics that could be associated with the events to monitor subtle changes, applying the ISC process safety lead metrics guidance document (ISC, 2015).

1. Case studies

A possible method to track creeping changes is presenting the phenomenon through the story of past events. Those cases demonstrate how subtle changes to the system can contribute to accidents. It is then possible to drive the conclusions how these changes can be managed in the future. Creeping changes are difficult to capture based on their nature of being hidden and small modifications at a time. One should not forget, that all industrial sites, the organization itself and the environment constantly change, nothing remains static. Therefore, it is inevitable that any modification to the system, the original design, procedures and roles within the organization can lead to accumulation of creeping changes over time. The following two case studies may provide some further thoughts of what creeping changes are and how they can be captured. The first case is the tragedy of the Herald of Free Enterprise from 1987 and the second one is the industrial incident occurred in an oil refinery in 2000.

1.1 Case 1 – The Herald of Free Enterprise

The tragic event of the Roll on-Roll off (Ro-Ro) ferry, the Herald of Free Enterprise took the lives of 193 when it sank off the port of Zeebrugge, Belgium on 6 March in 1987. Most part of what happened was described in Kletz's book (Kletz, 2001) and the investigation report was written by the Department of Transport (Department of Transport,1987). The ferry was leaving the harbour of Zeebrugge en route for Dover on 6 March in 1987 when water entered the hold and car decks via the open bow door. The Herald was manned by crew of 80 together with 459 passengers, 81 cars, 47 freight vehicles and three other vehicles. She passed the mole at 18.24 and capsized approximately four minutes later. Even though the ferry did not sink entirely, as it was in shallow water above a sandbank, there was not enough time for passengers and crew to escape which contributed to the large loss of life.

Creeping changes associated with the case

The bow door, which was left open on the Herald, was used for loading vehicles. The ferry did not have bulkheads within the car decks; therefore, it was easier to load more vehicles faster. It was a normal practice on Ro-Ro ferries. However, it meant that when water entered the ship it then moved to one side of the deck and the ship became unstable. Even though the Parliament passed an act requiring iron ships of over 100 tons to have divided hulls, the shipping lobby got it repealed. Most ships had divided hulls, but Ro-Ro ferries tended not to because of the difficulties of loading their cargo and the desire to maximise loads. This is a change which fundamentally seems like nothing was changed since the bulkheads remained non-applicable on these ferries. However, it also means that these ships followed a practice which eventually altered from the new regulations; lobbying for and then applying their own old rules.

The Assistant Bosun, whose job was to close the bow doors as the ship left harbour, had fallen asleep on his bunk and missed the loudspeaker warnings about to departure. The Bosun was on the main deck but he did not consider it his duty to close the doors or to ensure that there was someone to do it. The Captain assumed that everything went well and proceeded to set sail. Leaving the port without making sure of the status of the bow door was a bad practice which was repeated from time to time. That highlights the aspect of normalisation of deviance.

The first ferries had had so-called visor doors that lifted so that the Captain could see from the bridge the status of the doors (open/closed). The door design had been changed to a clam type and the doors were not visible from the bridge anymore. This change never went through a management of change process and therefore, risks associated with the new design were never revealed.

The investigation report found, that on several previous occasion's ships had left harbour with their doors open and several captains had asked for indicator lights to be installed but their requests had been ignored. That aspect shows normalization of deviance up to a certain extent, because captains knew they would leave the port again with open doors. The fact, that they had informed the management about the problem may have given the impression that the issue would be or was solved; thus, the unsafe behaviour was sustained.

The holding company had only owned the company for a few months before the accident. It is qualified as organizational change, one form of creeping change.

Three crews and five sets of officers were employed in manning the Herald. Consequently, the officers did not always have the same crew. There was a lack of consistency in the duties of each set of officers and of the members of each crew. This aspect can be considered as creeping change due to the lack of consistency, a subtle variation of modus operandi which eventually contributed to the accident.

1.2 Case 2 – Oil refinery fire

The Fluidised Catalytic Cracker Unit (FCCU) was shut down on the 29th May 2000 following the power distribution failure and was being restarted after an 11-day shutdown. On 10th June 2000 during start-up a significant leak of hydrocarbons was discovered, creating a vapour cloud which ignited resulting in a serious fire. Workers escaped before the blast, nobody got injured in the incident (HSE, 2000).

Creeping changes associated with the case

The leak was as a result of failure of a tee-piece connection at the base of the debutaniser column which found a source of ignition nearby. The tee-piece connection which had originally been installed in the 1950's was correctly specified but incorrectly fitted, and then hidden by lagging. There was no subsequent amendment to the plant layout drawings to identify that change.

Since the 1950's, sections of the FCCU had been significantly modified. Prior to the modifications in 1986, changes had been made to the pipework at the base of the column and a valve had been removed. This resulted in there being inadequate support for the remaining pipework and the tee-piece connection. Between 1996 and 1998 the FCCU had been experiencing considerable difficulties and did not operate consistently. This resulted in an increase in the number of start-up/shutdown cycles for the plant and pipework.

An incident occurred in 1999 during a prolonged start-up on the FCCU. It resulted in an ignition of a torch oil vapour cloud. Contrary to plant operating instructions in the master operating manual, the torch oil had been admitted to the regenerator when the unit was at too low a temperature. The plant had solid procedures in place, yet, the operating procedure was ignored by the staff. As a result, ignition of the torch oil did not occur in the regenerator. Although ignition had not been verified, a considerable further quantity of torch oil was injected, and it is believed that hot spots in the slumped catalyst bed vaporised the torch oil. The provision of a temperature interlock had previously been considered and discounted, as it was decided that operating procedures alone provided enough control. This decision shows alteration from the original design that would have been required but then was excluded. The change was made based on assumption instead of risk assessment.

In the 11 weeks preceding the incident in 2000, 19 start-up attempts had been made and only 7 were successful. Failure of the tee-piece connection pipework was probably caused by a combination of the incorrectly fitted tee-piece connection, the inadequately supported pipework and the cyclic stresses/vibration caused by the increased number of start-up/shutdown activities on the plant. Eventually they led to fatigue failure of the pipework in the vicinity of the welded connection. These are the subtle changes that had been gone unnoticed for a long time before they were discovered.

The safety report failed to reflect the reality of the condition of the FCCU. The 1997/98 revision concluded that "hardware and software controls in place on the FCCU are adequate to prevent the occurrence of a major accident". Incidents with vibration of the transfer line had occurred over the two years prior to the explosion. These events were not reported or investigated which resulted in changes went unnoticed.

On the 25th May a cable-laying operative from the cable-laying contractor hired by the company observed a damaged tile and cable in preparation for laying a cable. However, he did not report the damaged cable in the belief that it was dead, and it had already been reported. When such a failure is not reported to the management, it is a missed opportunity to identify a creeping change that could lead to a catastrophic event.

2. Leading metrics identified with the case studies

The IChemE Safety Centre has published a guidance document on process safety lead metrics in 2015. In the guidance document the Centre states that "Tracking process safety metrics is vital, to help us understand the state of our facilities and systems, as well as providing us with an indication of impending issues. Importantly, while lagging process safety metrics will inform you of history, which can be used to monitor improvement, they will not necessarily predict future loss-of-control events. While leading metrics are proactive and provide the opportunity to manage developments, they are also not predictive of the future". The layout of the guidance was developed along the lines of the ISC functional elements of process safety (ISC, 2014). The six functional elements, with leadership across all of them are as the followings:

- knowledge and competence,
- engineering and design,
- systems and procedures,
- assurance,
- human factors, and
- culture.

In total, 21 lead process safety metrics were identified in the guidance document around the six functional elements, as it is shown in Table 1.

Elements	Metrics
Knowledge and competence	Conformance with Process Safety related role competency requirement
Engineering and design	Deviations to safety critical elements (SCE) Short term deviation to SCE Open management of change on SCEs Demand on SCE Barriers failing on demand
Systems and procedures	SCE Inspections Performed Versus Planned Barriers fail on test Damage to primary containment detected on test/inspection SCE maintenance deferrals (approved corrective maintenance deferrals following risk assessment) Temporary operating procedures (TOPs) open Permit to work checks performed to plan Permit to work non-conformance Number of process safety related emergency response drills to plan
Assurance	Number of process safety related audits to plan Number of non-conformances found in process safety audits
Human factors	Compliance with critical procedures by observation Critical alarms per operator hour (EEMUA, 1999) Standing alarms (EEMUA, 1999)
Culture	Open process safety items Number of process safety interactions that occur

Table 1 — Lead process safety metrics (ISC, 2015)

2.1 Lead process safety metrics identified related to Case 1

Relating to the case of the Herald of Free Enterprise, a strong lead metric would be the Conformance with Process Safety related role competency requirements. This metric measures the overall capability of personnel to consistently manage and implement work activities in accordance with company requirements and expectations (including behaviours). In this case, personnel were overworked; the investigation revealed that the officers were required to work 12 hours on and not less than 24 hours off. In contrast, each crew was on board for 24 hours and then had 48 hours ashore. Also, they simply could not implement work activities in accordance with company requirements because the company lacked such expectations, procedures.

An additional metric associated with the case is linked to safety culture. For example, during the interviews after the accident, the Bosun stated it was not his duty to check if the doors were open or closed. Another problem the investigation discussed was the fact that the management ignored the advice of their experts on different problems with the ferries. There were numerous events when onshore management did not listen to the advice of their well-qualified ships' masters. These included requests for bigger ballast pumps, fewer passengers, and complaints that draught marks were hard to read in addition to the requests for indicator lights.

Barriers failing on demand is a metric that could be identified in this case. A high number of failures upon demand would indicate either an engineering design issue or the need for improvement in the effectiveness of the inspection and maintenance of the barrier or determine if the demand frequency matches the design of the protection loop. The lack of divided hulls is a significant barrier failure which could have prevented the ship to become unstable and move to one side of the deck and finally overturn.

Safety critical elements inspections performed versus planned. The metric identifies the level to which SCEs are not being inspected or tested within the required inspection period. The metric will indicate problems related to planning, resourcing requirements or culture relating to the acceptability to allow SCEs to remain in service after required inspection periods have lapsed.

Albeit indirectly, Open Management of Change on safety critical elements is a metric can be identified in this case. The change in the design of the visor doors would have required an MoC process. When a new hazard is identified as part of an incident and requires an instrumented system to be installed. The same metric could be applied considering the several occasion's ships had left harbour with their doors open and several captains had asked for indicator lights to be installed.

The metric of compliance with safety critical procedures by observation is a critical indicator in this case. It tracks compliance with safety critical procedures at all levels of the organisation, those related to the processing facility safety critical elements and tasks where failure to follow the procedure correctly could lead to a process safety incident. Apparently, the Herald of Free Enterprise lacked operating procedures. The situation got worse with officers not having the same crew which resulted in the lack of uniformity in the duties of each set of officers and of the members of each crew.

In terms of assurance, there were no audits had been carried out, which could have highlighted the lack of hazard analysis, missing procedures and other non-conformances in the operation of the ferry, such as carrying of excessive numbers of passengers; occasionally even 10-20% more than the limit.

2.2 Lead process safety metrics associated with Case 2

In this incident, lead process safety metrics are simpler to identify compared to the case of non-process safety incidents, such as the Herald of Free Enterprise. However, many of the past events show that there is still a lack of proper implementation and understanding of what lead metrics are and how to monitor them. This session of the paper shows examples of process safety lead metrics that could have been in place in this oil refinery.

The tee-piece connection played a significant role as safety critical element, therefore the metrics in connection with safety critical elements (SCE's) should be identified, especially relating to the ISC functional element "Engineering and design". For example, the increased number of start-up/shutdown cycles for the plant and pipework could be monitored by implementing the metric Demand on SCE's. It monitors the frequency when safety systems are called to function. The increased number of start-ups and shutdowns would have been tracked applying this metric.

The metric "Compliance with safety critical (SC) procedures by observation" could have revealed whether critical procedures, such as start-up procedures, are correctly followed. In this case, an incident occurred in 1999 during a prolonged start-up on the FCCU. It resulted in an ignition of a torch oil vapour cloud. Contrary to plant operating instructions, the torch oil had been admitted to the regenerator when the unit was at too low a temperature.

Open management of change on SCE's can be identified relating to the modification of the plant, particularly the removal of a valve on the pipework, at the base of the column which supported the pipework and the tee-piece connection.

Incidents with vibration of the transfer line had occurred over the two years prior to the explosion. These events were not reported or investigated which resulted in changes went unnoticed. Also, the company reviewed the FCCU to find out why it did not operate properly but the findings were never implemented or communicated properly. These are aspects that illustrate the absence of lead metrics monitoring culture.

Open process safety items metric measures for example internal audits, internal or external incident investigations and regulatory compliance actions.

The safety report failed to reflect the reality of the condition of the FCCU. The 1997/98 revision concluded that "hardware and software controls in place on the FCCU are adequate to prevent the occurrence of a major accident". The metric called "Number of non-conformances found in process safety audits" could have provided further insights of this mishap. It could have been a valuable indicator both to the company and the competent authority. This metric provides assurance to the board and the senior management that process safety systems are implemented and effective in the plant. The purpose of having process safety auditing as a safety metric is to provide assurance of the quality of activities associated with other process safety lead metrics.

3. What can you do?

In addition to the lead metrics recommended along with the case studies, the following tips to managers, supervisors and operators could be listed to tackle creeping changes more effectively. Tables 2-4 are the extract from the ISC Safety Lore (ISC, 2019) and they show the list of the responsibilities for managers, supervisors and process engineers and operators.

3.1 What can managers do about creeping changes?

Management
Be aware that changes in management or ownership can have large consequential hazards, therefore make sure that organisational changes go through a Management of Change (MoC) procedure.
Incidents often occur after some change in the system. Make sure that changes as a result of adoption of new or altered processes, loss of skills and new knowledge brought into the operation are addressed in the MoC process.
Ensure that audits address changing behaviour to check that the process is carried out as designed.
Every system and its environment change over time. Make sure to apply strategies to adapt to changing environment, changing in the safety management system.
Have the safety case or safety report kept as a living document that needs constant review to follow up the changes might occur over the years.
There can be significant difference between the designed and the built system. If an incident scenario is not considered in the design phase but that scenario is possible, then it needs to be incorporated into the leading metrics programme.
Signs of change are difficult to detect, therefore consider implementing a system and structured process for identifying them, detecting how the process should operate and what the current status is.
Make sure that leading metrics are implemented in the risk management programme and responsibilities are assigned for checking the metrics and following them up in case problems are found.
Have an action plan in place to ensure that leading metrics exist and they indicate when and how they will be checked and have an action associated with them. Periodically review and update the list of leading metrics.
Make sure that near miss events are identified and investigated as they can be precursors of a major incident. Pay attention to cumulative causes that help to identify dramatic changes that may have been overlooked.
Ensure that change is detected and even small changes to the system are documented in the incident investigation reports instead of simply focusing on proximal events.
In case of an incident, check if leading metrics are in place and why they failed to identify the problem to prevent the incident, or, if they did, why effective action was not taken.
Make sure that cost cuts do not impact safety and they do not threaten plant integrity.
Make sure that process knowledge is maintained and transferred.
Make sure you record trending of the leading metrics, ensure that the process functions as it is intended based on the original design.
Ensure that you document all changes, particularly safety critical ones and near misses immediately and these records are incorporated in the plant operating procedures.
Starting up a process unit results in significant changes (operating temperature, pressure) on the pipework and vessels as they are brought up to the required operating conditions from ambient. Be aware that increasing the frequency of start-ups results in fluctuations in conditions and increased cyclic stresses on mechanical systems.
Pay attention to the signs of normalisation of deviance where operators might alter from the original procedures, to make sure that safe operation is in place.

Have up-to-date plant layout drawings and maps to follow up changes and keep record of the original design layouts.
Report and investigate all cases of violations, unauthorised changes and workarounds in the system.
Make sure that you follow the operating, maintenance and emergency procedures and do not deviate from them.
Report any damage or irregular event immediately to the supervisor.
If the procedures cannot be followed, report the situation to your supervisor for investigation and resolution.

Table 2 — Responsibilities of managers

3.2 What supervisors and process safety engineers can do to manage creeping changes?

Process Engineer/Supervisor
Make sure you record trending of the leading metrics, ensure that the process functions as it is intended based on the original design.
Ensure that you document all changes, particularly safety critical ones and near misses immediately and these records are incorporated in the plant operating procedures.
Starting up a process unit results in significant changes (operating temperature, pressure) on the pipework and vessels as they are brought up to the required operating conditions from ambient. Be aware that increasing the frequency of start-ups results in fluctuations in conditions and increased cyclic stresses on mechanical systems.
Pay attention to the signs of normalisation of deviance where operators might alter from the original procedures, to make sure that safe operation is in place.
Have up-to-date plant layout drawings and maps to follow up changes and keep record of the original design layouts.
Report and investigate all cases of violations, unauthorised changes and workarounds in the system.
Make sure that you follow the operating, maintenance and emergency procedures and do not deviate from them.
Report any damage or irregular event immediately to the supervisor.
If the procedures cannot be followed, report the situation to your supervisor for investigation and resolution.

Table 3 — Responsibilities of supervisors and process engineers

3.3 What operators can do to manage creeping changes?

Operator
Make sure that you follow the operating, maintenance and emergency procedures and do not deviate from them.
Report any damage or irregular event immediately to the supervisor.
If the procedures cannot be followed, report the situation to your supervisor for investigation and resolution.

Table 4 — Responsibilities of operators

4. Conclusions

The cases presented in the paper show how even subtle but gradual changes to the system can contribute to accidents. This paper demonstrates the phenomenon of creeping changes taking two case studies from entirely different sectors. In addition, it suggests a variety of lead metrics which could be associated with each event. Lead metrics are helpful tools for any organisations to monitor the process and the changes. If they are applied with appropriate knowledge and understanding of what we want to achieve and why, they can help to prevent tragic events. Every organisation can benefit from implementing lead metrics regardless the profile of the industry. To be able to capture creeping changes relevant to the job, and make relevant stakeholders aware of their own responsibility, the paper provides advices to managers, supervisors, process engineers and operators. Creeping changes are difficult to identify based on the nature of them being hidden and small, subtle modifications at a time. However, with the necessary care and vigorous monitoring of the system, these changes can be captured in time to prevent a major incident.

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