An Analysis of Common Causes of Major Losses in the Onshore Oil, Gas & Petrochemical Industries

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A review has been carried out of 100 major losses in the onshore oil, gas and petrochemical industries over the last 20 years. The purpose of this study is primarily to guide insurance risk engineers on which loss control areas to focus on during a typical risk engineering survey of onshore oil, gas and petrochemical facilities. This study supports the Lloyd's Market Association's key information guidelines for risk engineering survey reports[1] and the guidelines for the conduct of risk engineering surveys[2] and also builds upon previous studies.

The energy insurance industry is in a unique position in that it has experience and detailed knowledge of many industry losses, unlike many individual operators who may never experience a major loss. This study may therefore also be of interest to those working in the oil, gas and petrochemical industries who are looking for lessons learned opportunities to assist in their own risk management programmes. The analysis comprised a review of available loss information, primarily from insurance industry reports, as well as public domain sources.

Keywords: Loss analysis, insurance risk engineering, common causes of loss

METHODOLOGY

Scope

For this study 100 major onshore oil, gas and petrochemical losses over a 20 year period from 1996 to 2015 were analysed. Only 'man-made' fire and explosion losses were considered (natural catastrophe events were excluded). It should be noted that, since the focus of the study is on losses with significant monetary impact, some major events resulting in fatalities or injuries might not be included.

Although numerical data is provided and trends have been identified where possible, this should not be considered a detailed statistical analysis.

No attempt has been made to identify underlying or root causes since this information is usually not available to (Re)Insurers. Instead, the aim is to identify the most important risk control elements that can be most easily assessed by an insurance risk engineer during a typical 2-3 day risk engineering survey.

Loss Information

The Willis Energy Loss Database (WELD)[3] was used to identify onshore oil, gas and petrochemicals losses from 1996 to 2015 with a total loss value exceeding USD 50 million. This loss amount was the sum of the ground up property damage plus the associated business interruption costs, excess of the insurance waiting period and only where this cover was provided. Other costs were excluded e.g. environmental clean-up, civil fines, reputational damage, personal liabilities, etc.

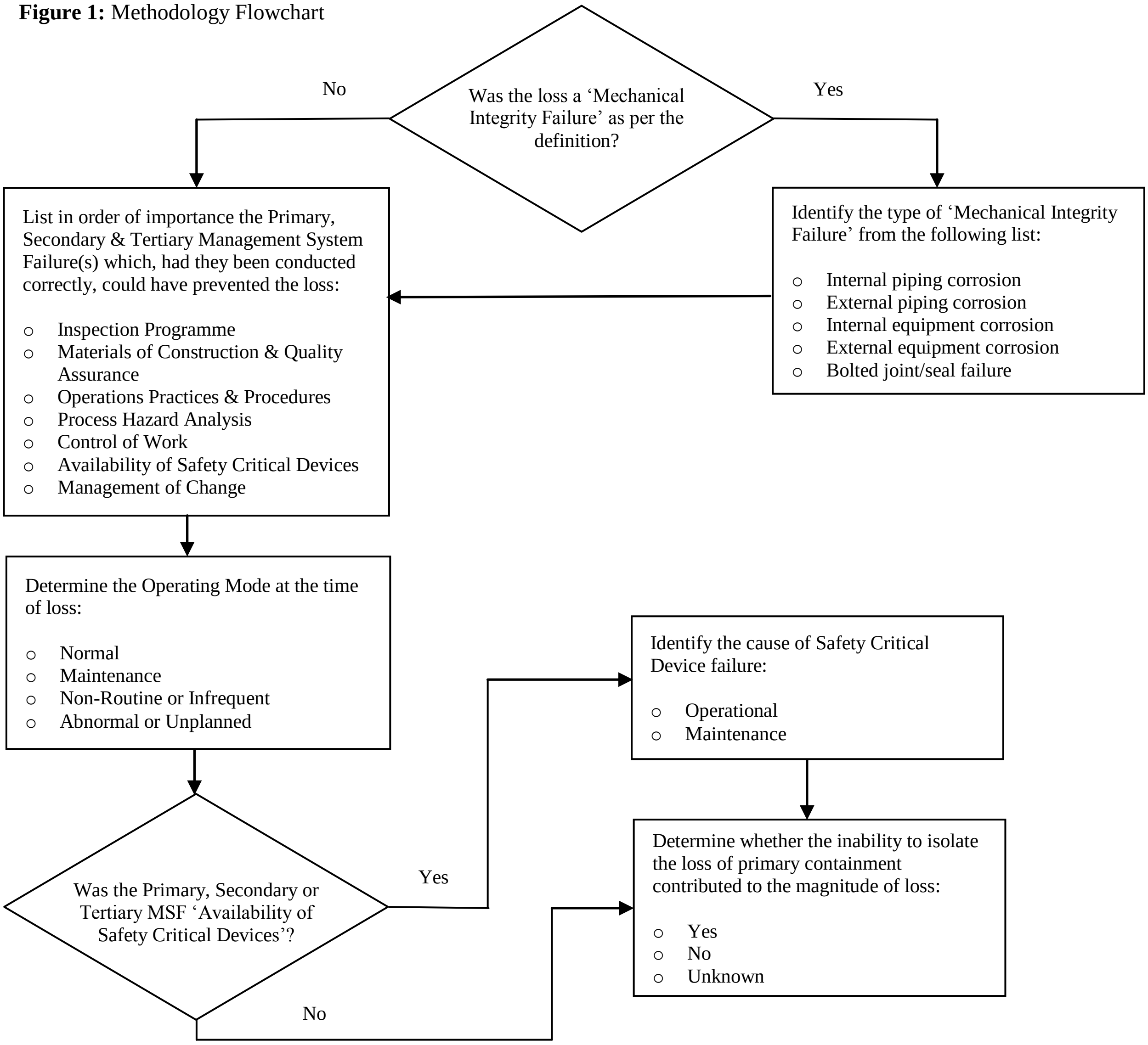
The losses within WELD are anonymous with only basic details provided and significant work was undertaken to ascertain the actual case in question in order to review the causes of loss. Individual loss amounts ranged from USD 50 to 1,500 million. In total 100 losses were identified for analysis, including all of the top 50 losses in WELD (by total loss value).

Information on the background and causes of these losses was obtained from available loss information, primarily from insurance industry reports, other insurance industry publications and data sources[4] as well as public domain sources. Losses were only included where there was sufficient information to determine causation to the level required by the analysis methodology.

Loss Analysis Methodology

A flowchart of the process is provided in **Figure 1**.

Figure 1: Methodology Flowchart



'Mechanical Integrity Failure' Losses

It was deemed important to separate out 'Mechanical Integrity Failure' losses as these were identified during a previous loss analysis as being responsible for a large proportion of the losses analysed[5] [6]. The losses were therefore initially filtered to distinguish between 'Mechanical Integrity Failure' losses and 'Non-Mechanical Integrity Failure' losses based on the following definition:

Mechanical Integrity Failure	Failure of the primary pressure-containing envelope due to a specified failure mechanism. This largely relates to corrosion through metal although it also includes any bolted joint or seal failures. This excludes failures induced by operation outside of safe operating limits.

The types of 'Mechanical Integrity Failure' were classified as follows:

- Piping internal corrosion
- Piping external corrosion
- Equipment internal corrosion
- Equipment external corrosion
- Bolted joint/seal failure

For the purpose of this document, corrosion is considered to include all damage mechanisms that lead to mechanical integrity failures of equipment and piping as more fully described in API RP 571[7]. Every loss, whether caused by 'Mechanical Integrity Failure' or not, was analysed using the methodology described in **Figure 1**.

Management System Failure Model

Major losses are considered to occur because of simultaneous failures of loss prevention and mitigation barriers, in line with the 'Swiss Cheese' accident model[8]. Rather than attempt to analyse all of the barrier failures associated with each particular loss analysed, those loss prevention barrier failures perceived to have made the most significant contribution to the loss, were identified. **Up to three** of these so called 'Management System Failures (MSFs)' were assigned to each loss in order of perceived contribution and termed Primary, Secondary and Tertiary MSFs.

Identifying the MSFs and their order of importance was based on engineering judgement supported by peer review. Identifying the order of MSFs due to 'Mechanical Integrity Failure' was generally straightforward as the MSFs were usually clear and limited in number.

The MSFs developed and their definitions are listed below.

Management System Failure (MSF)	Definition
Inspection Programme	Intended to cover all aspects of a static equipment and piping inspection programme including identification and risk assessment of damage mechanisms.
Materials of Construction & Quality Assurance	Intended to cover deficiencies in mechanical design, fabrication and installation of equipment during original construction or subsequent change e.g. during maintenance. This excludes deficient design specification (a process design issue) but does include equipment not installed to specification (a quality assurance/quality control issue). The following are examples: incorrect materials installed, installation not as per design specification, fabrication defect and mechanical installation fault. Note: Losses caused by the selection of materials unsuitable for the service was considered to be an intentional (design) decision and the MSFs for these losses were therefore classified as either Management of Change (MoC) or Process Hazard Analysis (PHA).
Operations Practices & Procedures	Intended to cover all aspects of operational management except Control of Work and management of Safety Critical Devices (see below). Examples include manning, shift communications, supervision, training, competence assurance, Standard Operating Procedures (SOPs), Emergency Operating Procedures (EOPs), response to alarms etc. In the case of SOPs and EOPs examples include: no procedure, incorrect or incomplete, incorrectly followed, document control.
Control of Work (CoW)	This is applied to any work activity which would ordinarily require a Permit to Work (PtW) and/or safe isolation procedure. The scope includes hazard identification and risk assessment, process preparation, work execution and return to operation. The work activity could be undertaken by maintenance or contractors during operational or shutdown periods (e.g. turnaround and grade change), or by operations (e.g. operators switching equipment using operational blinds).
Process Hazard Analysis (PHA)	Intended to cover items which should be addressed through the plant's PHA programme including process design weaknesses, inherent safety and learning from losses. PHA is taken to include Hazard & Operability (HAZOP) studies, Layers of Protection Analysis (LOPA) and Safety Integrity Level (SIL) assessment and any other hazard identification and risk assessment techniques. The PHA could be the original plant PHA at the time of construction and any subsequent PHA revalidations/reviews. Identification and analysis of Safety Critical Tasks and identification of Safety Critical Devices (SCDs) would fall under this category.
Management of Change (MoC)	This is applied whenever a failure in change management contributed to the loss with 'change' defined in the broadest sense including 'non-hardware-related' changes such as organisational and operational change. Change management is taken to include all aspects of MoC from initiation to close-out and specifically including the hazard identification and risk assessment of the change by whatever technique. The change could have occurred during the original construction, subsequent projects or operational plant changes.
Availability of Safety Critical Devices (SCDs)	This is applied whenever a SCD is unavailable or fails on demand during a loss scenario. The failure could be due to a lack of maintenance or the equipment had been consciously defeated (or bypassed). The definition of SCD is suitably broad and this category is also intended to capture non-SIL rated process-critical instrumentation which may or may not strictly meet the definition of a SCD (e.g. distillation column level instrument) but which played a significant contributory role in the loss.

In a significant number of the losses analysed, the absence of Remotely Operated Emergency Isolation Valves (ROEIVs) was cited as a factor which could have prevented escalation of the initiating event i.e. could have reduced the size of the loss. The presence (or absence) of ROEIVs has therefore also been considered in this analysis as a loss mitigation feature.

Operating Mode

The 'Operating Mode' at the time of loss was considered with one of the following descriptors assigned to each loss.

Operating Mode	Definition
Normal	Plant was running under steady state conditions and within normal operating limits.
Maintenance	A specific maintenance activity was ongoing with direct relevance to the loss. A maintenance activity is taken to be a job typically requiring a permit to work and would include the operational aspects of plant preparation and reinstatement. This includes turnaround maintenance activities and any plant modification work.
Non-Routine or Infrequent	Operations that are considered to be non-routine or planned operations that occur relatively infrequently. Examples would include plant or equipment start-up, planned plant or equipment shutdown, operation with a non-standard configuration, batch operations, equipment switching, storage tank line-up and grade changes.
Abnormal or Unplanned	Abnormal operations range from non-steady state or upset conditions through to operation outside design specification or Safe Operating Limits (SOLs). Unplanned operations are those typically in response to an initiating event such as unplanned shutdown or other emergency operational activity.

DATA ANALYSIS

Occupancy

The occupancies of all the 100 losses analysed are distributed as shown in Figure 2.

Note that no attempt has been made to normalise loss frequency against the relative number of each occupancy.

As can be seen 51% of losses occurred at refineries and 28% on petrochemical plants.

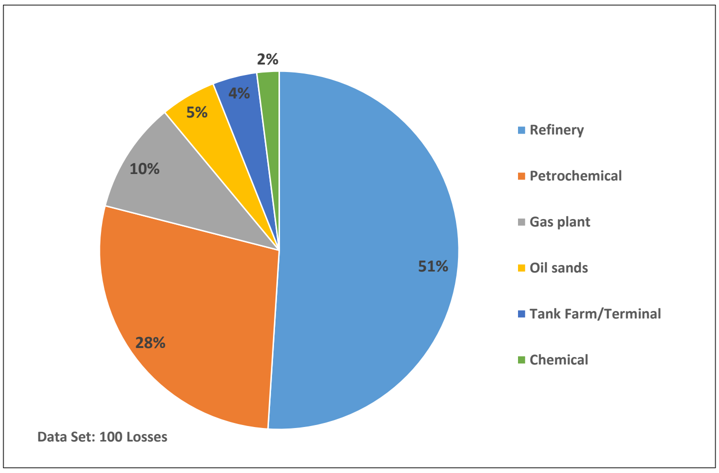


Figure 2: Occupancy distribution of the losses analysed

'Mechanical Integrity Failure' Losses

43% of the 100 losses analysed were due to 'Mechanical Integrity Failure'.

As shown in Figure 3, 'Mechanical Integrity Failure' is a far more likely cause of major loss for refineries than for other occupancies.

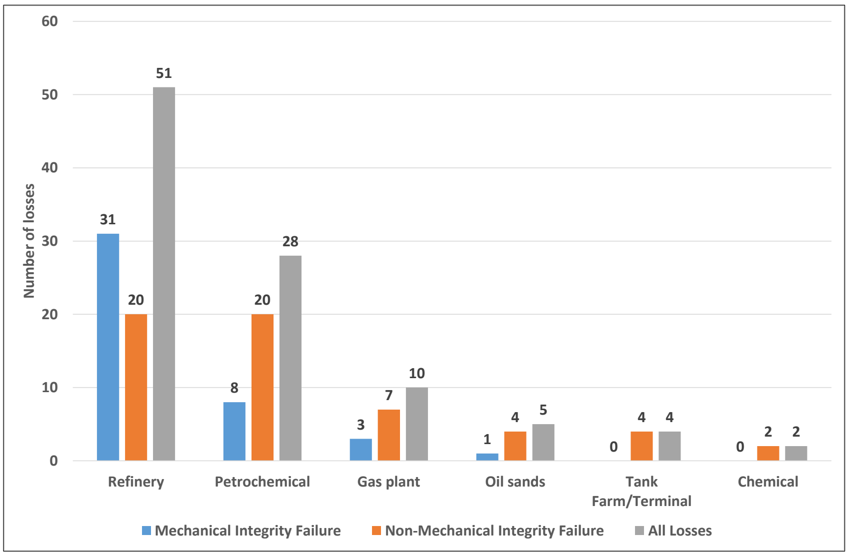


Figure 3: Breakdown of losses by type and occupancy

'Mechanical Integrity Failure' Types

The types of 'Mechanical Integrity Failure' are split as shown in Figure 4.

With respect to piping and equipment corrosion, these results are in line with insurance risk engineers experience i.e. that the mechanical integrity of pressure vessels is generally well enforced worldwide, primarily driven by regulation. Process piping, on the other hand, is generally not as highly regulated and is therefore left to the operator to devise an appropriate inspection programme, introducing the opportunity for inconsistency. Another factor is the vast amount of process piping on a typical refinery or petrochemical

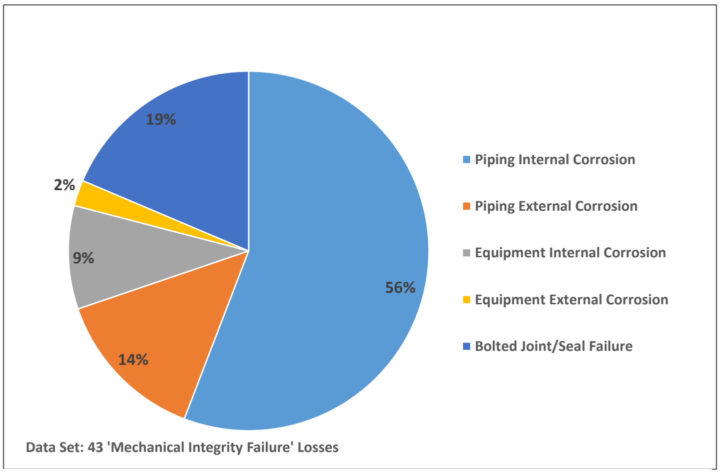


Figure 4: Types of ‘Mechanical Integrity Failure’

- 70% of all 'Mechanical Integrity Failures' were due to corrosion (as defined previously) of process piping, mostly due to internal corrosion. External corrosion was primarily due to corrosion under insulation.
- 'Mechanical Integrity Failure' of static equipment (including pressure vessels) is far less common (approximately 10%).
- There were five bolted joint failures in the data set due to inadequate bolting. In two cases flange bolts became loose due to pressure relief valve chattering or excessive pipe vibration following a significant operations event. In these cases it was impossible to determine whether the bolting was inadequate or whether the vibration was so severe that inadequate bolting could not be blamed. However, it does raise an important issue regarding the adequacy of joint bolting, particularly in critical services.
- There were three valve component/valve seal failures.

Operating Mode

Figure 5 summarises the distribution of 'Mechanical Integrity Failure' losses by operating mode.

More than 70% of 'Mechanical Integrity Failure' losses occurred during normal operation. This is not surprising as losses of this type are generally unexpected and sudden.

Eight 'Mechanical Integrity Failure' losses occurred during start-up operations (classified as ‘Non-Routine or Infrequent’) where the transient process conditions revealed weaknesses in the plant previously unnoticed under steady state conditions.

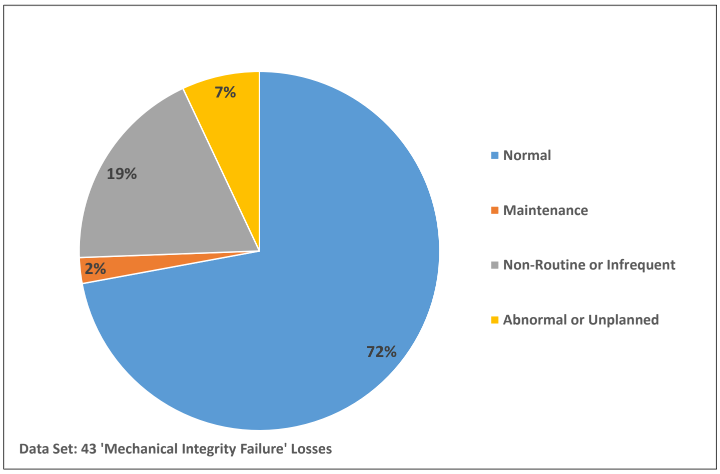


Figure 5: Operating Mode - ‘Mechanical Integrity Failure’ Losses

Figure 6 summarises the distribution of 'Non-Mechanical Integrity Failure' losses by operating mode.

As can be seen less than 10% of 'Non-Mechanical Integrity Failure' losses occurred during ‘Normal’ operation. What is also significant is the high combined contribution of ‘Non-Routine or Infrequent’ and ‘Abnormal or Unplanned’ operating modes which could collectively be termed ‘Transient’ operations. These accounted for more than 60% of 'Non-Mechanical Integrity Failure' losses i.e. there is a strong relationship between ‘non-normal’ operation (of various types) and the likelihood of a major loss.

Nearly 30% of 'Non-Mechanical Integrity Failure' losses occurred during maintenance activity, typically due to inadequate control of work.

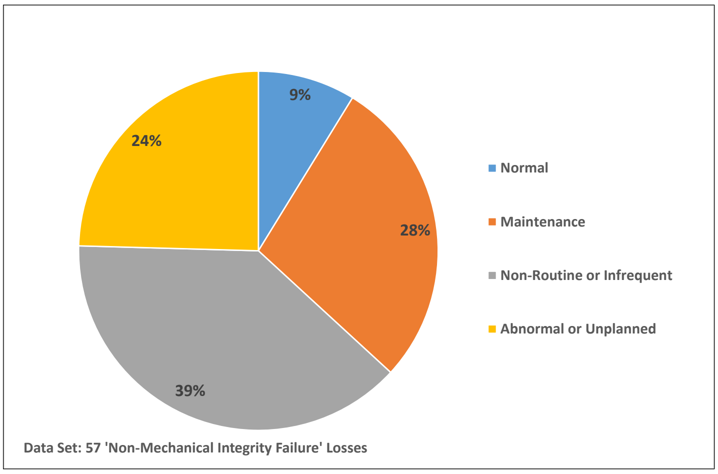


Figure 6: Operating Mode - ‘Non-Mechanical Integrity Failure’ Losses

Table 1: Transient Precursors – All Losses (‘Mechanical Integrity Failure’ and ‘Non-Mechanical Integrity Failure’)

Non-Routine or Infrequent Activities	#	Unplanned Events	#	Abnormal Situations	#
Start-up	19	Power failure	4	Blockage	4
Equipment switching	9	Equipment trip	2	SOL excursion	2
Shutdown (planned)	0	Steam failure	1	Other	3
Other	2	Cooling water failure	1		
		Other	0		

For non-routine or infrequent activities, ‘start-up’ accounted for 19 losses and is by far the most important transient precursor. ‘Equipment switching’ is also an important precursor resulting in 9 losses. This is a broad categorisation covering numerous types of equipment switching including such operational activities as:

- Reactor switching (batch reactors, coke drums, etc.)
- Storage tank switching during filling operations
- Olefins cracking furnace decoke cycles
- Switching parallel heat exchangers or pumps

Management System Failures

Figure 7 summarises the number of Primary, Secondary and Tertiary MSFs for 'Mechanical Integrity Failure' losses.

It is noted that Mechanical Integrity-related MSFs, i.e. Inspection Programme and Materials & QA, are dominated by their Primary MSFs. This is because generally a major loss of integrity has few other MSFs to prevent the loss.

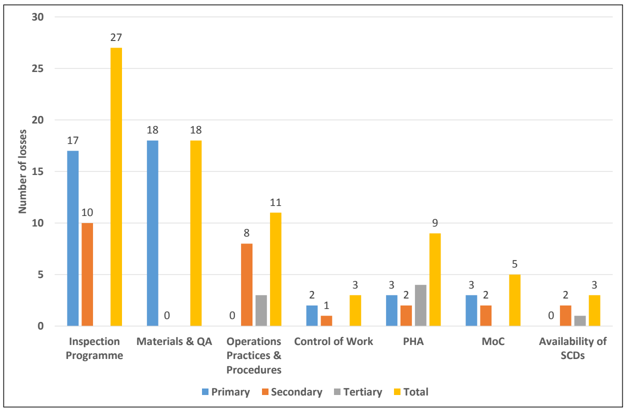


Figure 7: Breakdown of MSFs for ‘Mechanical Integrity Failure’ losses

Figure 8 summarises the number of Primary, Secondary and Tertiary MSFs for 'Non-Mechanical Integrity Failure' losses.

As can be seen, the Primary MSF is dominated by Operations Practices & Procedures and Control of Work (safe maintenance) i.e. these MSFs are the first line of defence. PHA is typically a second line of defence as shown by the dominance as a Secondary MSF, demonstrating the importance of effective PHA to prevent major losses. The Availability of SCDs and MoC become more important as a Tertiary MSF, i.e. where other barriers have already failed.

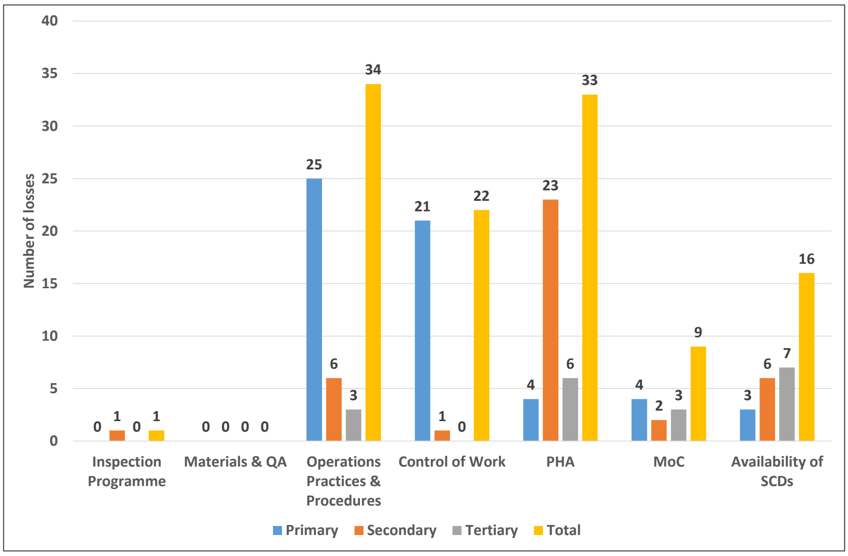


Figure 8: Breakdown of MSFs for 'Non-Mechanical Integrity Failure' Losses

Based on the combined number of Primary, Secondary and Tertiary MSFs for all losses (assuming equal weighting), the relative importance of each MSF is as follows:

a) Inspection Programme and Materials & QA (Mechanical Integrity-related MSFs)
b) Operations Practices & Procedures
c) PHA
d) Control of Work
e) Availability of SCDs
f) MoC

MANAGEMENT SYSTEM FAILURE ANALYSIS

Inspection Programme

As shown in **Figure 9**, 39% of Primary MSFs for 'Mechanical Integrity Failure' losses were attributed to an inadequate or incomplete inspection programme i.e. the potential for mechanical integrity failure could have been identified before the loss occurred if a more thorough and effective inspection programme had been in place.

Many of the inspection-related losses resulted from the failure to identify potential damage mechanisms and then implement appropriate inspection programmes to suit (in fact this is considered a fundamental issue underlying most of the losses). Of particular note are localised damage mechanisms which can be difficult to detect. For some of the losses analysed, corrosion had been detected before the loss but there was a failure to act on this

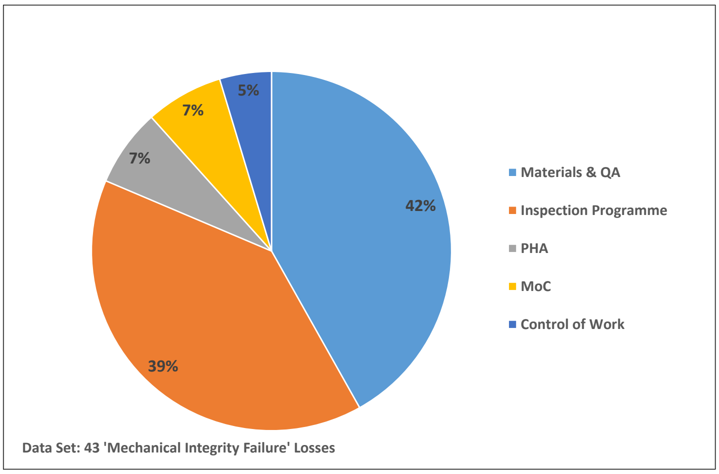


Figure 9: Primary MSFs for 'Mechanical Integrity Failure' Losses

Several failures occurred partly because external inspection would have been difficult.

In some cases, operational changes impacted the damage mechanism. These and some other losses emphasise the importance of identifying damage mechanisms and the need to establish Integrity Operating Windows (IOWs).

There were five bolted joint failures due to inadequate bolting. Although mentioned here, their Primary MSFs were either PHA (3)

Materials of Construction & Quality Assurance

As shown in **Figure 9**, 42% of Primary MSFs for 'Mechanical Integrity Failure' losses were attributed to 'Materials of Construction & Quality Assurance' with the general failure mechanisms shown in **Table 2**.

Table 2: Materials of Construction & Quality Assurance Failure Mechanisms

# of losses	Materials of Construction & Quality Assurance Failure Mechanism
8	Premature corrosion due to the presence of incorrect materials of construction i.e. not in accordance with the design specification, primarily due to a failure of Quality Assurance(QA)/Quality Control (QC) practices and procedures during construction or maintenance.
7	Weld defects or material out of specification e.g. excessive hardness in piping or equipment (failure of QA/QC practices & procedures).
3	Valve component failure (design/specification related).

In many of these cases a more effective inspection programme could have identified a potential loss of integrity indicated by accelerated/unexpected corrosion rates. However in these cases 'Materials of Construction & Quality Assurance' rather than 'Inspection Programme' was chosen as the Primary MSF since it was the initiating cause of failure.

There were several cases of incorrect materials installed either when the plant was built or at a later, often undocumented, stage in the plant's history, resulting in premature failure. In all cases there were found to be individual 'rogue' components in piping systems, predominantly in ageing refineries (6 of the 8 losses caused by premature corrosion were in ageing refineries).

It should be noted that a further 3 'Mechanical Integrity Failure' losses were attributed to inappropriate materials of construction intentionally installed as a plant change leading to premature failure due to corrosion. Although the primary cause of failure was installation of incorrect materials of construction, these have been classified under Management of Change in this report.

There were 3 losses attributed to valve component failure (design/specification related).

Operations Practices & Procedures

As shown in Figure 10, 44% of Primary MSFs for 'Non-Mechanical Integrity Failure' losses were attributed to Operations Practices & Procedures.

In general, when the plant is running in normal or steady state conditions, losses due to Operations Practices & Procedures MSF are unusual. Losses tend to occur during infrequent activities or unsteady state conditions.

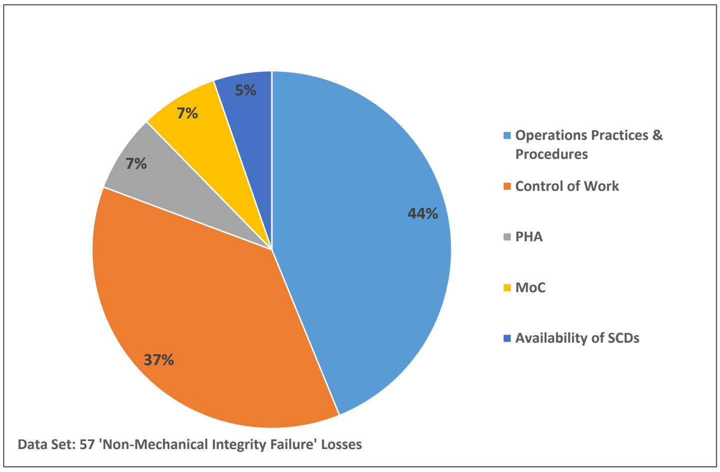


Figure 10: Primary MSFs for 'Non-Mechanical Integrity Failure' Losses

The most common causes of the losses associated with this MSF were as follows:

- Non-Routine or Infrequent Activities
  - Lack of compliance with (or absence of) operating procedures (including checklists) for infrequent activities such as unit and equipment start-up, discontinuous operations such as equipment switching, etc.
- Abnormal or Unplanned Events
  - Operational activities not subject to permit to work and/or safe isolation procedures, e.g. clearing blockages.
  - Incorrect or inappropriate response to an abnormal or unplanned event such as an emergency situation.
- SCD and critical bypass valve management
  - Safety critical devices defeated, not functioning (lack of maintenance) or not identified as safety critical (refer to 'Availability of SCDs'). Lack of control of the use of bypass valves.

Often too much reliance is placed upon Operations Practices and Procedures for loss prevention when the root cause is often associated with inherent design weakness, inadequate hazard identification or unavailability of Safety Critical Devices.

Although not specifically identified from the available loss reports, operator and supervisor experience, competency and manning levels will most likely have contributed to a number of the losses. However, this is normally an underlying issue at a level below the direct management system failures considered by this analysis. Loss of experience is evident in the industry due to a high turnover of staff in certain regions and a retiring workforce. All too often, retraining of operators only follows an incident. It would be more beneficial to define a systematic competence assurance programme with a particular focus upon critical tasks. Definition and provision of minimum safe manning levels covering all modes of operation is also an important factor.

Start-Up

'Transient event' losses most commonly occurred during planned start-up of plant and equipment. Common failings that led to such losses were:

- Procedures not followed.
- Lack of the use of checklists.
- Communications issues usually associated with shift handover.
- Inadequate staffing for demanding activities such as start up.

For example, the use of manual valves to isolate fuel gas was the cause of a number of furnace losses. The lack of formal checklists to ensure that these operations were carried out in the correct sequence was an important factor, as was operator competency leading to incorrect diagnosis of the problem and weaknesses in shift handover procedures.

Equipment Switching

Several losses occurred during what has been classified as equipment switching of various types. In all these losses, although there were failures of several management system barriers, the use of specific and well-designed operating procedures and checklists for these discontinuous activities would have provided a level of protection.

Blockages

There were several losses initiated by operators attempting to clear blockages in equipment.

Emergency Operating Procedures (EOPs)

The absence of effective EOPs, or failure to comply with the EOPs under emergency circumstances, contributed to some of the losses; in particular associated with key utility failures (EOPs are taken to cover predefined but unplanned scenarios). EOPs are also an important safeguard following loss of containment, demonstrated by a number of instances where operator action (or inaction) contributed to the magnitude of the loss. Appropriate action (rapid controlled plant shutdown) will often restrict the size of a loss.

Control of Work

As shown in **Figure 10**, 37% of Primary MSFs for 'Non-Mechanical Integrity Failure' losses were attributed to Control of Work. The Control of Work losses generally fall into three categories:

- *Safe isolation of equipment for maintenance.*
- *Permit to work (PtW) system including contractor management and handback to operations.*
- *Safe work practices.*

Safe isolation of equipment for maintenance

Piper Alpha and Pasadena Texas are well known losses caused by inadequate isolation during maintenance. The failure to adequately prepare and isolate equipment prior to the first line break remains a common weakness.

Reliance on remotely operated valves for safe isolation requires very careful consideration to ensure that they are not inadvertently opened, i.e. the motive force to open the device should itself be isolated as part of the overall isolation process.

There were two major losses caused by the use of operator-controlled line blinds. Although these incidents have been classified as 'Control of Work' they could just as easily have been classified as failure of 'Operating Practices & Procedures' or 'PHA' (both had PHA assigned as the Secondary MSF). They have been included here because although they require positive isolation either side of the blind before they are operated, these devices were designed to be used by the operators and are often not subject to a permit to work/safe isolation certificate. Guidance on the use of these blinds is available[9].

Permit to work system

Losses due to inadequate permit to work control tend to be less severe than those due to inadequate isolation.

Fires due to hot work activities are typically characterised by inadequate supervision of contractors when undertaking hot work activities. Specific risk areas for oil and petrochemical plants that require special attention are hot work near column packing.

The handback from job executor to plant owner is an important step and failure to verify the quality of work carried out contributed to a number of the losses. 5 losses occurred due to inadequate joint bolting practices and verification of flange make-up should form part of any PtW handback.

Safe Work Practices

There were a few losses caused by unsafe work practices during maintenance.

Process Hazards Analysis

As shown in **Figure 11**, inadequate PHA was cited as a Secondary MSF in 59% of 'Non-Mechanical Integrity Failure' losses. This is surprising considering that HAZOP studies and other related methods are mature methodologies that have been adapted and proven to be effective in many situations including for safety-critical tasks and procedures.

PHA features a total of 33 times in the 57 'Non-Mechanical Integrity Failure' losses analysed in this study. The following are particular weaknesses identified:

- *Inadequate quality of hazard identification studies*
- *HAZOP of Safety-Critical Activities/Transient Operations*
- *Identification of Safety Critical Devices*

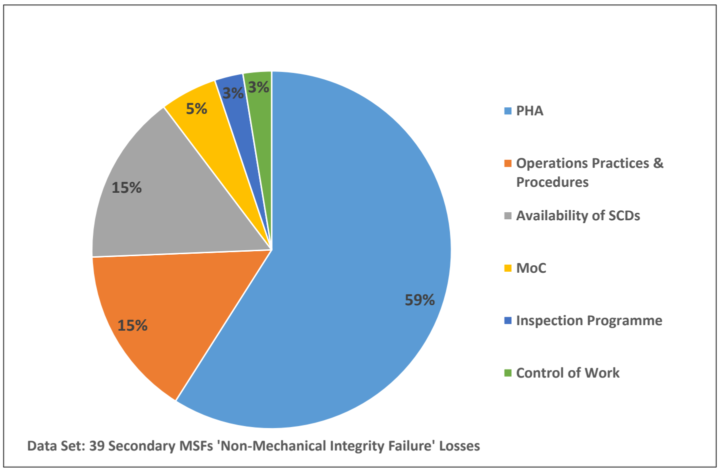


Figure 11: Secondary MSFs for 'Non-Mechanical Integrity Failure' Losses

Inadequate quality of hazard identification studies

There were a significant number of losses partly caused by the failure to identify hazards and/or provide suitable risk mitigation controls in the form of hardware process design features. This could be considered the basic function of a PHA and would therefore suggest that the quality of PHAs could be improved.

Quality assurance processes for HAZOP studies are rarely in place. An independent review of the quality of completed HAZOP studies would be of significant benefit, for example verifying the team composition, the time spent, sampling some of the hazards identified and verifying the recommendations made were appropriate and implemented.

Specifically, a number of losses occurred due to inadequate pressure relief system design.

HAZOP of Safety-Critical Activities/Transient Operations

A significant proportion of the analysed losses occurred during transient operations and in many of these cases the plant design was found to be inadequate with reliance then placed upon operator response. HAZOP studies should therefore ensure that all operating modes are considered in sufficient detail to ensure suitable risk mitigation controls are in place.

With respect to operating procedures, there are well established techniques for identifying hazards associated with transient operations for which safety-critical procedures should be in place, although they are still rarely carried out in the refining and petrochemicals industries. These "procedural HAZOP" studies can often plug the gaps left by conventional HAZOPs. For instance P&IDs may not show every design detail, particularly instrumentation details such as local bypass switches, logic or vendor-specific equipment details. A procedural HAZOP will highlight these details and ensure a greater focus on their function, operation and maintenance as well as analysing in detail each step of the procedure. There would likely be more benefit in using available resources to conduct safety critical procedural HAZOPs rather than the commonly adopted 5 year revalidation HAZOP studies, especially when a good MoC procedure is in place which should capture the vast majority of new hazards.

Based on this analysis it has been concluded that several of the losses described in this report could have been prevented by improved consideration of transient operations during PHAs and conduct of safety critical procedural HAZOPs [10] [11] [12].

Identification of Safety Critical Devices

Several losses were attributed or partially attributed to Safety Critical Devices (SCDs) not being available on demand. HAZOP and Layer of Protection Analysis (LOPA) studies are well established techniques for identifying SCDs which is an important step feeding into operating procedures and safety-critical maintenance programmes. Many of the losses analysed fall into this category i.e. the SCD was not identified and therefore the defeating or maintenance of the device was not treated as safety-critical by either the operations or maintenance departments. Appropriate identification of SCDs is a forerunner to the development of appropriate Inspection, Testing & Preventive Maintenance (ITPM) programmes.

Also of importance is the identification, via HAZOP and LOPA, of what might best be described as other "critical" process devices or Independent Protection Layers (IPLs). These might not be formally SIL rated but still need to be managed as Safety Critical Devices.

Availability of Safety Critical Devices

As shown in **Figure 7** and **Figure 8**, the 'Availability of SCDs' was cited as an MSF in a total of 19 losses. Inadequate management of SCDs is often due to a lack of formal identification in the first instance which should otherwise ensure that the associated availability controls are in place.

Losses related to the availability of SCDs were divided into two categories in this analysis:

a) Maintenance-related – the SCD was unavailable due to a lack of or an inadequate ITPM programme.
b) Operational-related – the SCD was unavailable as it had been intentionally defeated or bypassed.

The split between Maintenance-related and Operational-related for the 19 'Availability of SCDs' losses was 13 to 6 (or 68% and 32%) respectively i.e. most failures were due to inadequate testing and preventative maintenance.

What became evident during the analysis was the importance of certain critical process instrumentation which may not typically be classified as a SCD but was a key contributor to the loss as it was not functioning correctly (e.g. column level instrumentation). For this analysis, these have been included within this MSF.

Several large losses have occurred primarily because Safety Critical Devices (trips or interlocks) were disabled or by-passed. While these could also be classified as Management of Change or Operations Practices &Procedures in this analysis they have been classified as SCD Operational-related MSFs. There is guidance on managing the defeating of SCDs[13].

Inadequate management of the bypassing and disabling of SCDs is often a decision borne out of a lack of awareness of the importance of the system and the consequences of failure. It might be deemed necessary due to a design problem or a maintenance issue (such as a lack of spares). It is often the case that the only way of keeping the plant running in these cases is to bypass the trip or interlock. In other words a maintenance or design problem becomes an operator's problem.

The cause of losses is sometimes attributed (in loss reports) to a lack of operator training, competence or supervision. However practical experience suggests that design or maintenance faults that require the disabling of trips and interlocks, or result in these systems not functioning as they should, can become the long-term norm if a formal system of risk assessment, authorisation and regular reporting of status to senior management is not in place. It is worthy of note that two of the losses involved the use of a local field bypass which had become a routine part of the SOP and was not subject to the same control procedures other control room plant bypasses might have been.

Management of Change

Management of change (MoC) does not feature as often as some of the other management system failures, although this category excludes the bypassing of safety-critical trips and interlocks. In some cases, no formal MoC had been carried out whereas in other cases the hazard identification and risk assessment was found to be inadequate. The majority of MoC losses were related to 'hardware' changes although operational and organisational changes did also feature. There is practical guidance on Management of Change[14].

It is observed that there have been some major losses caused during the plant design and construction phase in which changes were made after P&IDs were issued for construction i.e. after HAZOP studies had been carried out. Specifically these related to a change in materials of construction.

Emergency Isolation

The absence of ROEIVs is frequently cited in loss reports. Whilst in most cases the presence of ROEIVs do not prevent losses, unless they are activated before ignition occurs, their presence, nonetheless, enables loss of containment to be isolated quickly thereby reducing the size of the loss and providing valuable loss mitigation. Many major loss investigation reports cite the absence of ROEIVs as a factor which could have prevented escalation of the initiating event. For 25% of all the losses analysed it could be demonstrated that the absence of ROEIVs resulted in a delay in the isolation or shutdown of the plant, causing subsequent escalation of the event and thereby increased the size of loss significantly. It is suspected that the true figure is probably much higher than this. Guidance on the use of ROEIVs can be found in several sources[15] [16].

CONCLUSIONS

This study has analysed the causes of 100 major losses in the oil, gas and petrochemical industries primarily to provide guidance to insurance risk engineers on what to focus on during risk engineering surveys. It is also hoped that operators of oil, gas and petrochemical facilities will find the results of this analysis useful in their loss prevention and risk management programmes. This paper has highlighted the methodology and findings although further details including loss examples are provided within the full report available through the Lloyd's Market Association[17].

Specific focus areas for insurance risk engineers and their (Re)Insured include:

- Inspection programmes for process piping
- Material verification programmes for new and existing installations (during construction and maintenance)
- Identification of Safety Critical Tasks and the application of systematic risk assessment techniques to these tasks (plant startup is a notable example)
- Verification of the quality of HAZOP and other PHA studies
- Safe isolation practices (in particular awareness of the hazards associated with remotely operated valves and inline blinds)
- Identification of Safety Critical Devices (SCDs) with implemented ITPM programmes and availability controls
- Effective MoC procedures with particular focus on the type and quality of risk assessment (notable examples include post-HAZOP materials of construction changes during projects)

With an established database and loss analysis methodology, it will be possible to add future losses to increase the data set and potentially also publish more in depth analysis of particular topics.

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