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***Crude Gas Main through-wall failure
investigation, identification and root cause
analysis***

Study Skills (ACMA4039)

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1 Introduction

The aims and objectives of this investigation is to assess the principles and application of risk management within engineering industry practice. I will relate this investigation to a Crude Gas Main through-wall failure, identification of failure and associated root-cause analysis.

Evaluation will be made regarding the effectiveness of root cause analysis (RCA) as a tool for engineers and will further consider elements such as risk mitigation and risk management. The study will also assess the criticality of effective risk management in high-risk sectors with particular attention to the steelworks industry, of which I work as project engineer.

It is critically important as an engineer to thoroughly understand the importance of risk management and being able to identify potential hazards before they cause harm, thus ensuring an ongoing adherence to safety requirements and regulatory standards.

2 Literature Review

Risk management is one of the core obligations that aligns closely with the principles of the IMechE Code of Conduct. Members, as outlined in Section 1 (Institution of Mechanical Engineers, 2023) *Practice competently and maintain up-to-date knowledge and skills: Quantify and limit risk in all aspects of professional work, including with those who are working under our authority.*

Within the manufacturing sector, risk management is a legal, regulatory and operational requirement. Risk management is crucial within this sector as it ensures primarily safety, but also ensures business continuity and compliance. An integral international standard that upholds the principles of risk management within the manufacturing sector would be ISO 31000.

The two primary components of the ISO 31000 risk management process are:

- The Framework, which guides the overall structure and operation of risk management across an organisation; and
- The Process, which describes the actual method of identifying, analysing, and treating risks (*Riskconnect*, 2021).

Engineers carry out a critical a role in ensuring legislative compliance by carrying out and documenting risk assessments, strategising engineering controls before administrative or personal protective measures as per the hierarchy of control. The requirement for risk assessments is outlined in the Management of Health and Safety at Work Regulations 1999. Section 3 (GOV.UK, 2015) states that: *Every employer shall make a suitable and sufficient assessment of:*

(a) the risks to the health and safety of his employees to which they are exposed whilst they are at work; and (b) the risks to the health and safety of persons not in his employment arising out of or in connection with the conduct by him of his undertaking.

Root cause analysis (RCA) is a structured method used by engineers to identify the primary causes of a failure rather than just addressing the symptoms. RCA allows engineers to make justified decisions based upon knowledge of risk, which is revealed in further detail by using recognised, credible RCA techniques. This knowledge then allows implementation of long-term corrective strategies to prevent reoccurrence and ensure safety and stability of the plant or process.

There is an inherent risk in manufacturing and engineering processes that RCA techniques aim to mitigate. Failures to plant or equipment are costly and exposing employees to unsafe equipment is unacceptable by Health and Safety, moral and professional standards. RCA aligns with engineers duties and responsibilities to ensure that equipment processes operate safely, effectively and drive continuous improvement.

Pietsch *et al.* (2024) state that: *RCA remains a significant concern in manufacturing. Driven by customer orientation and the associated high quality requirements as well as increasing cost pressure, failure-free production is becoming more and more indispensable.*

The 5 Whys methodology, originally developed by Sakichi Toyoda as part of the evolution of Toyota's manufacturing system, is a widely recognised root cause analysis technique used to systematically identify the underlying causes of a problem.

The 5 Whys technique offers an interrogative scientific approach to explore the cause-and-effect relationships underlying a particular problem by repeating why 5 times to unravel the nature of the problem while suggesting a potential resolution to such problem (Keyser and Pooyan, 2022).

3 RCA

A localised loss of containment was identified on the Blast Furnace 5 Crude Gas Main which resulted in a Blast Furnace Gas mixture of CO, CO², H₂, N₂, Steam & Nitrogen being released into the local atmosphere in low quantities. The Crude Gas Main (see *Figure 1 below*) serves to transport gases from the furnace top to a downstream cleaning cycle.



Figure 1: Crude Gas Main Column (Source: TATA Steel Internal Image)

The area of loss of containment was located as a small hole measuring approximately 3mm x 3mm (9mm² area opening) and adjacent to an area of previous through-wall failure (see *Figure 2 below*). Given the previous failures within this area, internal erosion was identified as a potential cause of the problem.



Figure 2: Localised through wall failure (Source: TATA Steel Internal Image)

Identification of the failure area prompted a structured brainstorming session to determine possible causes of the area of failure. Possible causes identified were: internal or external erosion/corrosion, system over-pressurisation, missed inspections or physical impact to the surface area.

Based upon this brainstorming event and the knowledge of previous through-wall failures in the same area caused by internal erosion, it was concluded that this would be the likely cause.

3.1 5 Whys Method (RCA)

The 5 Whys method was then applied to identify the fundamental cause of the failure, based upon the most likely cause being internal erosion. The results were:

- 1) Why did the pipework section lose containment? Because the pipe wall section was eroded internally until it became thin enough to fail under normal operating pressure.
- 2) Why was the internal wall eroded? Because deposits associated with the cleaning cycle impacted the internal walls at high velocities, uniquely in this bend section.
- 3) Why are deposits causing erosion at this specific area? Because of the pipework geometry, this area would be more prone to deposit impacts.
- 4) Why was there higher than expected velocities within this section or excess process deposits? The design of the pipework has underestimated the rates and velocities of deposits within this section.
- 5) Why were design measures deemed adequate for the velocities and process deposits? The initial design of the process vessel did not account for excessive process deposit velocities and therefore no protective layer added.

3.2 Risk Priority Number (RCA)

The next RCA method applied was the Risk Priority Number (RPN) method. This technique is used to assign a score based upon the current control measures and then re-score using further mitigation controls. RPN method is an effective way to highlight areas of high risk and allow engineers make informed decisions based upon these levels of risk.

The Risk Priority Number (RPN) assessment table (Figure 3, p.7) initially identified a loss of containment with a severity of 7, occurrence likelihood of 7 and detection capability of 4, resulting in an overall RPN of 196.

Item:	Crude Gas Main	Responsibility:	Iron & Burdending Department	RCA number:	1
Model:	SVAL Ltd Design	Prepared by:	Ryan Tamin (Area Engineer)	Page :	1
Core Team:	Ryan Tamin (Area Engineer), Mark Thomas (Iron & Burdending Departmental Engineer), Sarah Lewis (Compliance Engineer)			FME/Date (Orig):	15/03/2024
				Rev:	1

Figure 3: Root Cause Analysis table (RPN Scoring System)

Recommended mitigation actions included:

- Perform Ultrasonic Thickness Measurement (USTM) grid scans over a wider area to map remaining wall thickness against the 8mm design value and complete overplate repairs on identified thinned sections (see Figure 4).



Figure 4 – Identified thinned area (Source: TATA Steel Internal Image)

- Increase visual inspection frequency whilst using infrared (IR) cameras to detect changes in material surface temperature (see Figure 5).



Figure 5 – IR camera recordings (Source: TATA Steel Internal Image)

Following implementation of the actions, the Risk Priority Number (RPN) assessment table (see Figure 3, p.7) was updated to include: the severity reduced to 4, likelihood to 3, and detection capability increased to 8, resulting in an overall RPN of 96.

A score comparison table and graph has been formulated displaying score totals with current and further mitigation controls (see Figure 6 and 7, p.10)

3.3 Risk Priority Number Scoring Justification

The initial assessment, with the current control measures in place at the time of the localised through-wall failure was scored with the following: Severity: 7, Occurrence likelihood: 7, and Detection capability: 4, resulting in an overall RPN of 196.

Severity was scored as 7 because a release of pressurised Blast Furnace Gas containing CO, CO₂, H₂, N₂, Steam and Nitrogen would be highly toxic to personnel in the local area.

This gas mixture contains up to 30% CO concentration, which, dependant on inhalation quantities and duration could be fatal to personnel in the immediate exposure area, Short term exposure risks may also include headaches, dizziness and fatigue.

Occurrence was scored 7 because of previous through-wall failures adjacent to the localised area of failure.

Detection was scored 4, as the Crude Gas Main was limited to visual, statutory PSSR inspections which included spot ultrasonic thickness measurements (USTM) and visual checks from adjacent, fixed platforms. With this considered, the detection capability was very limited.

Post recommended mitigation actions applied, the Risk Priority Number (RPN) assessment table was updated to include: the severity reduced to 4, likelihood to 3, and detection capability increased to 8, resulting in an overall RPN of 96.

Severity was scored 4 because over-plating restored the pipework to the 8 mm design thickness, grid scans confirmed no further thinning and any future failure would likely be limited to a minor pinhole leak with minimal gas-exposure risk.

Occurrence was scored 3 because the grid scan USTM and overplate repairs mitigated the risk of re-occurrence within this isolated area.

Detection was scored 8 because the increased inspection frequency has increased and now incorporates the use of Infrared (IR) camera technology to detect surface temperature anomalies which would indicate potential defects. These Infrared thermographic inspections was in adherence with ISO 18434-1 and ISO 18434-2, and all qualified to ISO 18436-7.

Risk factor	Current controls	Post further mitigation controls
Severity	7	4
Occurrence likelihood	7	3
Detection capability	4	8
RPN score total	196	96

Figure 6 – RPN score comparison table

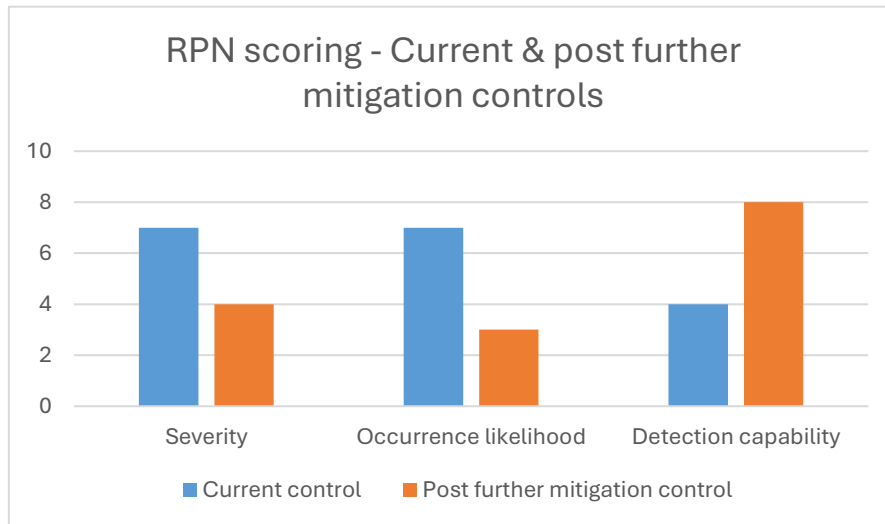


Figure 7 – RPN scoring comparison graph

4 Conclusion

The investigation concluded that the failure was a through-wall failure in a thinned area of the Crude Gas Main. RCA techniques carried out during the investigation indicated the underlying cause of failure was localised wall thinning, which had thinned due to accelerated corrosion rates associated with the accumulation of process deposits.

The 5 Whys technique effectively directed the investigation to discover that the initial design of the process vessel had not considered for excessive process deposit velocities and therefore no protective layer added.

The excess process deposits were correctly identified using infrared (IR) camera scans which were an implemented further control measure from the RPN assessment.

The advantages of using RCA techniques as an engineer are that it allows engineers to discover the underlying causes of failure and highlights areas of high risks throughout the plant or process. RCA uses structured and recognised methods such as brainstorming, the 5 Whys and RPN in addition with accumulated data to make informed decisions to mitigate overall risk within our industry.

However, the disadvantages of using RCA techniques as an engineer are that the process is dependent on the accuracy of the data obtained as well as the skill and competency of the individuals carrying out the analysis. Inaccurate data or poor data interpretation can reduce the effectiveness of RCA.

5 References

Institution of Mechanical Engineers (2023). *Code of Conduct explained - IMechE*. [online] www.imeche.org. Available at: <https://www.imeche.org/about-us/imeche-governance/governance-and-finance-reviews/code-of-conduct-explained>.

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Pietsch, D., Matthes, M., Wieland, U., Ihlenfeldt, S. and Torsten Munkelt (2024). Root Cause Analysis in Industrial Manufacturing: A Scoping Review of Current Research, Challenges and the Promises of AI-Driven Approaches. *Journal of Manufacturing and Materials Processing*, 8(6), pp.277–277. doi:<https://doi.org/10.3390/jmmp8060277>.

Riskconnect and Riskconnect (2021). *The Basics of ISO 31000 – Risk Management*. [online] Riskconnect. Available at: <https://riskconnect.com/en-gb/business-continuity-resilience-en-gb/the-basics-of-iso-31000-risk-management/>.

Keyser, C. and Pooyan, A. (2022) ‘Applying the 5 Whys Method to Root Cause Analysis’, *Journal of Continuous Improvement Studies*, 14(2), pp. 45–56.

6 Appendices

Personal Development Plan

Name – Ryan Tamlin

Degree – BEng Hons Mechanical Engineering

Previous Qualifications – HNC Mechanical Engineering

Previous Experience – 15 Years Industry Experience within the Heavy Engineering Sector

Long Term Goals (5 to 10 years)				
Gain CEng status within the IMechE. Progress to Engineering Project Manager at Tata Steel, specialising in large-scale CAPEX project delivery.				
Short Term Goals (0 to 5 years)				
Obtain BEng Hons Mechanical Engineering within UWTSD. Develop project management expertise by completing the APM PMQ qualification alongside practical experience gained in my role.				
Goal	Objective	Resources Required	Measurement	Target Date
Improve technical writing skills for reports	Practice structuring and writing technical summaries	Access to writing guides. Lecturer feedback	Completion of weekly summaries	Mid semester
Improve core pure mathematic skills	Practice implementing mathematic skills	Access to MS Teams further learning. Lecturer feedback	Completion of weekly lessons and module progression	End of semester
Improve core electrical and electronic skills and knowledge	Practice implementing electrical and electronic skills	Access to guidebooks and studies. Lecturer feedback	Completion of weekly lessons and module progression	End of semester
Improve communication skills and public speaking ability	Practice communication skills and develop public speaking ability	Access to communication guides. Lecturer feedback	Completion of weekly lessons	End of semester