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UNIVERSITY OF WALES

Trinity Saint David

Establishing a Reliability Strategy
for Dow Silicones Barry Finishing to
Achieve 2023 Reliability Goals
Major Project

MSc Engineering Project Management

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**DOW SILICONES CORPORATION
UNIVERSITY OF WALES TRINITY SAINT DAVID**



1 Abstract

ROWLANDS, M., 2023. Establishing a Reliability Strategy for Dow Silicones Barry Finishing to Achieve 2023 Reliability Goals. MSc Engineering Project Management. University of Wales Trinity St. David.

This report has established a reliability strategy for Dow Silicones Barry Finishing, providing clear direction on achieving the 2023 reliability goals. The report identifies thirteen areas for reliability improvement with nine actionable recommendations for 2023.

The report used 2022 reliability data to develop quantitative reliability recommendations. The report systematically analyses historical reliability losses in the following categories: raw material shortages, equipment failure, operating discipline, process technology, product reprocessing, logistics, and utilities. Research is completed into reliability losses and recommendations are made supported by the research.

The report recognises the financial and resource constraints Dow currently has and identifies solutions that can be implemented within the boundaries of the constraints. The report investigates the influence of leadership, management and team roles when implementing solutions. Recommendations are made on structuring the workgroups responsible for implementing the solutions as well as aligning the workgroups to the current organisational structure.

The report identifies solutions providing a 5.49% reliability improvement greater than the 3.9% improvement goal in the report's objectives. The report provides recommendations on how to implement and monitor these solutions effectively.

2 Acknowledgements

The author would like to thank Dow Silicones for agreeing to be the subject of the report. Dow has provided personal support throughout the research and development of this report and allowed access to all relevant information and documentation. Recognition should be given to Dow employees that have provided knowledge and insight through discussion, and formalised information for reference purposes.

Finally, I would like to thank the University Of Wales Trinity St David project supervisor for their support, encouragement and guidance.

3 Declaration Statement

I declare that the work in this dissertation was carried out in accordance with the regulations of UWTSD. The work is original except where indicated by special references in the text and no part of the dissertation has been submitted for any other degree.

Any views expressed in the dissertation are those of the author and in no way represent those of the UWTSD.

The dissertation has not been presented to any other University for examination either in the United Kingdom or overseas.

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7 List of Abbreviations

AU	Asset Utilisation
BDM	Base Discharge Mixer
BOM	Bill Of Materials
CEC	Dow Technology Centre Chennai
CHU	Continuous Hydrolysis Unit
CSE	Confined Space Entry
CTM	Conical Tilt Mixers
DCS	Distributed Control System
ERA	Equipment Reliability Assessment
ERP	Enterprise Resource Planning
ERS	Equipment Reliability Strategy
ETCH	Ethynyl Cyclohexanol
FMEA	Failure Mode Effect Analysis
FRS	Facility Reliability Strategy
FSR	Fluoro Silicon Rubber
HCR	High Consistency Rubber
HVF	High Viscosity Fluid
IBM	International Business Machines
JIT	Just In Time
LOD	Lack Of Demand
MAC	Maximum Asset Capability
MGP	Multi-Generational Plan
MOC	Management Of Change
MRO	Maintenance, Repair and Operations
NVC	Non Volatile Content
OD	Operational Discipline
PLC	Programmable Logic Controllers
PM	Preventative Maintenance
PSR	Product Supply Reliability
PSSR	Pressure Systems Safety Regulations
RCA	Root Cause Analysis
RM	Raw Material
ROI	Return On Investment
SAP	Systems, Applications & Products in Data Processing
SME	Subject Matter Expert
TAR	Turnaround
UK	United Kingdom
USA	United States of America
USD	United States Dollar
VLVF	Very Low Viscosity Fluid

8 Introduction

8.1 Barry Finishing Reliability Problem

The Dow Barry Finishing Plant is a reliability challenged production organisation. From January to October 2022, the Plant's reliability was 81.5% compared to its goal of 85.4%. This investigation will establish a strategy to provide a 4% reliability improvement and achieve the 2023 reliability goal.

Reliability is the plant's ability to meet its expected production consistently. Improving plant reliability is essential as it maximises the output of the current assets more efficiently. Reliability is a Dow-wide goal and is second only to safety in the business priorities. Therefore, resolving the plant reliability issues is important to Dow Global and the Dow Barry Site.

The Facility Reliability Strategy (FRS) is revised and updated yearly; previous work to identify reliability opportunities have not used data analysis to determine the greatest potential reliability opportunities. The distinction of this report from previous work is the implementation of a data-based approach to identify the most significant opportunities for reliability improvement in which the reliability strategy will be based upon. Furthermore, this data-based approach will allocate resource proportionally to the potential reliability improvement. In addition, using a data-based approach will help secure financial investment from the business to implement chosen strategies as the Return On Investment (ROI) can be quantified.

8.2 Rationale

This report is relevant and important to me as the Reliability Engineer for the Barry Finishing Plant. The primary objective of my role is to identify and support the implementation of site reliability opportunities to meet and exceed the reliability goals. My role as Reliability Engineer will allow me to support and implement the recommendations of this report. Therefore, the recommendations from this report will be implemented and have a quantifiable effect on plant reliability.

8.3 Introduction to Dow Silicones Barry Finishing

Dow Silicones is a division of the Dow Chemical company. Three Dow production sites manufacture silicone-based products; Carrollton USA, Barry UK, and Zhangjiagang China, together they combine as Dow Silicones. The three sites manufacture basic silicone product, around 10% of which is processed on-site into various high-value silicon products, referred to as 'Finished' products. These finished products are shipped to industries such as buildings and construction, chemical manufacturing, consumer goods and appliances, paints, inks and coatings (Dow, 2022b). 90% of unfinished basic silicon product is sold to Dow's competitors, where additional finished silicones are manufactured. As a product in Dow's global range, the basic silicon is referred to as a 'Feedstock' product, and the finished silicon product is a 'High-Value Downstream' product. Figure 1 illustrates Dow's long-term model for business growth. A key part of Dow's long-term strategy is increasing the proportion of feedstock and intermediate products they internally manufacture into high-value downstream products; this will increase the margins in which Dow sell products and simultaneously reduce supply to competitors. Therefore, increasing growth and reliability in the Barry Finishing production plants directly aligns with the Dow Global business strategy.

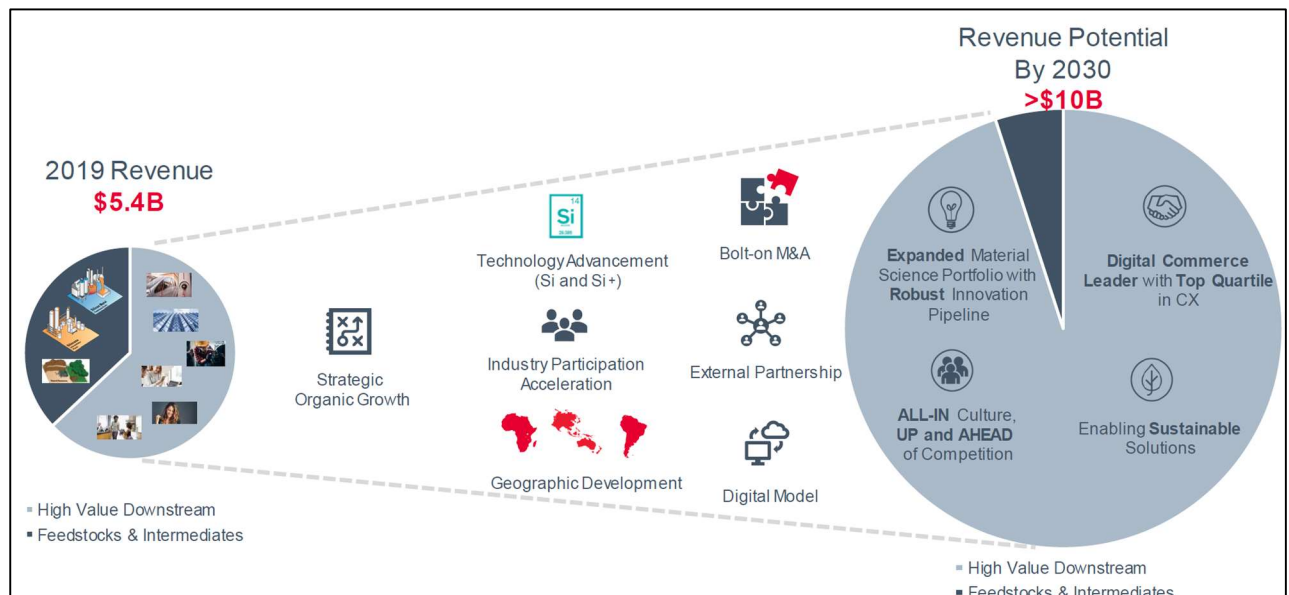


Figure 1 - Dow's Long-term Model for Business Growth (Head, 2022)

Barry Finishing manufactures hundreds of finished products from basic silicon. The finished products are manufactured by nineteen production lines/systems, called 'assets'; these assets are categorised into two product ranges: polymers and elastomers.

Elastomers Assets	Polymers Assets
Base Discharge Mixers (BDM's)	383 Blender (B383)
Compounding Fluoro Silicon Rubber (FSR)	Continuous Hydrolysis Unit (CHU)
Compounding High Consistency Rubber (HCR)	Gum in Cyclics Process (GiC)
Gum Rig	High Viscosity Fluid (HVF)
Tilt Mixers (Tilts)	1303 Kettle (K1303)
	150 Kettle (K150)
	250 Kettle (K250)
	703 Kettle (K703)
	903 Kettle (K903)
	941 Kettle (K941)
	Very Low Viscosity Fluid (VLVF)
	309 Plant (W309)
	407 Plant (W407)
	422 Plant (W422)

Barry Basics Production Plants supply the basic silicon product; therefore, the finishing assets' reliability depends on a reliable raw material supply from Basics. However, additional basic material can be shipped from the Carrollton and Zhangjiagang basics plants. Importing base silicon from other Dow sites must be planned due to extensive shipping times and is not a realistic reaction to breakdowns; shipping products from the other silicone sites can only be undertaken for planned downtime and has to be scheduled upfront.

Cabot is a neighbouring manufacturing plant. Cabot is supplied with by-products from Dow Basics silicon manufacturing and produces intermediate silicones, which are supplied back to the Dow Barry finishing plants and other European silicon manufacturers, including other Dow sites.

Each of the finishing assets produces its own range of products, many of which require intermediate manufacturing from other production lines; this results in a complex multi-layered production model for finishing manufacturing. Finishing production is complicated further as some production lines use waste products from basics. Therefore, the finishing assets' reliability can affect the basics plant's reliability by controlling the levels of by-products. Finishing also supplies basics with a relatively small

amount of product to allow the basics chemistry run more efficiently. In summary, many complex production links exist between basics and finishing production, although a clear business demarcation exists.

Finishing production includes batch production assets and continuous production assets. Some assets produce a single product, up to 237 tonnes a day; others have a large variety of products but in smaller volumes, such as 2.4 tonnes a day (Dow, 2022a). The Maximum Asset Capability (MAC) is measured in tonnes per 30 days. The MAC is the highest volume of product manufactured in 30 days over a 90-day average, providing a historical best production output for each asset.

8.4 Introduction to Product Supply Reliability (PSR)

Reliability is consistent and dependable performance (Atkins and Escudier, 2013). Production reliability is consistently manufacturing at the desired quality, volume and timescale (Murthy, Rausand and Østerås, 2008). Many variables can affect production reliability, including; supplier management, equipment failure, operations, the manufacturing process, and environmental factors (Levin and Kalal, 2003). This report considers all areas of reliability losses to the Barry Finishing production.

Product Supply Reliability (PSR) is a Dow metric used to quantify the percentage of Maximum Asset Capability (MAC) that has been utilised. PSR is the percentage each asset is utilised each month compared to its MAC. Therefore, any production losses are referred to as PSR losses and would have the value of $\text{MAC} - \text{PSR} (\%)$.

Each asset has a PSR goal set in December for the following year. The PSR goal is set through a discussion between Barry Finishing and the business, with production demand balanced against the realistic performance of the plant. Table 1 lists the PSR goal for each asset in 2023.

Table 1 - 2023 PSR Goals by Finishing Asset

Asset	2023 PSR Goal	MAC as % of Combined Finishing MAC ¹
Gum Rig	83.3%	9.8%
Base Discharge Mixers	73.2%	5.8%
Compounding Fluoro Silicon Rubber (FSR)	94.2%	0.6%
Compounding High Consistency Rubber (HCR)	94.0%	4.5%
Tilt Mixers	75.5%	3.9%
Elastomers Total	82.7%	24.60%
383 Blender	90.6%	4.1%
Continuous Hydrolysis Unit (CHU)	91.5%	4.6%
Gum in Cyclics Process (GiC)	90.0%	2.7%
High Viscosity Fluid (HVF)	87.0%	7.6%
1303 Kettle	71.8%	3.0%
150 Kettle	85.4%	0.8%
250 Kettle	90.5%	4.2%
703 Kettle	64.8%	0.3%
903 Kettle	78.4%	0.4%
941 Kettle	83.7%	1.0%
Very Low Viscosity Fluid (VLVF)	72.0%	3.4%
W309	90.0%	1.6%
W407	93.7%	7.4%
W422	88.5%	34.3%
Polymers Total	87.1%	75.40%
Finishing Total	85.4%	100%

The Elastomers, Polymers and Overall Finishing PSR goals are calculated through a weighted average of the individual asset PSR goals, with production in tonnes as the weighting value. Therefore, if an asset has a high volume (MAC), its reliability will have a greater impact on the PSR for Finishing overall than an asset with a low volume capability; Table 1 illustrates each asset's weighting towards the combined MAC¹. Therefore, improving reliability in the assets with the greatest MAC will consequently impact Finishing PSR overall and help to provide prioritisation throughout this report.

The production engineers submit PSR data daily through Asset Utilisation (AU) software; the previous day's production data is submitted into the software to catalogue all production variations and losses. At the end of the month, all data is reviewed for accuracy and consistency before it is presented to the wider organisation to track production progress. Every production loss must be accounted for in this software, and continuous training is provided to ensure data accuracy is maintained to a high standard. Potential production losses are split into categories and subcategories to help group similar

¹ Percentage of PSR is used in this table and throughout this report. The MAC in Tonnes is restricted information not covered by the confidentiality agreement for this paper.

losses together; a 'loss comment' is also provided with each PSR loss to help identify the specific loss from other similar losses. Losses can be submitted under the following categories:

- Lack of Demand
- Product Mix
- Budgeted Turnaround
- Operating Discipline
- Reprocessing or Blending
- Equipment Failure and Maintenance
- Process Variability
- Process Technology
- Process Control
- Capital Projects
- Utilities
- Severe Weather and Unusual Emergencies
- Environmental
- Logistics
- Design Capacity Imbalance
- Raw Material Shortages
- Product Transfer Limitations

A breakdown of the sub-categories can be found in Appendix 1. PSR losses include all production losses that are inside battery limits (within the control of the plant). Losses that are outside battery limits are not classed as PSR losses. Outside battery limit losses are; lack of demand, product mix, design capacity imbalance, planned maintenance turnarounds and capital projects. Figure 2 illustrates the losses that contribute to PSR and those that do not contribute to PSR.

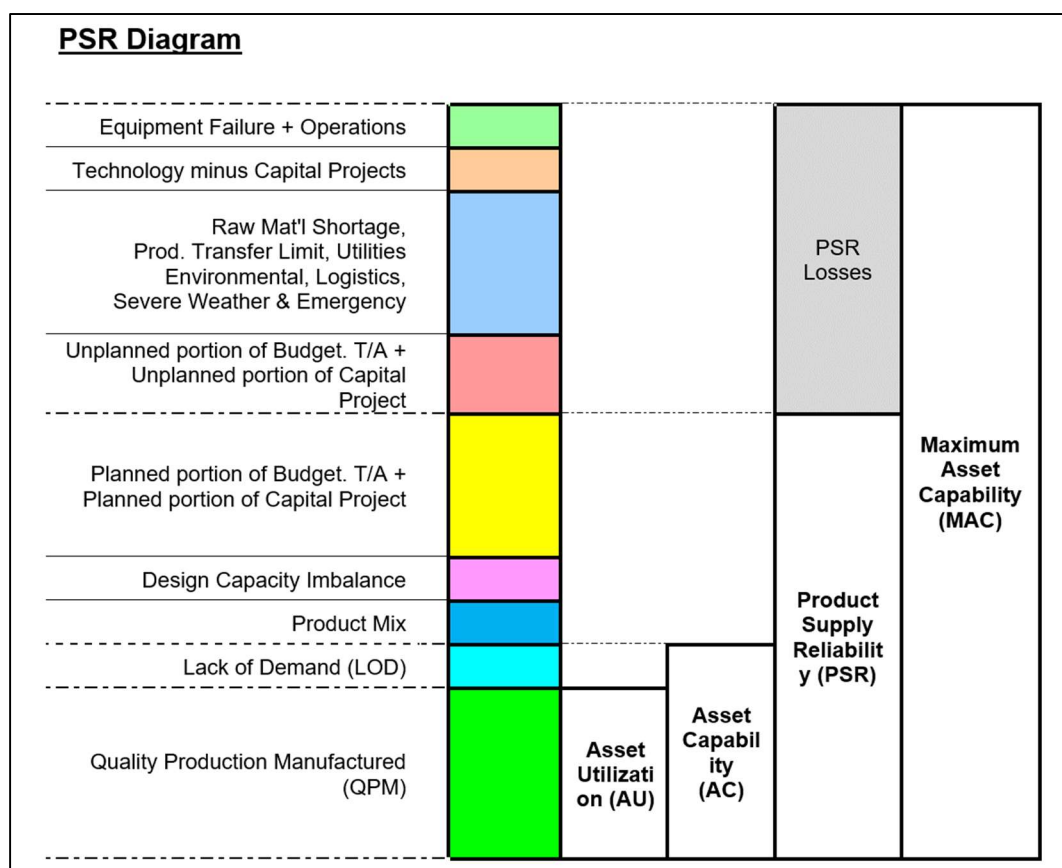


Figure 2 - Dow AU losses and Reliability Metric Breakdown (Head, 2021)

8.5 Introduction to the Report

8.5.1 Aim, Objectives, and Scope

This report aims to create a reliability strategy for Dow Silicones Barry Finishing, providing clear direction on achieving the 2023 reliability goals.

The objectives of this report are:

- Close the 3.9% PSR gap between 2022 performance and the 2023 goal
- Identify a strategy to achieve the 2023 reliability goals using 2022 AU data to support the strategy and recommendations
- Identify a strategy that meets the financial and resource constraints of Barry Finishing
- Identify a strategy that aligns with Dow practices and can be implemented seamlessly
- Implement a process that can be repeated to produce a high-quality facility reliability strategy each year

The scope of this report is to improve the reliability of all Dow Silicones Finishing Assets to meet there 2023 reliability goals, as well as the weighted average goal for Barry Finishing. The scope includes the potential to improve all reliability losses inside battery limits. The scope includes improving the site culture and behaviour towards reliability.

The 2023 reliability strategy is a one-year plan for reliability utilising 2022 AU data to support recommendations; it will contribute to the Facility Reliability Strategy. The Facility Reliability Strategy is a long-term reliability plan used by Barry Finishing, which includes multi-generational plans for investment and projects; it considers business strategy, product development, and sales trends. The full Facility Reliability Strategy is not included in the scope of this work; however, if recommendations for the Facility Reliability Strategy are made, they will be included in the recommendations.

8.5.2 Constraints

This paper must consider the constraints that have been set by Dow internally, and by market trends, and global supply chains. The first constraint Dow imposes is safety; no safety compromises can be made for production; this is a Dow-wide standard aimed at driving global workplace injuries to zero.

The second restriction set by Dow is financial. Financial constraints have resulted from decreasing half two sales in 2022 combined with decreasing product margins. This is primarily due to increased energy, shipping and raw material costs. Decreasing margins have culminated in profits reducing drastically compared with half one 2022; this decline is predicted to continue throughout 2023. To counteract decreasing profits, a global spending reduction has been implemented; this is a medium-term solution in quarter four of 2022 and is expected to remain in place throughout 2023. Due to the spending reduction, the reliability improvement budget for Finishing Plants globally has been removed. Therefore, any investment in reliability will come from the Barry Finishing Site maintenance budget. The Barry Finishing maintenance budget is 2.9 Million USD for 2023, and the 2022 spending was 3.4 Million USD (Hall, 2023). Therefore a 15% spending reduction will have to be made in 2023 to meet the maintenance budget requirements. As a result, major reliability spending will not be approved, and the production leader must approve costs over \$5,000. In addition, site stores stock additions above \$5,000 require offsite financial approval. These financial constraints must be considered when creating the 2023 reliability strategy.

The reliability recommendations in this report must form a twelve-month strategy, proposed in January 2023 and implemented at an achievable rate throughout the year. The multi-generational plan can include reliability opportunities that are identified in this report and require longer than twelve months to achieve. Reliability opportunities identified in this report that are suitable for the multi-generational plan should be listed within this report; however, they should not be over-detailed as they do not meet the aims and objectives of this report.

A further constraint upon the strategy proposed in this report is people resources. Figure 3 illustrates the Barry site finishing organisation². All team members will have plant reliability as a key goal within their role; however, the time they spend on proactive reliability work rather than reactive plant operations and maintenance will vary greatly. The Polymers plants have thirty process operators, and Elastomers Plants have seventy-seven. The operators work twelve-hour shifts and rotate on a shift pattern, illustrated in Appendix 8 and 9. The operators provide additional resources for reliability work with knowledge and experience in running the plants.

² The names of team members within the organisation chart have been removed and replaced with initials of the role followed by a number to indicate number of personnel in the role

		Barry Finishing Production Leader								
		Polymers Area						Elastomers Area		
		K903 / K703 / K941 / W309	W407, K250, 383 Blender	K150, K1303, CHU	Seat A - W322 Hot Oil, W403 packaging, W404 Tank Farm, W405 VLVF, W406 Splitter/Cyclics Distillation, W422 IVF		Seat B - HVF, 1107, GIC	Gum Rig	Base Discharge Mixers and Tilt Mixers	Compounding FSR and HCR
Operations	Operations Leader	OL 1						OL 2		OL 3
	Run Plant Eng.	RP 1	RP 2	RP 2	RP 3	RP 3	RP 1	RP 4		RP 5
	Improvement Eng.	IE 1	IE 2		IE 1			IE 2		
	Tech Advisor	TA 1			TA 2			TA 3		
	Activity Coordinator	AC 1			AC 2			AC 3		
	Safety Tech	ST 1						ST 2		
	Quality Manager	QM 1						QM 2		QM 3
	Prod. Coordinator	PC 1						PC 2		
Maintenance	Process Safety Eng.	PSE 1								
	Maintenance Group Leader	MGL 1								
	Maintenance Engineer	ME 1						ME 2		
	Instrumentation Engineer	IE 1								
	Maintenance Technologist	T1						T2		
	Work Planner							P2		
	Maintenance Supervisor	MS 1								
	Reliability Engineer	RE 1								
Turnaround Planner	TP 1									

Figure 3 - Barry Finishing Operations and Maintenance Organisation

The relationship between proactive and reactive maintenance is complex; it is difficult to break the cycle of constant reactive maintenance without neglecting breakdowns to implement a proactive strategy; the more proactive the maintenance is, the less reactive breakdowns will occur; therefore, more time is available to plan proactive maintenance (Swanson, 2001). The strategy should understand that the plant is reliability challenged; therefore, the organisation is consumed with reactive maintenance and operations. If internal plant resource is required to complete reliability work, it should be understood that it needs to be given clear priority and agreement with the resource owner (management/leadership team) for the work to be completed throughout the year.

Although onsite resource constraints exist, offsite engineering and reliability assistance is available from a Dow Technology Centre in Chennai India (CEC). CEC can provide remote technical assistance in various tasks such as data mining and analysis, SAP updates, procedure writing and documentation checking. Using CEC for time-consuming tasks can free up site resources to complete local reliability work that cannot be completed remotely. Balancing CEC and site resources to work harmoniously can ensure the constant progression of reliability opportunities.

9 Literature Review

Throughout this report, I will use research supported by credible sources to make informed recommendations on how to improve Barry Finishing Reliability. To ensure the research is well-balanced, I will use a wide range of sources, including academic and industrial engineering documentation, government information, including scholarly reviews and primary sources. I will ensure that all academic sources are credible and have been peer-reviewed. All government references will be from original sources, and I will use the most recent versions of any sources and regulations published.

Academic research will be used to find solutions to reliability issues. Each subject will be researched broadly to find all possible solutions, and more detailed research will be conducted into the most viable solutions.

Internal Dow documentation and procedures will be used as a source of primary information. When Dow procedures are documentation are created, they are subject to internal review; this is part of the Management Of Change (MOC) protocol. Based on the criticality ranking of the document/procedure, the MOC will be reviewed by three to eight experts in various fields to ensure it is correct, fit for purpose, and it will have no unforeseen effects other than its intended purpose. Therefore, all Dow documentation has an internal peer review process. Dow procedures will impose restrictions and guidelines upon the outcomes of this report; therefore, for this report to be successful and the recommendations to be implemented, this report should follow the guidelines set out in Dow procedures and policies. All Dow references are unpublished and are restricted internal documents; relevant sections of Dow documentation will be included in the Appendix.

Emails may be used as a primary source of information to document knowledge provided by Dow employees when evidence is not available through internal procedures and documentation. The emails will be attached in the Appendix, and information will only be used for email when the author is an expert in the field. As this information cannot be peer-reviewed, the report will limit the use of internal emails as a source of information.

Dow Asset Utilisation (AU) software is a data submission and storage system where every reliability loss is documented. This data in Dow AU will make up the base of this report. The production engineers submit the information in this database daily; therefore, the database is up to date. There is a monthly review of the data with all the production engineers and reliability engineers to ensure that the losses are categorised consistently by all the engineers. This review also allows for any reliability losses with

an unknown root cause when the data was originally submitted to have their actual root cause submitted.

PI ProcessBook is a software database Dow Silicones uses; it continuously collects data from live process instrumentation. PI ProcessBook provides a comprehensive database that can be used to identify mechanical and manufacturing issues. The data is a primary source of information, and the data should be considered accurate as there are legal requirements to maintain the instrumentation to a high standard. The data in PI ProcessBook will provide key information in understanding reliability issues in Barry Finishing.

Dow Silicones use SAP Enterprise Resource Planning (ERP) software for planning, scheduling, and all aspects of maintenance, repair and operations (MRO), including store stock inventory. This report will use SAP data as a primary information source to provide reliable data. SAP data is accurate as it is internally and externally audited to maintain financial transparency, as Dow is a publicly traded company.

10 Structure

This report will begin by introducing the problem, followed by the aims and objectives of this report. Setting aims and objectives at the start of a report is important to provide direction for the rest of the report to deliver a defined goal. It is essential to set out the aims so that the report's effectiveness can be quantified against these aims when the report is concluded and understand if the report has been successful in achieving its function.

Once the problem statement, aims, and objectives have been set out, the project's scope has to be established. The scope allows the report to be directed constructively at the problem and helps prevent the research and content from diverting from the problem. In conjunction with the scope, the constraints of the report should be established; this will prevent the report from making recommendations that cannot be fulfilled or supported by Dow.

The main body of the report will use Dow AU loss categories as headings. These are:

- Budgeted Turnaround
- Equipment Failure
- Operating Discipline
- Utilities
- Process Technology
- Reprocessing or Blending
- Raw Material Shortages
- Logistics

For each of these headings, the report will follow the same structure. Firstly, the reliability losses for each Dow AU category will be detailed by their subcategory. The data and statistics for each subcategory will be analysed to identify any trends.

Dow AU categories with no significant or repeated PSR losses will not be included in this report; this has been determined to keep the report concise and allow research to concentrate on areas with large and repeated reliability losses.

Significant or repeated PSR loss will be highlighted, and academic research will be undertaken in these areas. The research will aim to understand why the PSR loss has occurred and how to prevent the loss from reoccurring. Based on the research, recommendations will be made for the largest PSR losses.

Once the Dow AU loss categories have been analysed, with research and recommendations made, further research will be completed into implementing the report's recommendations, including cost, leadership and management, team roles, resource requirements, and change management. Considerations should be made into how the recommendations will be implemented most effectively.

Finally, any appropriate solutions will be detailed in the 2023 Reliability Strategy; this section will concisely summarise all the recommendations made throughout the report, providing a quantitative value for expected reliability improvements.

In the conclusion, the solutions will be analysed for suitability to see if they meet the scope and constraints of this report. Solutions that meet these criteria will be detailed in the recommendations of this report.

Finally, all the recommendations from the report will be concisely listed. Further work that needs to be completed to validate the report or implement the recommendations will be stated along with the recommendations.

11 Reliability Tools

Throughout this report, various reliability tools will be referenced and utilised. Some tools will be industry standard, and some will be internal Dow tools.

11.1 Root Cause Analysis

Root Cause Analysis is a process used widely throughout all businesses and industries including Dow. Root Cause Analysis (RCA) identifies and classifies the causes of events that influence safety, production, quality, reliability, and the environment (Rooney and Heuvel, 2004).

RCA is a process to discover the origin of problems to identify appropriate solutions (Doggett, 2005). RCA systems believe it is much more effective to systematically prevent and solve underlying issues rather than reactively taking action once the problem has occurred (Robitaille, 2010).

By determining what, how, and why the problem occurred, root cause analysis helps avoid recurrence (Williams, 2001). Root causes are underlying, are profoundly identifiable, and, once identified, allow for recommendations to be generated (Andersen and Fagerhaug, 2006). Data collection, cause mapping, root cause investigation, generating recommendations, and implementing the chosen control measures are all parts of the RCA process (Wald and Shojania, 2001); this is illustrated in Figure 4 showing a recommended process flow diagram for an RCA.

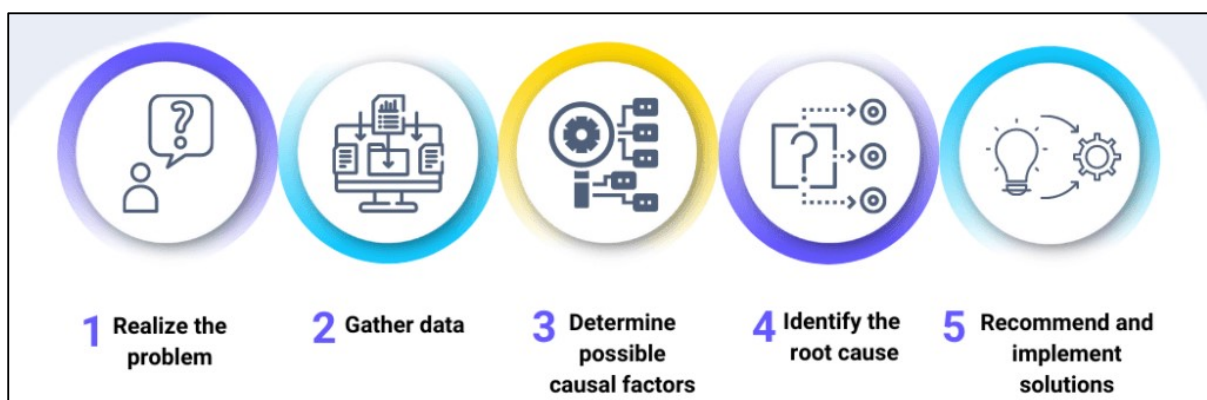


Figure 4 - Root Cause Analysis Process Flow Diagram (Latino et al., 2006)

RCA is a tool used by Dow to improve reliability; the RCA process can be used to identify the true causes of reliability losses so that the loss can be prevented at its source. RCA is useful when the cause of a PSR loss is unknown. There may be historic PSR losses throughout this report that have an unknown cause; therefore, it may be recommended for an RCA to be completed so that the loss can be prevented from reoccurring.

One significant problem with RCA is extremely complex problems require a lot of expertise and resources to drill down to the initial cause (Wald and Shojania, 2001). Therefore, the resources required to complete the RCA must be balanced with the potential return on time investment.

11.2 Equipment Reliability Strategy (ERS)

An Equipment Reliability Strategy (ERS) is a Dow structure to establish comprehensive equipment reliability and ongoing preventative maintenance. Figure 5 illustrates the four steps to complete an ERS.



Figure 5 - The Four Steps to Completing an ERS (Walker, 2021)

The first step in completing an ERS is 'Definition'. The definition includes equipment selection; this ensures that the correct equipment is prioritised for the ERS. Equipment can be prioritised for many different reasons, including:

- Production cost
- Cost of downtime
- Availability of replacement equipment/spares
- Equipment value
- Equipment obsolescence

(Afzali, Keynia and Rashidinejad, 2019)

The equipment selected for an ERS may be part of a long-term reliability strategy, or it could be reactive to an increased rate of failures. The ERS strategy should align with the global business strategy, business reliability strategy, and facility reliability strategy; this is illustrated in Figure 6.

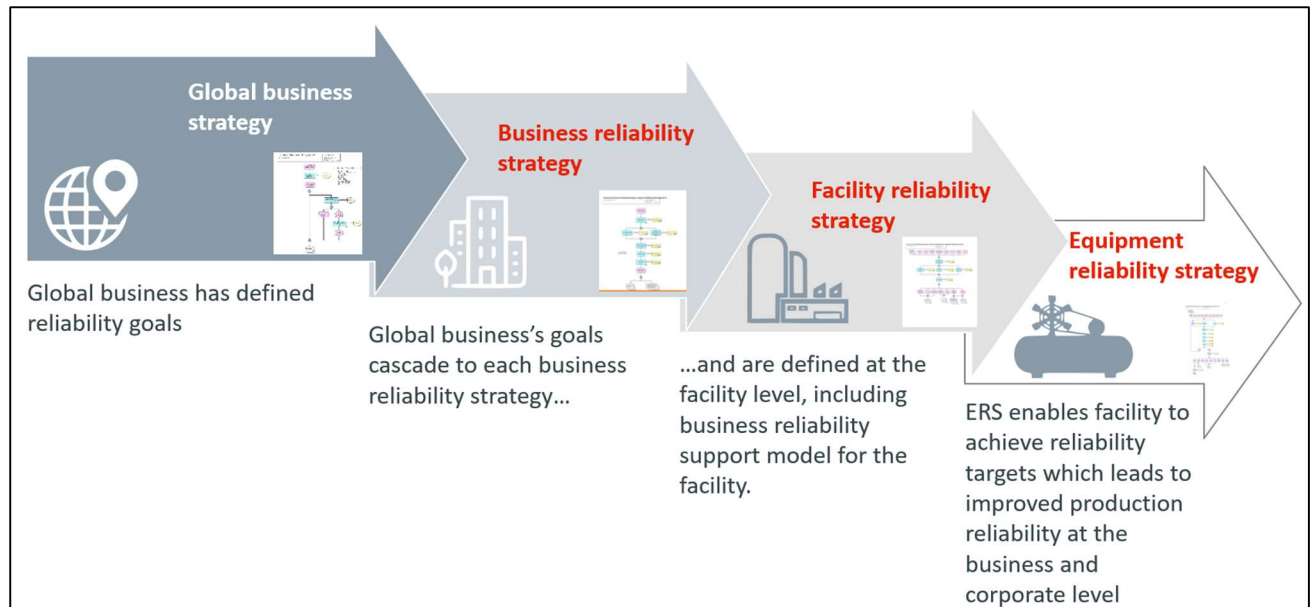


Figure 6 - Establishing equipment reliability strategies originates from the global business strategy (Walker, 2021)

Once the equipment has been chosen, the boundaries of the ERS have to be established. The boundaries set what equipment is included and excluded in the ERS work scope. For example, the ERS could be for a centrifugal pump; however, it could include the pumps suction and discharge pipework, mechanical seal, seal support system, drive coupling, gearbox, motor, control valves, PLC, DCS, pump instrumentation, and process instrumentation. All this equipment will affect the pump's reliability but may be included/excluded in the scope of the ERS, depending on the requirements and constraints. This decision may be driven by resource and time availability to complete the ERS, as broadening the scope will require additional resource to complete.

The last part of defining the ERS is to set the outcome of the ERS, as there may be multiple drivers for completing each ERS, including:

- Eliminating all unplanned downtime
- Reducing spares to a cost-effective inventory level
- Extending the life of the equipment
- Reduce major unplanned downtime events (> 1 shift)

(Murthy, Rausand and Østerås, 2008)

Once the ERS has been defined, the Failure Modes and Effects Analysis (FMEA) can be completed. FMEA is a systematic strategy for reviewing a system to find potential failure points and assess the impact of each failure to determine what intervention or control measures are required (Goddard, 2000). FMEA is not exclusively a Dow tool but a widely recognised, trained and implemented technique through manufacturing industries (Mikulak, McDermott and Beauregard, 2017). As part of

the ERS, every component within the equipment boundaries requires an FMEA. The FMEA is broken down into five steps, illustrated in Figure 7. The desired outcome from the FMEA is to identify all possible failure modes and assign a risk priority number to each (Chiozza and Ponzetti, 2009). The risk priority number is an accumulation of the failure severity, likelihood, and detectability of each failure mode (Cassanelli *et al.*, 2006).

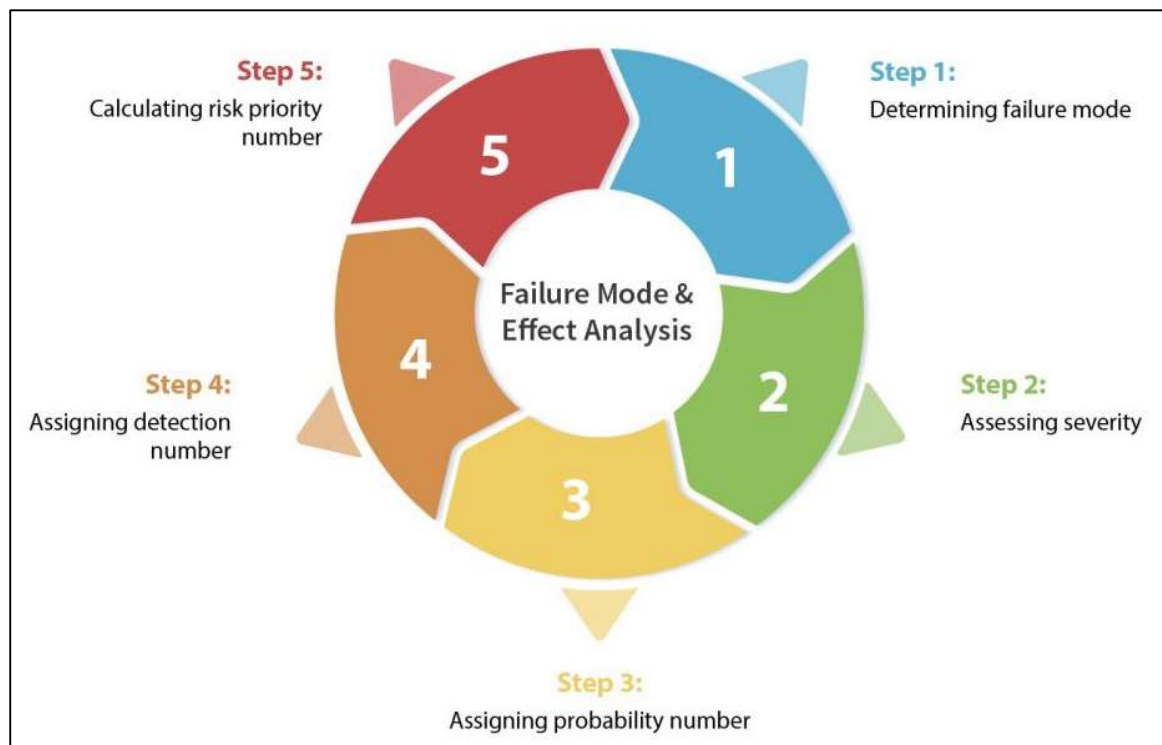


Figure 7 - FMEA Process (Wilson, 2020)

Mitigating actions are control measures that are put in place to prevent each potential failure mode (Card, Ward and Clarkson, 2012). The previously established risk priority number indicates the failure mode's frequency, consequence and detectability to allow control measures appropriate for the potential impact to be applied (Carbone and Tippet, 2004). Some failure modes may require no control measure due to the unlikelihood of occurrence, minimal impact or high cost of prevention (Reid, 2005). During the ERS definition, the accepted risk level should have been established along with the cost/budget to implement control measures. Mitigating actions will not always be able to eliminate the risk of failure. However, they may be able to reduce the frequency, reduce the impact and predict the failure time to eliminate unplanned maintenance (Price and Taylor, 2002). Examples of typical mitigation actions implemented as part of an ERS in Barry Finishing are:

- Proactive lubrication programme
- Vibration analysis
- Spares holding
- Time-based bearing replacement
- Lubrication analysis
- Belt tensioning and replacement programme
- Pully measurements

- Instrument function checks
- Cycle-based component replacement
- Torque checking fasteners
- Taking wear measurements
- Replacing sacrificial components
- Establishing process alarms
- Ultrasonic leak checks
- Filter changes based on differential pressure
- Aligning maintenance with offline production windows
- Cleaning procedures and schedules
- Hose inspection and replacement programme

(Coleman, 2023)

The final stage of ERS implementation is Document and Implementation; this stage ensures the long-term execution of the ERS by ensuring all aspects required to establish continuing success are in place. Documenting the decisions made within the ERS process is key; this will allow future employees to understand the decisions made when future changes are considered. Comprehensive documentation of the ERS also allows other identical or similar equipment to leverage the ERS outcomes to prevent unnecessary rework. Documentation does not only include the historical recording of decision-making; it requires supporting information in ERP software and all other potential documentation to be updated. Documents that likely require updating include a Bill of Materials (BOM), maintenance procedures, stores policies and risk assessments. Implementation is the final stage of the ERS and can only be completed once all the documentation is updated. Most of the implementation is completed on SAP as maintenance plans and stock items changes, but implementation can include physical equipment changes.

Overall, the ERS is designed to be comprehensive in its approach to equipment reliability; all failures are considered, and a statistical risk-reward system is used to ensure economically viable solutions are implemented. A Reliability Engineer typically leads this detailed strategy and must engage multiple Subject Matter Experts (SME) to complete the ERS. Typically, an ERS will take six months to a year to complete.

11.3 Equipment Reliability Assessment (ERA)

An Equipment Reliability Assessment (ERA) is a compressed ERS designed to be completed within a month. An ERA is an easily understandable and intuitive process available to all maintenance team members. The ERA is designed to achieve high level of reliability without the time and resource commitment of an ERS. Due to its relative ease of completion, ERAs can be used to close reliability gaps quickly to a high but not comprehensive quality. Similarly to an ERS, the ERA has four steps to complete, illustrated in Figure 8; however, these steps are much less detailed.

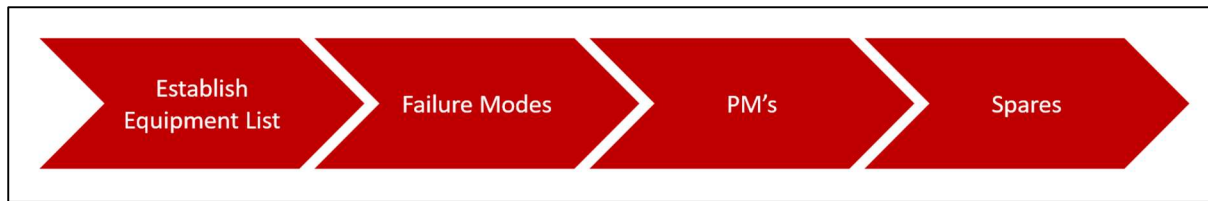


Figure 8 - Four Stages to Complete an ERA (Walker, 2021)

The first stage of an ERA is to 'Establish an Equipment List'. One ERA can be completed for multiple similar pieces of equipment; for example, if there are twenty valves all of the same make and model but in varying sizes, an ERA could be completed for all valves at once. Identifying large groups of similar equipment allows each ERA to have a wider reliability impact. Opposingly to an ERS, the ERA only identifies one piece of equipment at a time rather than having a large boundary; for example, an ERA may be completed on a centrifugal pump, whereas an ERS may include the pump, gearbox and motor. Once the equipment list is established, the variations in the equipment listed have to be identified, as the failure modes and PMs may be the same for each piece of equipment the parts they require may differ.

The second stage of an ERA is to identify 'Failure Modes'. Unlike an FMEA, the failure modes are considered for the whole piece of equipment, not each individual component; although this process is not as detailed, it is much quicker. At this stage, along with identifying the failure modes, mitigating actions should be established for each failure mode. Some failure modes may have no mitigating actions if deemed unlikely to occur or if the failure consequences are acceptable.

The third stage of an ERA is to implement 'PMs' (Preventative Maintenance). The PMs take the mitigating actions and establish proactive activities that can be used to prevent the failure modes from occurring. The PMs must be documented in procedures and implemented in SAP to ensure they are executed as intended.

The final stage of the ERA is to review the available 'Spares'. The current spare parts for the equipment should be reviewed to ensure the available spares can support the PM strategy. Caution should be taken at this point to ensure that varying equipment models have the correct spares. This section of the ERA includes a review of the Bill Of Materials (BOM) in SAP. The stock levels of each material should also be reviewed to ensure the maximum quantity held, reorder point, and delivery time support the rate of consumption implemented in the PMs. Stock level considerations should be made for common spares that multiple pieces of equipment may consume. Dow has IBM software available to evaluate the historic consumption rate of store stock parts, including lead time fluctuations. The IBM software produces recommendations on the maximum quantity and re-order point to prevent

stock-out occurrences; however, human intervention is required if the consumption rate is likely to change due to newly implemented PMs.

In conclusion, ERAs are simple to complete allowing reliability gaps to be identified and closed quicker than an ERS. ERAs are best utilised where multiple items of equipment of the same make and model can be identified providing the broadest achievable reliability improvements. The ERA is not as detailed as the ERS and will not comprehensively eliminate failure modes and unplanned downtime. To decide if an ERS or ERA is implemented as a reliability strategy, the equipment criticality, production impact, and the resource availability should be considered.

11.4 Weibull Analysis

Equipment reliability can be assessed using the Weibull Analysis. Weibull distribution is applied statistics and statistical theory that can be utilised in various functions (Lai, Murthy and Xie, 2006). Weibull Analysis can use equipment failure data to identify trends and dependability characteristics (Rinne, 2008). Weibull distribution can be utilised to identify classic bathtub lifecycle curves for equipment (Thoman, Bain and Antle, 1969). Weibull analysis uses a gamma figure to depict if equipment failure rate is decreasing, constant or increasing, as illustrated in Figure 9 (Pinder III, Wiener and Smith, 1978). Weibull analysis can be applied practically to understand if the equipment has reached the end of its economically repairable lifespan (Dubey, 1967).

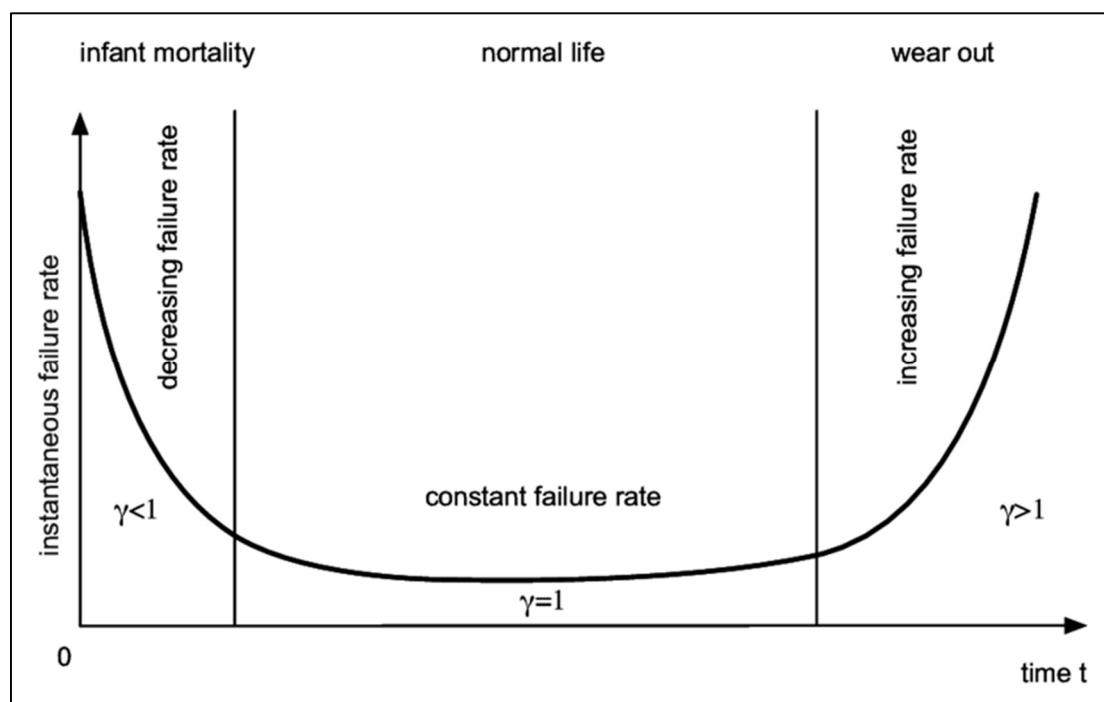


Figure 9 - Weibull Analysis, the Bathtub Curve (Lu et al., 2016)

12 2022 Reliability

The Barry Finishing Plant is a reliability challenged organisation. From January to October 2022, the Plant's reliability was 81.5% compared to its goal of 85.4%. Therefore, there have been 18.5% PSR losses, costing over \$40,000,000.00 of lost production³ (Jones, 2023), therefore a 3.9% PSR increase (as set out by the objectives of this report) could result in a potential \$8,500,000.00 potential production increase. Figure 10 illustrates the 18.5% PSR losses divided into Dow AU categories.

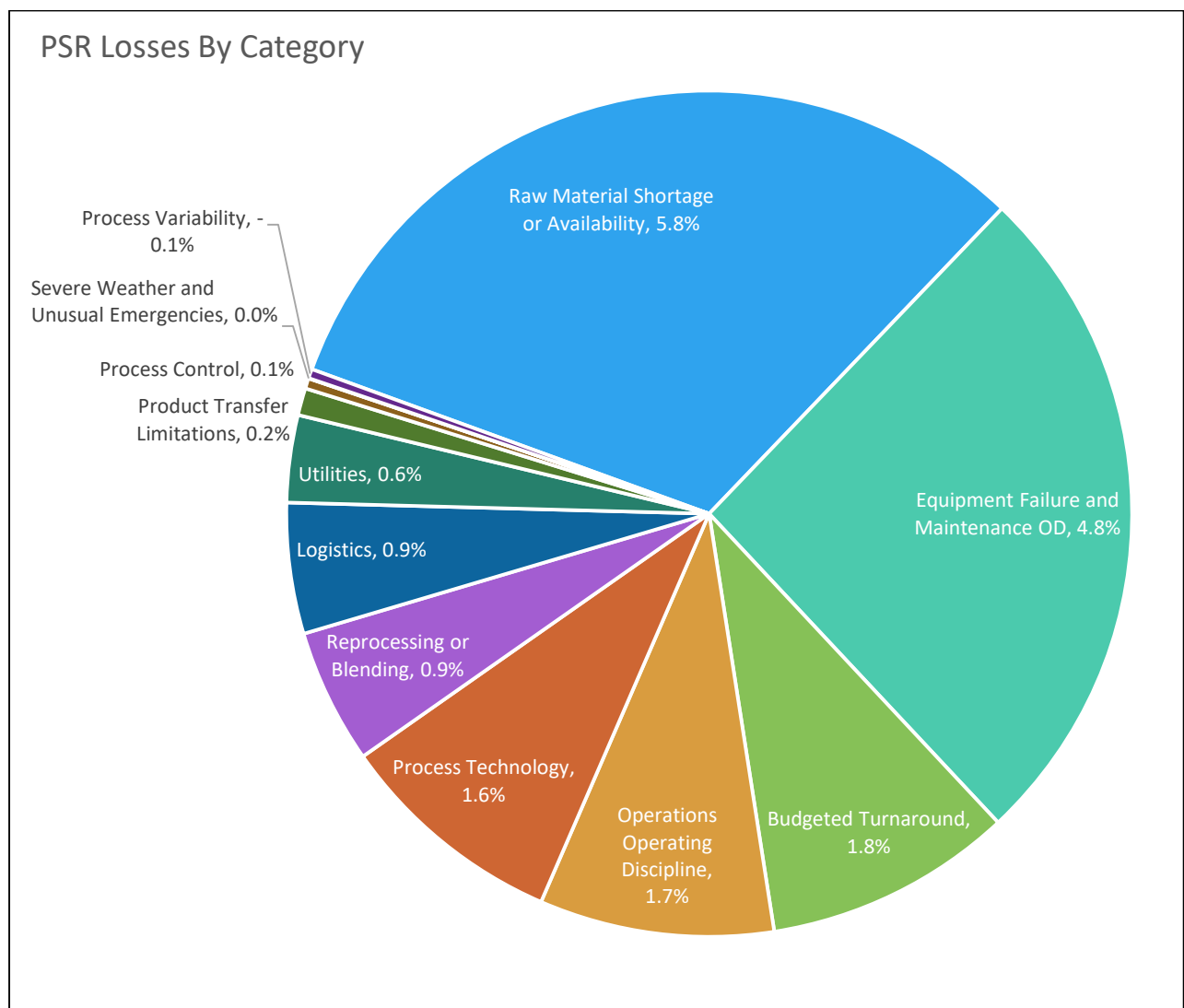


Figure 10 - January to October 2022 Dow PSR Loss Categories

³ This figure is an approximate figure used to provide a context of financial value for this report, specific production costs are available but not covered in the non-disclosure agreement between Dow and UWTSD

13 Raw Material Shortages and Availability

13.1 Data and Statistics

Raw material shortages were the largest category of PSR losses from January to October 2022, resulting in 5.8% of reliability losses. The raw material shortage category is further distributed into sub-categories, as illustrated in Figure 11.

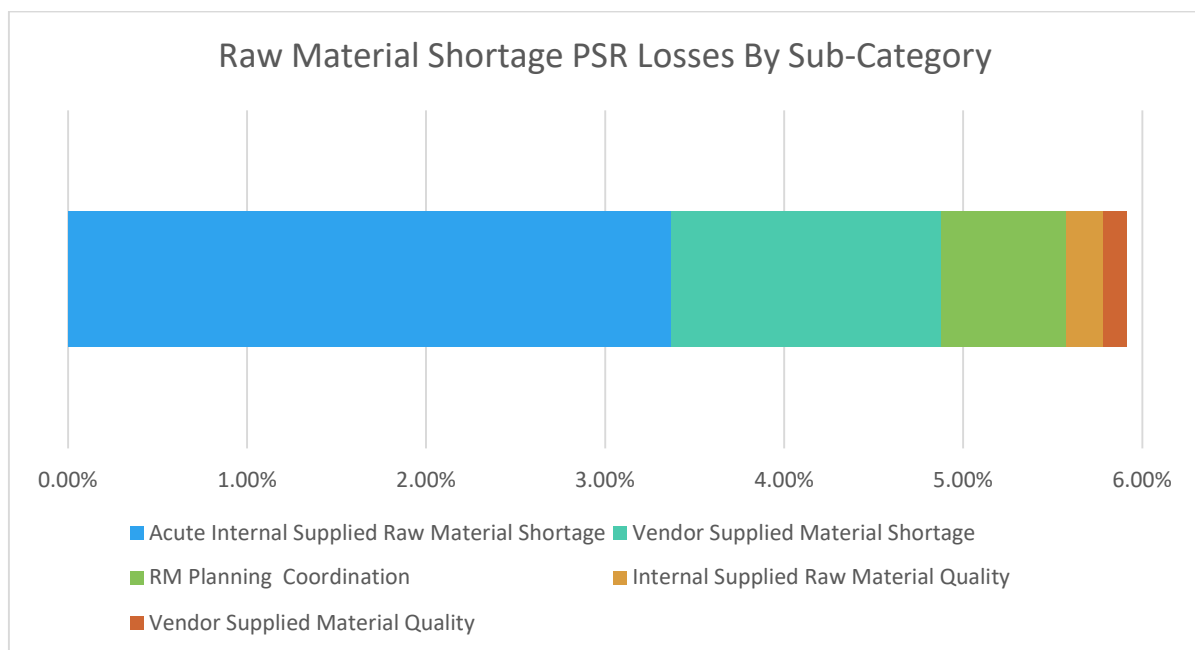


Figure 11 - January to October 2022 Raw Material PSR Loss Sub-Categories

Internal raw material supply is the biggest loss factor contributing to over 50% of all Raw Material PSR losses. Internal raw material supply losses are caused by the following losses⁴:

No gum from Gum Rig for BDM's and Tilts	0.98%
No Tri from Basics to run CHU	0.54%
No polymer from 250 Kettle for 383 Blender	0.41%
No Linear from W406 to supply 1303 Kettle	0.21%
No Dimethylcyclsiloxane (D4) for W422 and HVF	0.03%
No 2287 available for 250 Kettle	0.01%

The Gum Rig is a continuous production unit that manufactures a single basic gum product. This product is sold to customers; however, some of its product is used in downstream processes in the Bottom Discharge Mixers (BDM's) and Tilt Mixers. The BDM's and Tilts are batch processes and can

⁴ There are additional PSR losses that are statistically insignificant (<0.01%)

manufacture a wide range of finished products; these products are high value. The products the BDMs make sell for 59% more (on average in 2022) than the Gum Rig. The products the Tilts make sell for 231% more (on average in 2022) than the Gum Rig. However, balancing customer demand for the Gum Rig, BDM's and Tilts is key when deciding how to prioritise gum when there is a supply shortage. From January to October 2022, the Gum Rig asset PSR was 61.7%, compared to its 85.3% goal; this has not only affected the product supply from the Gum Rig but has had downstream effects on the BDM's and Tilts. The Gum Rig's MAC production is 1,063 tonnes a month; therefore, with a reliability of 61.7%, there have been 3,696 tonnes of lost production.

The Continuous Hydrolysis Unit (CHU) relies on Trimethylechlorisilane (Tri) manufactured in Basics. W422 plant and High Viscosity Fluid (HVF) rely upon Dimethylcyclsiloxane (D4) manufactured in Basics to run. W406 Splitter supplies linears to 1303 Kettle, and the W406 Splitter receives siloxanes from the W920 Basics Plant. Therefore, the reliability of the CHU, HVF and K1303 is directly impacted by the Basics plant's ability to supply these Finishing plants with raw material reliably.

The Basics reliability from January to October 2022 was 82.3%, exceeding the 81.0% PSR goal. The Basics reliability team will set their Facility Reliability Strategy to address the remaining PSR losses. However, as Basics is meeting its reliability goal, the Basics supply of Tri and D4 should be considered reliable as reasonable as practicable. Therefore, solutions other than improving Basics reliability should be considered.

The 250 Kettle supplies the 383 Blender with polymers. 250 Kettle and 383 Blender are batch units. From January to October 2022, the 250 Kettles PSR was 77.8%, compared to its 90.5% goal; this has not only affected the product supply from the 250 Kettle but has had downstream effects on the 383 Blender. The 250 Kettles MAC production is 450 tonnes a month; therefore, with an annual reliability of 77.8%, there have been 900 tonnes of lost production.

Vendor-supplied raw material shortages are the second largest loss factor contributing to 26% of all raw material PSR losses. Vendor supplied losses are distributed into the following losses⁵:

No Silica from Cabot for Gum Rig	0.51%
No Isalchem for 1303 Kettle	0.25%
No SilPhos for K250	0.23%
No Peroxide for Compounding FSR and HCR	0.22%
No ETCH for B383	0.15%
No oil for K1303	0.09%
No boxes to pack product from Compounding FSR and HCR	0.02%
No fibre kegs to package gum from Gum Rig	0.02%

⁵ There are additional PSR losses that are statistically insignificant (<0.01%)

All of the above losses should have their supply chains assessed; research should be conducted into how supply chains can be managed better and how this could apply to each supplier. PSR losses from Cabot's supply of Silica to the BDM's, Gum Rig and Tilts will be the most complex supply chain as Cabot's production depends on a reliable supply of raw materials from Basics along with many other contributing factors.

In 2022 there was one PSR loss from raw material planning and coordination; the supply of 4-2812 catalyst for the BDM's. This shortage occurred twice to accumulate an overall PSR loss of 0.67%.

In 2022 there were two PSR losses associated with internal raw material quality. The first was a 0.10% PSR loss from the D4 supplied from basics to the Gum Rig containing too much water. The second internal raw material quality loss was from out-of-spec Silionol supplied to the Gum Rig resulting in a 0.07% PSR loss.

In 2022 there was one vendor-supplied raw material quality PSR loss of 0.13% due to Silica supplied from Cabot not meeting specifications for the BDM's; this PSR loss was an accumulation of nine repeat losses.

13.2 Research

A business cannot supply its customers reliably without a reliable supply chain (Croxtan *et al.*, 2001). A supply chain can become vulnerable, and there is a range of potential weaknesses in any supply chain (Peck, 2006); these include:

- Poor contractual agreements
- Single sourcing
- Poor supplier choices
- An over-complex supply chain
- Just In Time (JIT) initiatives
- Focus on efficiency rather than effectiveness
- Poor control of the supply chain
- Outsourcing
- Decreased vertical integration

(Burkhardt, 2021)

In the case of Dow Finishing, the products where the external vendor supply chain is vulnerable to delays resulting in PSR losses have been identified. All characteristics of the supply chain should be considered to improve external vendor supply chain relationships, including the flow of money, information and goods (Stadtler, 2008).

Working with suppliers will help understand the range of risks to the supply of goods and allow the organisation to protect itself where the supply chain is vulnerable (Cox, 1999). Knowing the potential

impact duration from a supply chain failure is essential for the business when contingency planning, the supplier should provide assurances when predicting delivery times and identifying potential supply chain delays (Fredendall and Hill, 2000).

Strategies are available to mitigate supply chain vulnerability; these include:

- Stockpiling and redundancy planning
- Supplier selection and diversification
- Contract planning
- Supply chain management systems
- Shortening supply chains
- Insurance

(Ellram, 1991)

Stockpiling can add protection from inadequate supply chain reliability (Tomlin, 2006). Holding large volumes of stock and inventory reduces cash flow and absorbs business capital (Callioni *et al.*, 2005). Appropriate storage is required for extra inventory; therefore, stockpiling can also cause storage issues (Hughes, 1984). Increasing inventory won't alleviate the problems associated with unreliable supply chains; it can only provide a buffer for downstream customers (Lee, 2002).

One method of stockpiling is safety stock; this can help prevent stock-out occurrences (Baker, Magazine and Nuttle, 1986). Safety stock should prevent stock-out occurrences when there is a deviation from the anticipated lead time or consumption rate (Tallon, 1993). Figure 12 illustrates the use of safety stock when lead time and consumption remain constant; this is not a lean system but it provides protection from supply chain disruptions (Dillon, 1990)

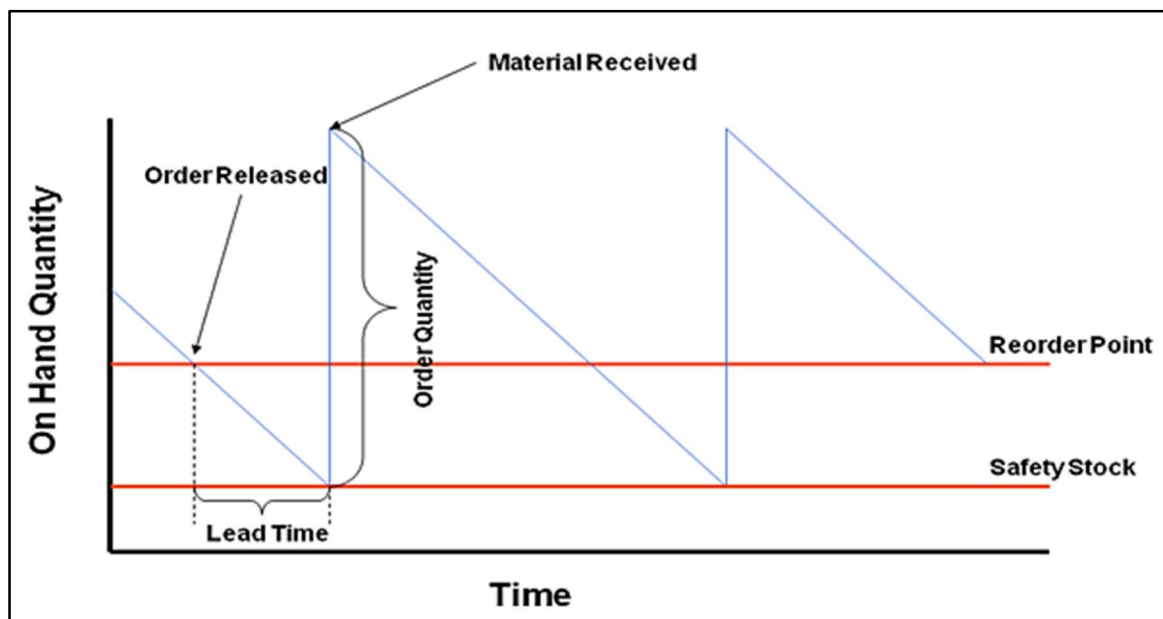


Figure 12- Graph of consistent inventory consumption and restocking with a safety stock present (Wallace, 2023)

The main drawback of safety stock is the capital expenditure required to purchase inventory that is not intended for use. In addition, there are significant holding fees, such as:

- Product deterioration/expiration
- Material Handling
- Labour
- Facility storage
- Product depreciation
- Record keeping
- Maintenance costs

(Dillon, 1990)

Supply chain resilience can start with reliable supplier selection. A company can be more vulnerable to supply chain disruptions if it depends on a limited number of suppliers. (Ellram, 1991). Multiple suppliers will enable the organisation to diversify its risk and supply chain vulnerability, in contrast with the high risk from a single supplier (Tan, 2001). Many criteria should be used when choosing suppliers; pricing will always be an important consideration, but supply chain reliability should be prioritised during the selection process (Stadtler, 2008).

Single-sourcing and multi-sourcing are two strategies that can be used to purchase raw materials; Table 2 compares these two approaches.

Table 2 - Comparison of Single-Sourcing and Multiple-Sourcing (Slack et al., 2006)

Single Sourcing	Multiple Sourcing
Streamlining the service	Maintains a backup source
Stronger long-term relationships	Geographical flexibility
Better pricing through higher volumes	Protects the buyer when there are product shortages
Reduced inventory and lead time	Maintains competition
Better quality through continuous improvements	Avoids complacency of a single supplier
Lower costs associated with product acceptance inspections	

Contracts can be utilised to reduce supply chain unpredictability (Christopher and Holweg, 2011). Contracts can vary in long-term, medium-term, and short-term duration with various suppliers to balance long-term stability with short-term agility (Lambert and Cooper, 2000). Changing the length of contracts gives the company a cost-effective balance of supply chain dependability and resilience (Davis, 1993). Every part of the supply chain, from logistics firms to suppliers, should have supply contracts to provide legal obligations to match the company's needs (Patterson, Grimm and Corsi, 2003).

Even with strong contracts in place, the supply chain should not be relied upon to manage itself; supply chain management systems should be used to provide visibility and control, offering dynamism and flexibility in the supply chain (Fawcett, Ellram and Ogden, 2007). Infrastructure and resources are

necessary for supply chain management to succeed; therefore, a team or department should be established to manage this responsibility (Cooper and Ellram, 1993). To guarantee supplier contracts can ensure a resilient supply chain and satisfy the demands of the business, the legal department should collaborate closely with the supply chain management team (Tan, 2002).

The likelihood of supply chain failures will be lower with a shorter supply chain; however, this does not necessarily mean a geographically shorter supply chain. A shorter supply chain can include fewer transportation stops, fewer modes of transportation, fewer logistics companies handling the transportation, and fewer countries transiting through to minimize the paperwork needed (Lummus and Vokurka, 1999). Shortening supply chains won't eliminate all vulnerabilities, but it will lessen their probability, which will lessen the susceptibility of the whole system (Lambert, 1992).

Insurance compensates and safeguards downstream customers rather than reduces the risk of supply chain vulnerability (Eggert and Hofmann, 2016). Insurance and contractual penalties should be employed when supply chain disruptions occur to safeguard the business (Fracarolli Nunes, Lee Park and Paiva, 2020). Insurance settlements can be reinvested into the business to prevent reoccurring supply chain disruption, used to expedite goods from alternative suppliers, or be passed onto the customer as compensation (Hematyar and Chaharsooghi, 2014).

Planning and coordination deficiencies have caused raw materials shortages, resulting in PSR losses for Dow Finishing. Supply chain planning and coordination vulnerabilities can be caused due to a failure to forecast product demand accurately and predict the correct amount of product required from suppliers (Kochak and Sharma, 2015). In the case of Dow Finishing, the supply of 4-2812 catalyst for the BDM's was poorly predicted and managed, twice contributing to PSR losses. The internal management systems should be reviewed to identify any shortfalls. Internal management systems commonly employ Enterprise Resource Planning (ERP) software to integrate information from various departments into one complete system (Monk and Wagner, 2012). Dow should understand their ERP requirements and ensure they utilise a system that can support their operating system, production and supply chain requirements (Jacobs, 2007). Figure 13 illustrates the variety of functions an ERP system can integrate.

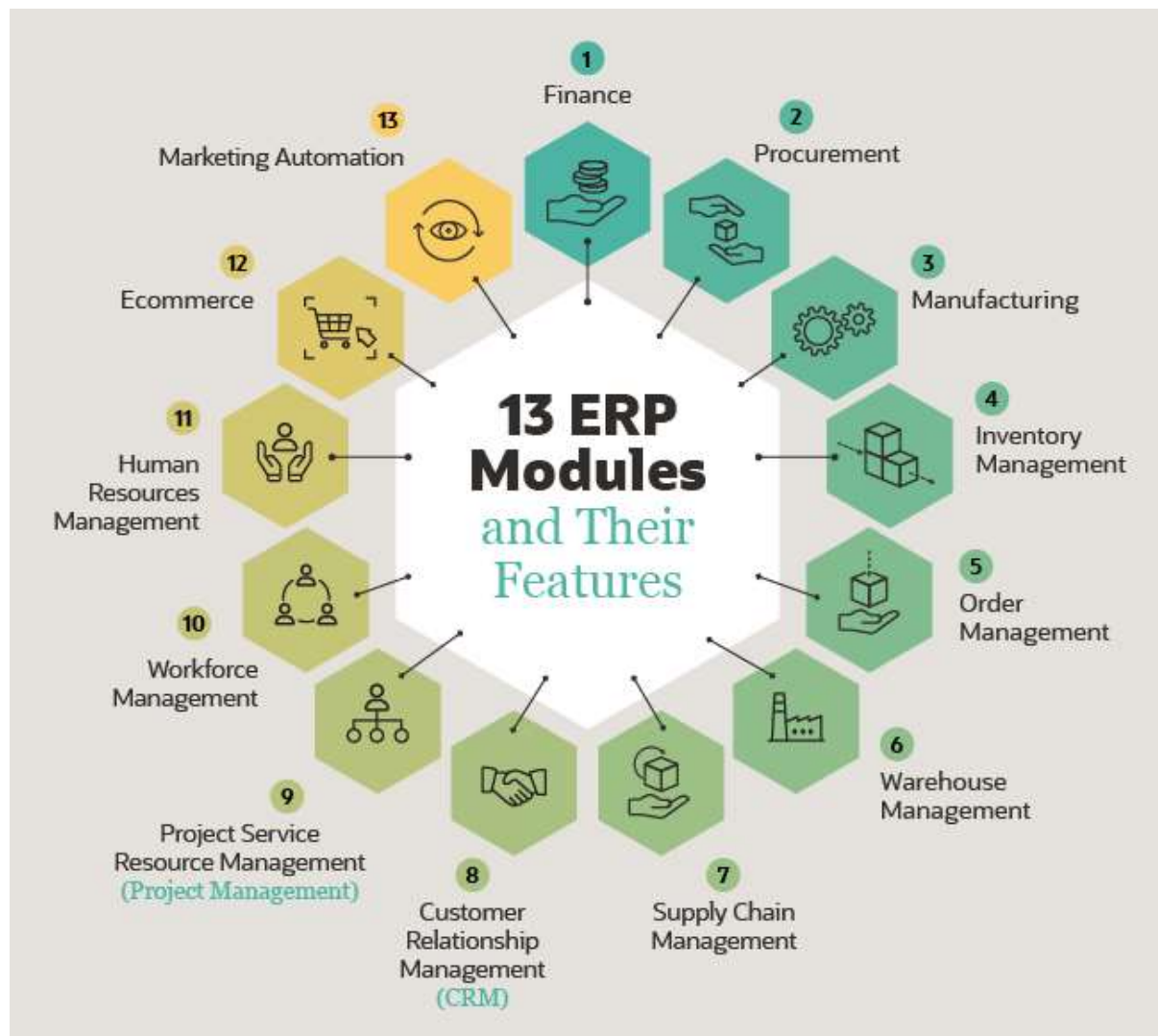


Figure 13- ERP Modules and Their Features (McCue, 2021)

13.3 Strategy

Below are all the PSR losses listed in descending order associated with raw material shortages. As this report is data-driven and there is a constraint on finance and resource to resolve reliability issues, the top PSR losses should be addressed to ensure our resource is allocated in the areas where the largest PSR gains are available.

No gum from Gum Rig for BDM's and Tilts	0.98%
Poor raw material planning resulted in a shortage of 4-2812 catalyst for the BDM's	0.67%
No Tri from Basics to run CHU	0.54%
No polymer from 250 Kettle for 383 Blender	0.51%
No Silica from Cabot for BDM's, Gum Rig and Tilts	0.51%
No Isalchem for 1303 Kettle	0.25%
No SilPhos for K250	0.23%
No Peroxide for Compounding FSR and HCR	0.22%

No Linears from Fluids to supply 1303 Kettle	0.21%
No ETCH for B383	0.15%
Poor quality Silica supplied from Cabot for the BDM's	0.13%
D4 supply for Basics has water contamination supplying HVF	0.10%
No D4 for W422 and HVF	0.10%
No oil for K1303	0.09%
Out of specification Silionol, supplied to the Gum Rig	0.07%
No boxes to pack product from Compounding FSR and HCR	0.02%
No Fibre Kegs to package gum from Gum Rig	0.02%
No 2287 available for 250 Kettle	0.01%

The Gum Rigs' inability to provide a reliable supply of Gum for BDM's and Tilts has resulted in the largest raw material shortage in finishing totalling 0.98% of PSR losses for Finishing. The Gum Rig's reliability was 61.7%, compared to its 85.3% goal; therefore, there is a large opportunity for improvement in the reliability of the Gum Rig. The Gum Rig should be prioritised highly for financial and personnel resources as part of the reliability strategy. Table 3 quantifies the PSR losses that the Gum Rig experienced from January to November 2022.

Table 3 – The 38.3% PSR losses for the Gum Rig by Loss Category

Loss Category	PSR Loss
Budgeted Turnaround	17.0%
Raw Material Shortage or Availability	7.6%
Logistics	5.0%
Operations Operating Discipline	1.7%
Product Transfer Limitations	1.7%
Equipment Failure and Maintenance OD	1.3%
Utilities	1.1%

It is clear from the data in Table 3 that the greatest cause of PSR losses was from budgeted turnarounds. However, the Gum Rig has 7.6% losses from raw material shortages; the report has already identified that there has been a shortage of Silica from Cabot for the Gum Rig. This shortage is the fifth biggest raw material shortage seen in Finishing and would have contributed to the unreliable supply of Gum to the BDM's and Tilts. Therefore, resolving the Budgeted Turnaround and Silica Supply issues from Cabot to the Gum Rig should provide a reliable supply of gum to the BDM's and Tilts.

Vendor supplied raw material shortages from Isalchem, SilPhos, Peroxide, and ETCH have resulted in a combined PSR loss of 0.85%. The contracts for each of these suppliers should be reviewed to ensure they meet the needs of the business. As well as reviewing the contracts, the suppliers should be diversified; therefore, if there is a supply shortage from one vendor, the business can increase supply

from the alternative source. Product consumption and delivery rate should also be reviewed to understand if there is an opportunity to hold safety stock that would prevent a stock-out scenario. Although in the case of chemical storage, a holding tank may have to be built, requiring additional investment.

Inadequate raw material planning resulted in a shortage of 4-2812 catalyst for the BDM's, contributing to a 0.67% PSR loss. From the data alone, it is not clear what the specific cause of the planning failure is. The cause of the PSR loss could range from human error to ERP shortfalls. Therefore, an RCA could be utilised to establish the source of the raw material planning issues, identify, and implement control measures to prevent the loss from reoccurring.

Tri shortages from Basics supplying the CHU resulted in a 0.54% PSR loss. Although Basics have its own reliability goals and strategy to achieve those goals, there is potential to hold a level of Tri as safety stock to alleviate production interruptions from Basics. Calculations could be made using historical data to identify the safety stock level that could be held to absorb any production variations from basics. This calculation could show the appropriate size storage tank, safety requirements, and distribution system. Due to the complexity, and likely duration of this work, this recommendation should form part of the Multi Generational Plan (MGP)

Targeting the three highest raw material PSR losses ensures resources are allocated in the areas where the largest return can be found. The losses that should be addressed are:

- The Gum Rig production to supply Gum for BDM's and Tilts (0.98% PSR Loss)
- Vendor supplied raw materials; Isalchem, SilPhos, Peroxide and ETCH (0.85% PSR Loss)
- Raw material planning for 4-2812 catalyst for the BDM's (0.67% PSR Loss)

As it will take throughout 2023 to identify and implement solutions, Dow does not expect to see a complete elimination of the PSR losses within the year. From previous raw material improvement initiatives, the losses will be reduced by around 25% in the year of implementation, 75% in the year after implementation and up to 95% reduction two years after implementation (Head, 2023). Although this is not a strict rule, each case will have a specific duration for it to be successfully implemented and influence PSR losses. This trend can be used to predict the effect of the solutions over the next three years using 2022 losses as an actual base value, illustrated in Figure 14.

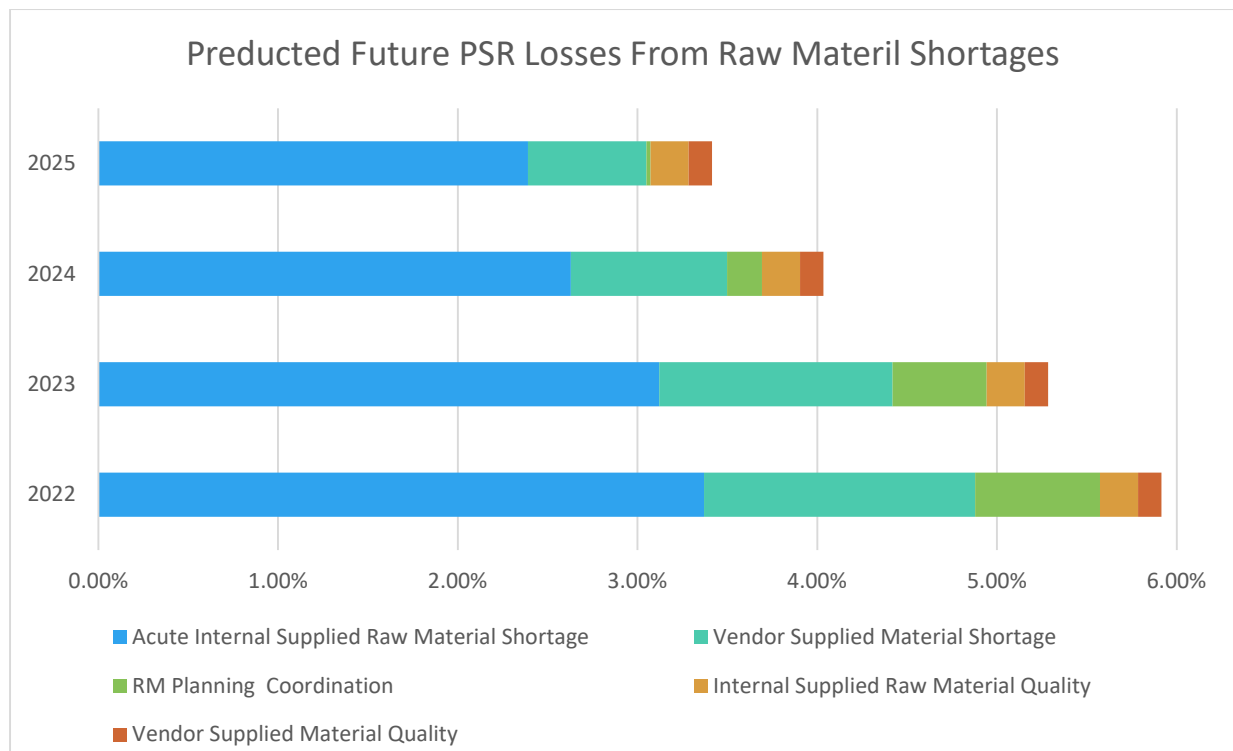


Figure 14- Decrease in PSR Losses for Raw Material Shortages if Proposed Solutions are Implemented Successfully in 2023

If the three stated solutions to reduce raw material shortages are implemented, raw material shortages should be expected to total 5.28% in 2023, a 0.63% improvement on 2022.

14 Equipment Failure and Maintenance

14.1 Data and Statistics

Equipment failures were the second largest category of PSR losses from January to October 2022, resulting in 4.8% of reliability losses. The equipment failure category is distributed into sub-categories below in Figure 15.

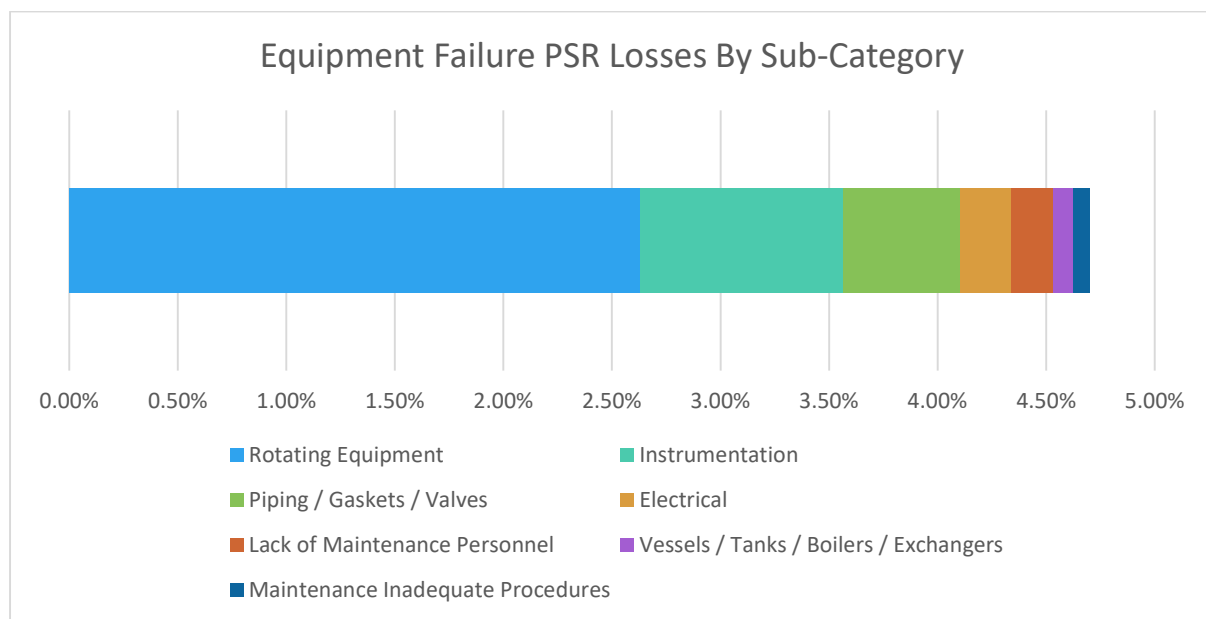


Figure 15 - January to October 2022 Equipment Failure PSR Loss Sub-Categories

Rotating equipment failures were the largest loss factor contributing to over 50% of all equipment failure PSR losses. These rotating equipment failures are divided into the following losses⁶:

W407 818 Vacuum Pump Failures	0.80%
Compounding HCR Low Pressure Barwell Failures	0.31%
W422 237 Pump Gearbox Failures	0.31%
Tilts 157 Mixer Bearing Failure	0.29%
W422 235 Pump Seal Failure	0.21%
Tilts sheared union on Process Water Supply to Colmec Mixer	0.10%
BDM 177 Mixer failures	0.06%
Compounding FSR and HCR CTM Failures	0.06%
250 Kettle 200 Pump Failure	0.06%
B383 382 Wilden pump failures	0.05%
BDM 277 Pick and Palace machine failures	0.05%
BDM 177 Pick and Palace machine failures	0.05%
250 Kettle 231 Pump Failure	0.05%

⁶ There are additional PSR losses that are statistically insignificant (<0.01%)

Tilts Colmec Mixer spindle stuck	0.05%
BDM 277 Mixer failures	0.04%
BDM 277 Log Wapping machine failures	0.03%
Compounding FSR High-Pressure Barwell Failures	0.03%
Compounding HCR BDM Failures	0.03%
Gum Rig 2587 Pump Coupling Failure	0.02%
250 Kettle 220 Pump Failure	0.02%
250 Kettle 202 Vessel Agitator Failure	0.02%

As this report is data-driven and there is a constraint on finance and resource to resolve reliability issues, the top PSR losses should be addressed to ensure the resource is allocated in the areas where the largest PSR gains are available. The top five rotating equipment PSR losses will be investigated; these losses contribute to 73% of the statistically significant rotating equipment PSR losses.

W407 818 vacuum pump has been the largest cause of PSR loss in rotating equipment failures. 818 vacuum pump is an RGC 400 hook and claw vacuum pump originally manufactured by Graham Vacuum Pumps. The pump was originally manufactured in 1997, and in 2009 Graham Vacuum Pumps were acquired by Busch (Morrison, 2020). Shortly after this takeover, Busch discontinued the range of RGC 400 vacuum pumps and major spare components; however, they continued to produce a range of 'soft' components that allowed the vacuum pumps to be serviced. Originally 818 vac pump had a complete spare; the primary maintenance strategy for this pump was to exchange the pump for its spare every two years during a scheduled turnaround when production would not be affected. The removed pump would then be serviced and ready for use as a complete spare. Currently, no spare 818 vacuum pump is available; the rotors and housing on the spare pump have worn extensively, increasing the tolerance beyond the ability of the pump to perform. The 818 vacuum pump currently installed also has deteriorated critical mechanical tolerances and is underperforming, making it less resilient to process variations. Therefore, there has been an increasing trend in failures in the last five years. Alongside the inability to refurbish the pump to an as-new condition, the 818 vac pump has been the cause of equipment failure resulting in the largest PSR losses for Finishing.

Compounding HCR Low Pressure Barwell Failures have caused 0.31% PSR losses. The Barwells are hydraulic ram extruders that compress and form rubber into desired shapes for customers, pictured in Figure 16. The Barwells are batch production; they process a large variety of materials in various colours and shapes and are in the final manufacturing stage in the Compounding HCR process. The Barwells must be cleaned to prevent product contamination and allow the next product shape to be set up; this results in downtime between batches. There are six Barwells, all over ten years old and purchased second-hand. In 2022 Equipment Reliability Strategies (ERS) were implemented on the

Barwells to prevent probable equipment failures cost-effectively and reduce unplanned downtime; however, there has been significant unforeseen downtime due to fatigue cracking.



Figure 16 - ECO Barwell Ram Extruder (ECO Clean Room Ram Extruders, 2022)

W422 237 pump gearbox failures caused 0.31% PSR losses. 237 Pump feeds 200 Fluid to 240 and 242 blenders which are key for W422 production. 237 Pump is an Ibex MOG 2030X gear pump driven through a Renold Carter gearbox reducer and motor. In 2022, W422 had to reduce rates multiple times due to a low level in 240 and 242 blenders because 273 pump was out of service as a result of a gearbox failure. 237 is a stand-alone pump with a common spare shared with other MOG 2030X pumps. 237 pump is critical to W422 production, although there is time to react to failure due to product level in the downstream 240 and 242 blenders; if a failure occurs for longer than the level in the blenders can sustain production, the pump will cause PSR losses. W422 is the highest volume-producing asset; therefore, due to weighted averages, a small downtime on this asset can contribute to significant PSR losses for Finishing; W422 generates 34.3% of Finishing's overall production.

157 mixer bearing failure resulted in a 0.29% PSR loss. 157 tilt mixer is one of two identical mixers that mix rubber products for the asset Tilts. The 157 mixer supplies half of the assets production needs. The Tilts are a batch process with an extended turnaround for cleaning between each batch. When one mixer is offline, it reduces the asset capacity by 50%. As well as the bearing failure, 157 mixer saw significant additional downtime in 2022; however, these additional PSR losses have been categorised as Process Technology rather than Equipment Failure; research and solutions to prevent further PSR losses from 157 mixer are detailed in the Process Technology section of this report.

W422 235 Pump seal failure caused a 0.21% PSR loss. 235 Pump feeds 200 Fluid to 230 tank, a key product required for blending in W422 production. 237 Pump is an Ibex MOG 2030X gear pump with a single mechanical seal. In 2022, W422 reduced rates due to low levels in 230 tank as a consequence of 273 pump being out of service due to a mechanical seal failure. 235 pump is a stand-alone pump with a common spare shared with other MOG 2030X pumps, including 237 pump. 235 pump is critical to W422 production, although there is time to react to failure due to the product level in the downstream 230 tank; if a failure occurs for longer than the level in the tank can sustain production, the pump will cause PSR losses.

Instrumentation failures were the second largest cause of PSR losses in the equipment failure category. These instrumentation failures are divided into the following losses⁷:

VLVF and W422 Plants tripped due to PLC failure.	0.19%
W407 Catalyst flow valve 5098 failed to operate correctly	0.06%
K250 5034 Level transmitter failure	0.04%

PLC 11 and 12 are the control systems for most polymers assets, including VLVF and W422. In 2022 failures of these PLCs caused 0.19% PSR losses. However, the time between PLC failure and recovery has been short, in most cases less than 30 seconds; once the associated plant trips, it can take hours to get an asset back online safely. The PLC systems are up to 40 years old and obsolete, and spares are no longer commercially available. The software for these systems will not run with Windows 10, and with global Dow limitations imposed on Windows 7 based applications in 2023, the site will lose the ability to access and modify these PLCs remotely, severely limiting support capability.

W407 Catalyst flow valve 5098 failed to operate correctly three times in 2022, resulting in 0.06% PSR losses. 5098 flow valve controls the catalyst flow from the 804 tank; this is a critical part of the W407 process. The data sheet for this control valve can be found in Appendix 2.

K250 5034 Level transmitter failed five times in 2022, resulting in 0.04% PSR losses. 5034 is the level transmitter on 550 tank, which supplies 250 Kettle. 5034 Level transmitter is Foundation Fieldbus and communicates with the DCS using Foundation Fieldbus. Foundation Fieldbus is not the standard DCS process automation; the site typically utilises Siemens 4-20mA. The level transmitter is obsolete. The site team and DCS vendor, Schneider Electric, cannot support the maintenance or commissioning of any Foundation Fieldbus instrumentation or control systems. Due to the foundation Fieldbus Control

⁷ There are additional PSR losses that are statistically insignificant (<0.01%)

system, standard 4-20mA instrumentation cannot be replaced as it is incompatible with the control system.

Piping, gasket and valve failures were the third largest equipment failure contributing to PSR losses of 0.54%; this was accumulated from the following significant losses⁸:

BDM 177 mixer lid seal inadequate and allowing oxygen ingress	0.22%
GumRig steam leak to reactor jacket	0.09%
W422 sample point failure	0.07%

The BDM 177 mixer had multiple lid seal failures in 2022, resulting in a 0.22% PSR loss. The 177 mixer is inert with nitrogen to allow safe operation; the oxygen levels are monitored inside the mixer. If the mixer lid seal is not functioning correctly, air can ingress, making mixing unsafe, and the oxygen analyser automatically trips the mixer. Some product mixes are time sensitive; therefore, if the mixer trips and undergoes downtime, the current mix has to be discarded, and the batch has to be started again. The mixer seal issues arose in February 2020 after a project to install extra machinery guarding was completed. The project had not considered the implications of their modifications on the mixer lid seal. After repeated failures, an RCA was completed; the RCA identified the project as the root cause of the failures. The RCA also identified an alternative upgrade that would satisfy the project and not affect the mixer lid seal, these recommendations were implemented in June 2022, and no further PSR losses have occurred from the mixer lid seal since.

The GumRig reactor jacket had a single steam leak resulting in a 0.09% PSR loss in 2022. The GumRig's primary asset is the gum reactor; it has a steam jacket used to heat and initiate the chemical reaction inside. The steam leak prevented the reactor from functioning and created a safety concern.

W422 sample point failure was a single incident resulting in a 0.07% PSR loss in 2022. Product sampling is taken every eight hours for lab testing; this sampling is used to ensure the product meets its specification. The sampling rate increases if the product becomes out of specification or during process startups. The sample point failed during the process start-up, and the repair delayed the start-up by 14 hours. W422 generates 34.3% of Finishing's overall production; therefore, even a small downtime event can cause a significant loss on Finishing PSR.

⁸ There are additional PSR losses that are statistically insignificant (<0.01%)

Electrical failures were the fourth largest equipment failure contributing to PSR losses of 0.24%; this was accumulated from the following significant losses⁸:

W422 Dalmec Failure	0.06%
K903 726 scales failure	0.03%

W422 Dalmec Failed twice in 2022, resulting in a 0.06% PSR loss. The Dalmec is a brand name for a weightless drum handling unit; this unit provides lifting assistance (depicted in Figure 17) to manually transfer catalyst from drums into 1810, 1830 and 5048 (VLVF) reactors. Without the Dalmec, the rigging team is required to lift the drums; therefore, production can continue; the PSR losses are from the time between when the Dalmec failed to when the rigging team could load the catalyst. W422 generates 34.3% of Finishing's overall production; therefore, even a small downtime event on this asset can cause a significant loss to Finishing PSR.



Figure 17 - Dalmec weightless handling unit ('Homepage - DALMEC- Industrial Manipulators and Material Handling - Manual lifts for the ergonomic handling of loads in weightless condition. Dalmec zero gravity balancers', 2021)

K903 726 scale failure caused 0.03% PSR losses in 2022. A single electrical failure to the scales resulted in a prolonged period of downtime whilst spares were acquired and maintenance completed. 726 scales are used to measure products before they are loaded into the 903 Kettle and to weigh the finished products from the 903 Kettle to ensure they are batched correctly for distribution. To reduce the impact of the failure of 726 scales, weighing was completed on scales shared with other assets.

However, at times, the scales were required by multiple processes at once, causing a backlog resulting in production delays on K903.

Lack of maintenance personnel was the fifth largest equipment and maintenance failure contributing to PSR losses of 0.19%; this was accumulated from the following significant losses:

B383 No maintenance resource for leak repair	0.10%
BDM No maintenance resource for filter change	0.09%

B383 experienced no maintenance resources for leak repair resulting in a 0.10% PSR loss. The leak repair required a welder and fabricator to complete an in-situ site weld. Dow Barry site employs one welder and one fabricator, supplemented by contract labour to manage scheduled fluctuations in workload. However, the assets must be prioritised for production impact if multiple unplanned events occur across the site requiring welding and fabrication resources to repair. In this case, the 383 Blender was prioritised lower than two other failures on site.

BDM received no maintenance resource for a filter change resulting in a 0.09% PSR loss in 2022. Two identical bottom discharge mixers are key in the manufacturing of BDM production. Each mixer has a set of filters to remove coarse silica supplied by Cabot before it enters the mixers. The filters are changed weekly as part of a periodic maintenance strategy. If the silica supplied from Cabot is coarser than usual for an extended duration, the filters saturate quicker than seven days. In this case, the filters saturated before the seven-day PM was completed requiring an unplanned and unscheduled filter change; no maintenance resource was available to complete this work.

14.2 Research

Proactive and preventative maintenance is used to foresee issues, failures and defects and fix them before they arise (Basri *et al.*, 2017). Reactive maintenance is performed once a piece of machinery has failed (Gertsbakh and Gertsbakh, 2000). Through proactive and preventative maintenance, breakdowns and PSR losses can be avoided (Doyen and Gaudoin, 2011). However, in the case of some of the PSR losses, preventative maintenance is not a viable option due to obsolescence. Therefore, strategies must be established for PSR losses associated with equipment failure that cannot be resolved through preventative maintenance. Investment, upgrades and technology improvements will be required to resolve some failure modes and obsolescence (Craig, 2002).

Figure 18 illustrates the cost and frequency of maintenance on the 818 vacuum pump; the data for this graph was extracted from SAP and is available in Appendix 3. The trendline on this graph shows a gamma figure greater than one, indicating the equipment is in a stage of 'wear out'. With this data and the obsolescence of the current pump model, it could be concluded that the pump has reached the end of its design life, and no additional preventative maintenance can be completed to level the gamma figure. Therefore, a new vacuum pump model is recommended for installation to increase the asset's reliability.

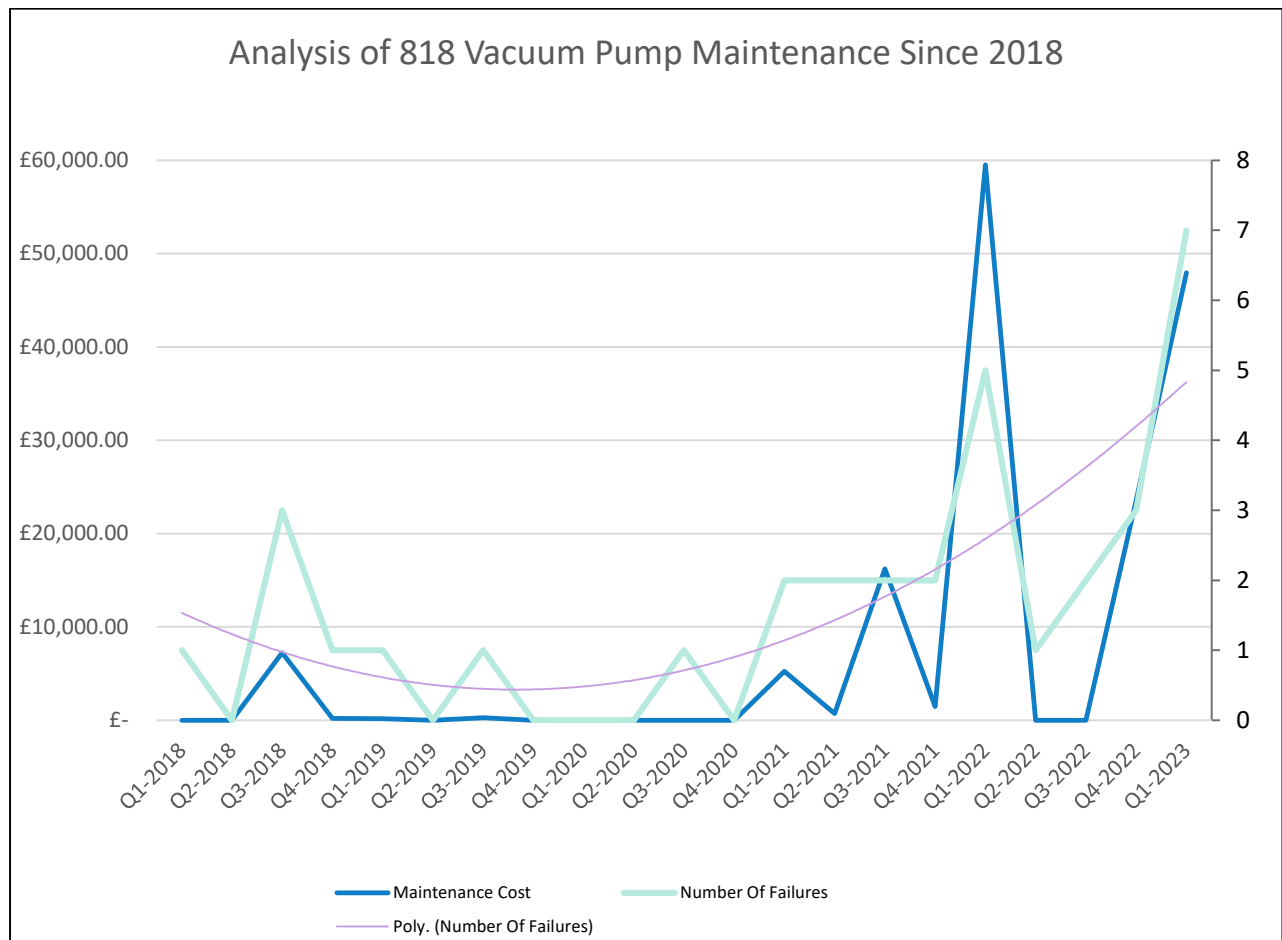


Figure 18 - Analysis of 818 Vacuum Pump Maintenance Since 2018

Compounding HCR low-pressure Barwell failures have been due to fatigue cracking. When a material experiences cyclic tensile stress over time, microcracks can form and propagate through the material until it reaches a point where the remaining portion abruptly cracks; this is called fatigue cracking (Nicholas, 1999). Only when stress changes, or when there are stress cycles, fatigue cracking takes place (Pyttel, Schwerdt and Berger, 2011). Cracks start to appear due to stress cycles (Tomkins, 1968). Any free surface can become the source of high-cycle fatigue cracks, but those near high-stress areas are especially vulnerable (Ballard *et al.*, 1995). In the case of the Barwells, cyclic fatigue is caused by the repeated pressurisation and force of the hydraulic ram extruding the product; this causes tension

and compression of the Barwell body cylinder. The primary method to prevent fatigue stress is to design the equipment to be less susceptible to fatigue cracking, this is achieved through consideration of materials, geometric design, stress release, stress avoidance and cycle reduction (Adams, 1972). It is possible to predict the cycle count before fatigue cracking occurs using the small-crack theory (Newman Jr, Phillips and Swain, 1999).

As the Barwells are second-hand, the complete history of the Barwells is unknown; therefore, fatigue cracking predictions cannot be calculated to estimate the duration before failure for each Barwell. Currently, the Barwells are run until a fatigue failure occurs, at which point a repair plan is established in accordance with the Pressure Systems Safety Regulations 2000 (PSSR). The repair process can take up to a month; this alone does not cause PSR losses, as there is capacity in the system to allow for one of the six Barwells to be offline. However, when other Barwells are taken offline for scheduled maintenance or a breakdown, this then causes PSR losses. The repair process involves extensive welding and heat treatment to return the equipment to a functioning state. In the case of the Barwells, it is not practical to redesign the equipment or change its function to prevent fatigue cracking. Therefore, it is recommended that the parts susceptible to fatigue cracking are held in stores as available replacements. The parts are on a 12-week lead time and are not an appropriate solution for breakdowns unless held on-site; the quote is available in Appendix 4. When the parts are available in stores, the strategy will be to run the Barwells until fatigue cracking occurs and replace the failed part with the stock item. This replacement strategy will take much less time than repairing the failed component and greatly reduce the vulnerability of the asset from other Barwell failures whilst the repair takes place.

14.3 Strategy

Below are all the PSR losses associated with equipment failure and maintenance in descending order. As this report is data-driven and there is a constraint on finance and resource to resolve reliability issues, the top PSR losses should be addressed to ensure our resource is allocated in the areas where most PSR gains are available.

W407 818 Vac Pump Failures	0.80%
Compounding HCR Low Pressure Barwell Failures	0.31%
W422 237 Pump Gearbox Failures	0.31%
Tilts 157 Mixer Bearing Failure	0.29%
BDM 177 mixer lid seal inadequate and allowing oxygen ingress	0.22%
W422 235 Pump Seal Failure	0.21%
VLVF and W422 Plants tripped due to PLC failure.	0.19%
W407 Hot Oil valve fails to operate	0.10%
Tilts sheared union on Process Water Supply to Colmec Mixer	0.10%
B383 No maintenance resource for leak repair	0.10%
GumRig steam leak to reactor jacket	0.09%
BDM No maintenance resource for filter change	0.09%
W422 sample point failure	0.07%
K250 202 stripper false running signal - low NVC	0.07%
W407 Catalyst flow valve 5098 failed to operate correctly	0.06%
BDM 177 Mixer failures	0.06%
Compounding FSR and HCR CTM Failures	0.06%
250 Kettle 200 Pump Failure	0.06%
W422 Dalmec Failure (1810 Bed Dump) - Unable to charge catalyst	0.06%
B383 382 Wildern pump failures	0.05%
BDM 277 Pick and Palace machine failures	0.05%
BDM 177 Pick and Palace machine failures	0.05%
250 Kettle 231 Pump Failure	0.05%
Tilts Colmec Mixer spindle stuck	0.05%
K250 Level transmitter on 550 tank failure	0.04%
BDM 277 Mixer failures	0.04%
BDM 277 Log Wapping machine failures	0.03%
Compounding FSR High-Pressure Barwell Failures	0.03%
Compounding HCR BDM Failures	0.03%
K903 726 scales failure	0.03%
Gum Rig 2587 Pump Coupling Failure	0.02%
250 Kettle 220 Pump Failure	0.02%
250 Kettle 202 Vessel Agitator Failure	0.02%

W407 818 Vacuum pump is the greatest equipment failure cause of PSR loss and has had increasing failures and maintenance costs in addition to a gamma value greater than one and obsolescence issues; therefore, a new vacuum pump system should be installed. 818 Vacuum pump should be a

high priority for the project team, with an implementation deadline of June 2023. From this deadline, Dow should expect the same rate of PSR losses from this pump until June and none after that. Therefore, Dow should expect a 0.40% PSR loss from 818 vacuum pumps in 2023 and no losses in 2024.

Purchasing the Barwell components susceptible to fatigue failures and storing them on-site is essential in reducing the PSR losses in Compounding HCR. Combined with implementing an ERS from 2022, this should eliminate PSR losses from the Barwells.

W422 237 and 235 are Ibex MOG 2030X gear pumps with Renold Carter gearbox reducers. These pumps are not obsolete; therefore, a preventative maintenance strategy can be established to reduce PSR losses from this equipment. Recommendations are to complete an ERA for the Ibex MOG 2030X pumps and Renold Carter gearbox; this should be extended to all pumps and gearboxes of the same model on site. Specific attention should be given to the failure modes that have caused historic PSR losses in this equipment to ensure these gaps are closed within the ERA. Implementing ERAs for this equipment should eliminate PSR losses for both pumps in 2023. Other Ibex MOG 2030X gear pumps with Renold Carter gearbox reducers include 236, 238 and 239 pumps on W422 pre-blenders; process details are included in Appendix 11. Although 236, 238, and 239 pumps did not cause any PSR losses in 2022, they will benefit from the ERA.

Due to a bearing failure, 157 mixer incurred 0.29% PSR losses; the mixer also incurred significant additional downtime in 2022. The additional PSR losses were categorised as Process Technology as opposed to Equipment Failure; accordingly, research and solutions to prevent further PSR losses from 157 mixer are detailed in the Process Technology section of this report. There will be a 0.29% PSR improvement in 2023 from the recommendations mentioned in the Process Technology section due to preventing further bearings failures.

VLVF and W422 Plants are vulnerable to PLC failures due to equipment obsolescence and incapability to maintain the current system. Therefore, a project is required to upgrade the current PLCs to meet Dow standards. The PLCs should be the second priority for the project team, with an implementation deadline of September 2023. With this deadline, Dow should expect to see the same rate of PSR losses from these PLCs until September and none after that. Dow should expect a 0.14% PSR loss from the PLCs in 2023 and no losses in 2024.

The BDM 177 mixer had multiple lid seal failures in 2022, resulting in a 0.22% PSR loss. After repeated failures, an RCA was completed; the RCA identified the project as the root cause of the failures. The RCA also identified an alternative upgrade that would satisfy the project and not affect the mixer lid

seal; these recommendations were implemented in June 2022. No further PSR losses have occurred from the mixer lid seal since, and no PSR losses should be expected in 2023 from the lid seal.

If the six recommended solutions to reduce equipment failure are implemented, the PSR improvements should be expected to total 2.91% in 2023, a 1.79% improvement on 2022, illustrated in Figure 19.

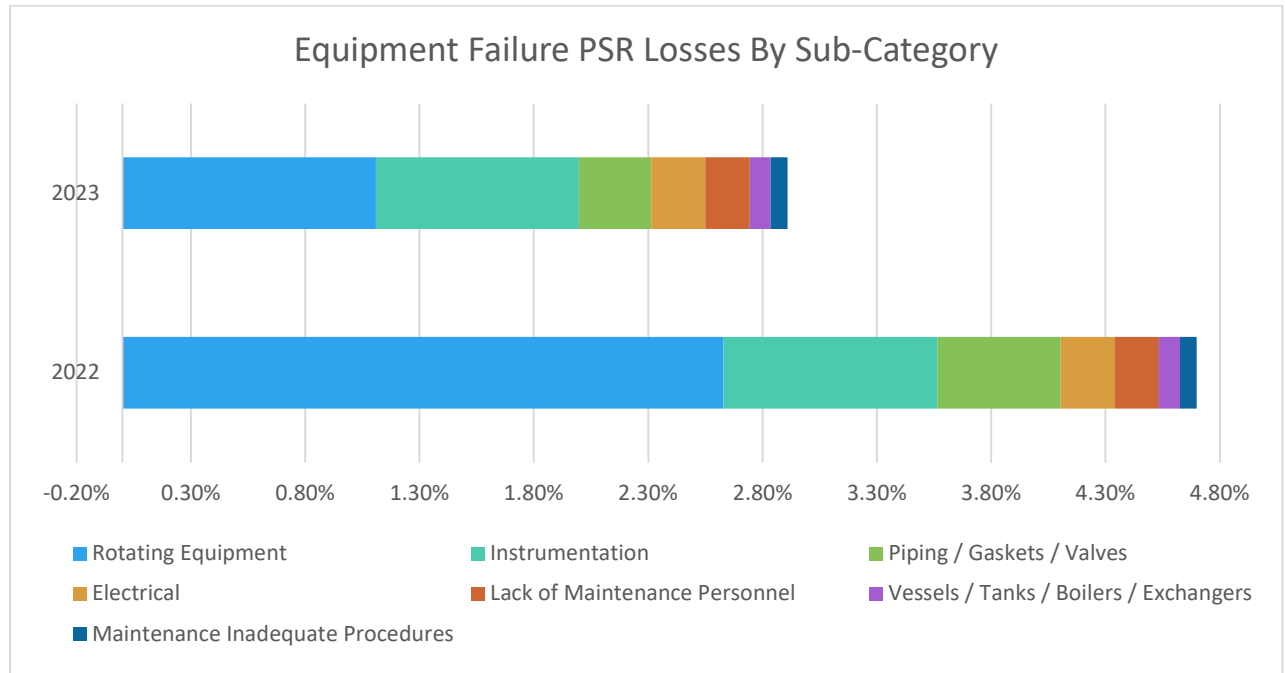


Figure 19 - Decrease in PSR Losses for Equipment Failures if Proposed Solutions are Implemented Successfully in 2023

15 Budgeted Turnaround

15.1 Data and Statistics

Budgeted turnarounds were the third largest category of PSR losses from January to October 2022, accumulating in 1.69% of reliability losses. Turnarounds are dedicated time in the production schedule when the process is taken offline to complete essential, often regulatory maintenance (Lenahan, 2011). Budgeted Turnarounds have multiple Dow AU subcategories, many of which do not contribute to PSR losses (as seen in Table 4); this is because the production downtime is planned and scheduled beforehand and communicated to the business so that reduced production can be planned for. Budgeted Turnaround subcategories that contribute to PSR losses are scenarios when the planned duration of the turnaround is exceeded due to poor execution or discovery of additional maintenance.

Table 4 - Budgeted Turnaround Subcategories that Contribute to PSR Losses

Budgeted Turnaround Sub-category	PSR Loss
3.01 Scheduled Maintenance Turnaround	No
3.02 Shutdown / Clear / Start-up (for Budgeted Turnaround)	No
3.03 Extended Turnaround due to Discovery	Yes
3.04 Extended Turnaround due to Poor Execution	Yes
3.05 Opportunistic Maintenance Turnaround during Lack of Demand	No
3.06 Element (Catalyst) Change during Turnaround	No
3.07 Opportunistic Element (Catalyst) Change during Lack of Demand	No
3.08 Process Cleaning during Turnaround	No
3.09 Opportunistic Process Cleaning during Lack of Demand	No

The subcategories of budgeted turnaround PSR losses are illustrated in Figure 20. From January to October 2022, there were two budgeted turnaround PSR losses. The greatest loss was from the Gum Rig turnaround overrunning due to poor execution. The PSR loss for this was 1.67%, a total of 1,156 hours (48 days) of unplanned downtime. The second PSR loss due to budgeted turnaround was due to the discovery of additional work on 150 Kettle; this caused a PSR loss of 0.02%, 213 hours (9 days) of additional downtime.

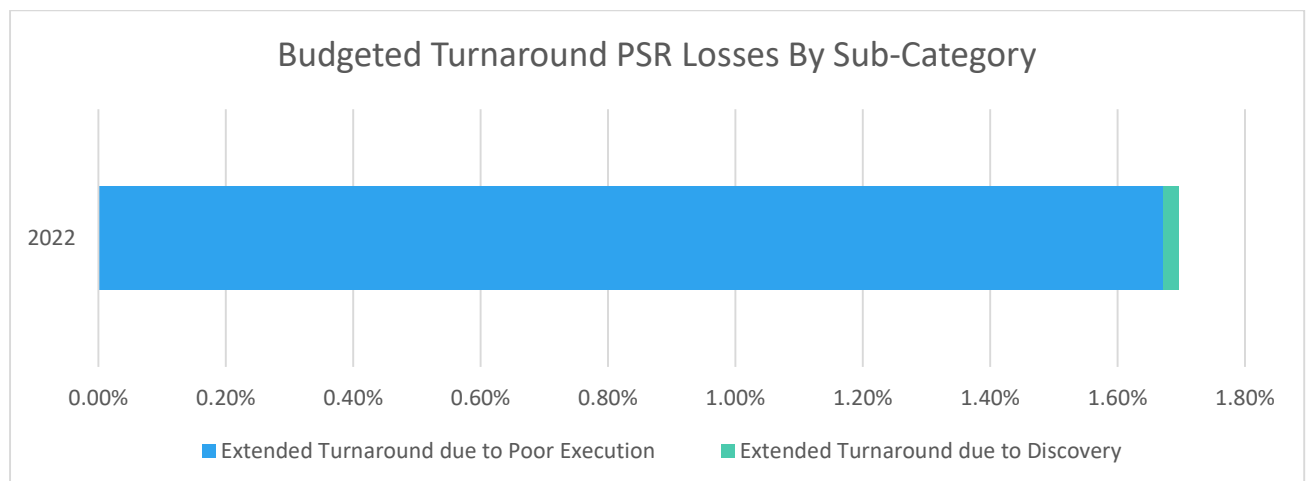


Figure 20 - January to October Budgeted Turnaround PSR Loss Sub-Categories

15.2 Research

Turnarounds are common in petrochemical and many other manufacturing industries with continuous production (Duffuaa and Ben Daya, 2004). Dow's long-term turnaround strategy schedules a major turnaround every two years for reliability work and a minor turnaround in-between each year, for only regulatory and compliance work to be completed. Most of the site's production is shut down during turnarounds except for some Finishing batch assets; these include the BDM's, Compounding FSR, Compounding HCR, Tilts, 1303 Kettle, 150 Kettle and 903 Kettle (Cleaver, 2023). The finishing batch assets that do not require their turnarounds to be aligned with basics have their turnarounds staggered throughout the year to reduce the strain on the resource required to plan and execute the turnarounds. All turnarounds are scoped, planned and scheduled by the turnaround team; work is executed using the plant maintenance and operations teams.

The 1.67% PSR loss from Gum Rig turnaround overrunning due to poor execution was not a result of planned maintenance during the turnaround; the delay was incurred post-maintenance during startup. It is unclear what startup issues caused the 48-day delay; therefore, an RCA should be completed to identify the root cause of the delays and implement control measures to prevent repeat losses.

The Gum Rigs' inability to provide a reliable supply of Gum for BDM's and Tilts has resulted in the largest raw material shortage in finishing and caused a 0.98% PSR loss for Finishing⁹. The Gum Rig asset reliability was 61.7%, compared to its 85.3% goal; therefore, there is an enormous opportunity for improvement. The greatest reliability improvement opportunity for the Gum Rig is the losses associated with the budgeted turnaround, as indicated in Table 5.

Table 5 - Gum Rig PSR Loss Categories

Loss Category	PSR Loss
Budgeted Turnaround	17.0%
Raw Material Shortage or Availability	7.6%
Logistics	5.0%
Operations Operating Discipline	1.7%
Product Transfer Limitations	1.7%
Equipment Failure and Maintenance OD	1.3%
Utilities	1.1%
Total PSR losses	35.4%

A 0.02% PSR loss occurred due to the discovery of additional work on 150 Kettle during a routine compliance inspection of 150 vessel. The Integrity Engineer was completing an inspection of the vessel's internals remotely with a camera; it was identified that bolts were missing that should secure the vessel's baffles to the vessel framework. The vessel had to be prepared for a Confined Space Entry (CSE) to allow a Maintenance Technician to enter the vessel and replace the fasteners. To provide a CSE, Dow administers additional layers of protection, illustrated in Appendix 12. These additional layers of protection take time to implement and remove once the maintenance is completed. This additional work for the CSE was not scoped or planned for during the turnaround.

Budgeted turnaround PSR losses are seen each year. However, the losses seen in 2022 are greater than in previous years, illustrated in Figure 21. Losses are inevitable due to the discovery of additional work and aggressive turnaround deadlines. Before the increased 2022 losses, the average PSR loss due to budgeted turnaround was 0.44%.

⁹ The raw material shortages associated with the Gum Rig were discussed in detail in the Raw Material Shortage section for this report.

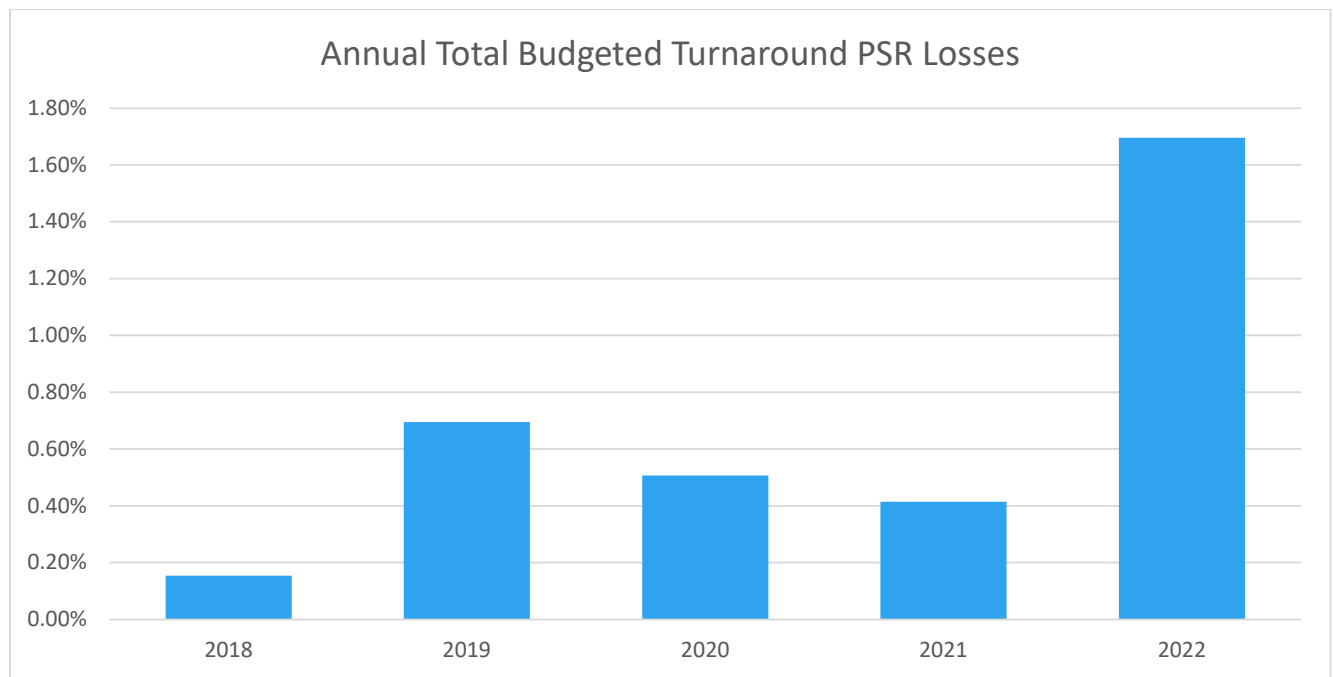


Figure 21 - Annual Total Budgeted Turnaround PSR Losses

15.3 Strategy

The 1.67% PSR loss due to poor execution of the GumRig turnaround is the single largest loss incident in 2022, illustrated in Table 6. Completing an RCA to identify the root cause of the start-up delays and implement control measures to prevent repeat losses should be the top reliability priority in 2023.

Table 6 - Top Five Finishing PSR Losses January - October 2022

PSR Loss Description	% of PSR Loss
Gum Rig Extended Turnaround due to Poor Execution	1.67%
Tilts 157 mixer jacket chloride stress corrosion cracking	1.19%
No gum from Gum Rig for BDM's and Tilts	0.98%
W407 818 Vac Pump Failures	0.80%
Poor raw material planning resulted in a shortage of 4-2812 catalyst for the BDM's	0.67%

The 2023 Gum Rig turnaround is scheduled for June 2023; therefore, the RCA should be completed with all its control measures implemented before the turnaround takes place. Dow should expect no PSR losses from Gum Rig extended turnaround due to poor execution in 2023 and beyond.

Dow should still expect PSR losses from budgeted turnarounds due to the challenging turnaround windows provided for maintenance and discovery of additional work. In 2023 the reliability strategy should expect to incur the historical average of 0.44% PSR losses from budgeted turnarounds.

16 Operating Discipline

16.1 Data and Statistics

Operating Discipline was the fourth largest category of PSR losses from January to October 2022, resulting in 1.7% of reliability losses. The operating discipline category is distributed into sub-categories, illustrated in Figure 22.

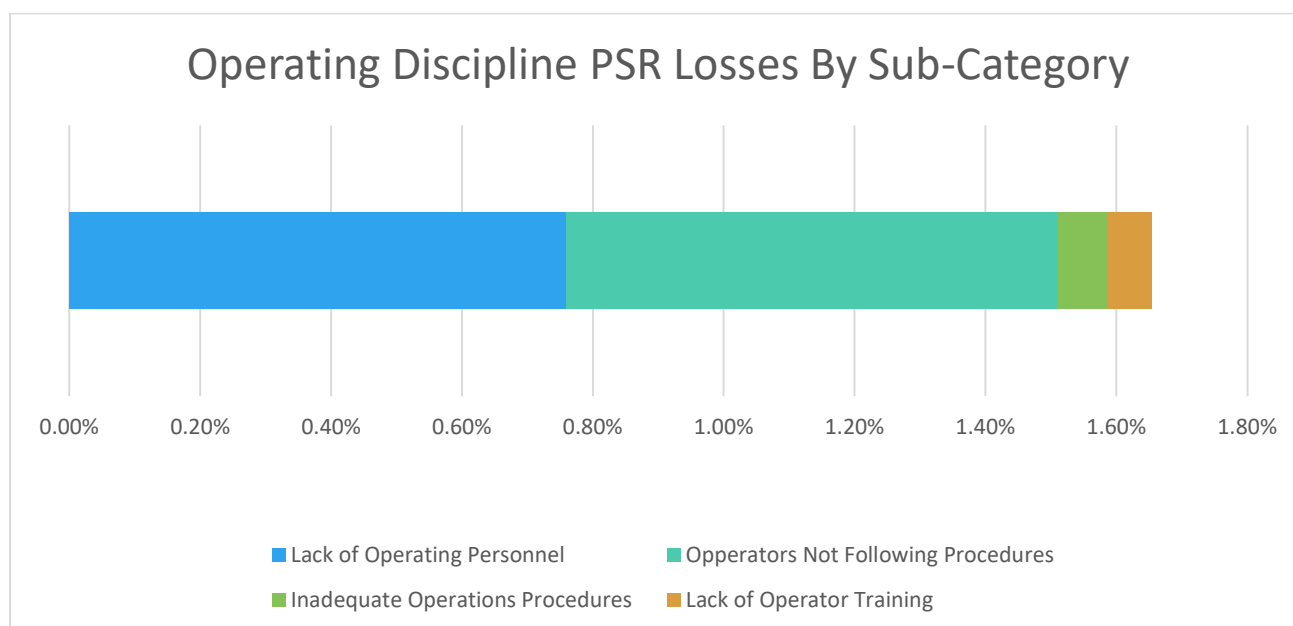


Figure 22 - January to October 2022 Operations and Operating Discipline PSR Loss Sub-Categories

Lack of operating personnel was the largest operational discipline shortfall contributing to PSR losses of 0.76%; this was accumulated from two significant losses¹⁰:

B383, K1303, K150 and K250 operators shared and prioritised for W407 and CHU	0.27%
BDMs, HCR, FSR and W407 Covid illness reducing available operator numbers	0.27%

0.27% PSR losses were caused by operators running multiple assets and consequently being unable to simultaneously complete operator tasks required on multiple plants. Polymers operators typically manage multiple plants; they must prioritise different assets when they are too busy. Operators align with the production coordinator to ensure correct asset prioritisation. Typically, W407 and the CHU are a higher priority than other Polymers assets; this is reflected in the data.

¹⁰ There are additional PSR losses that are statistically insignificant (<0.01%)

Low operator numbers caused 0.27% PSR losses due to Coronavirus. Dow implemented robust policies during the Coronavirus pandemic to meet legal obligations and protect their employees and production capabilities; these are illustrated in Figure 23 and further supporting documentation is available in Appendix 10.

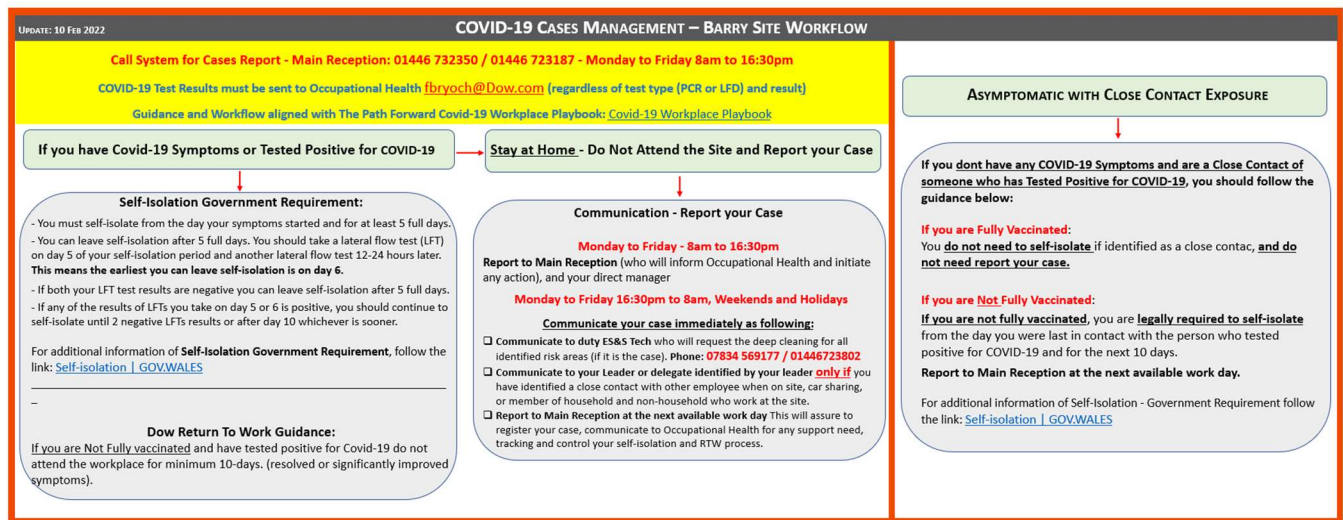


Figure 23 - Dow Barry Site Covid-19 Management Workflow

The Dow Covid-19 policies were continually updated to respond to changing risks. In 2022 there was no mandatory requirement for isolation; however, in some cases, employees were unable to attend work due to the virus. Dow operations utilise a 'primary cover' system, where one operator not at work remains on call to provide cover for any employee absences. However, if there are two absences, there is no obligation for cover; this can reduce operator numbers to a point where asset manning must be prioritised.

Operators not following procedures caused the second largest operating discipline shortfall contributing to PSR losses of 0.75%. There were sixty-nine incidences of operators not following procedures from January to October 2022, all of which had a very low PSR impact. However, if the data is combined by asset, the PSR impact of operators not following procedures can be seen, illustrated in Figure 24.

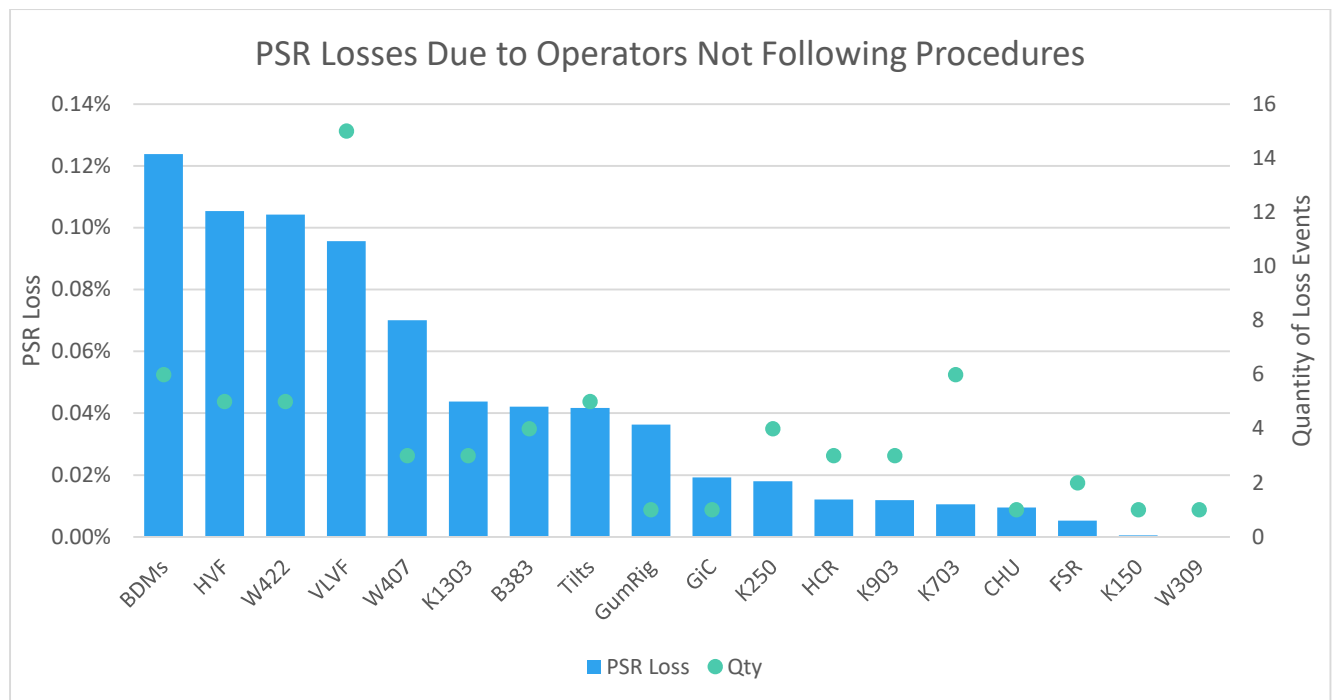


Figure 24 - PSR Losses Due to Operators Not Following Procedures by Asset Including Quantity of Losses

Figure 24 illustrates what percent impact and the quantity of events each asset has had due to operators not following procedures. The quantity of events is significant as an asset may have a high frequency of events but with a low PSR impact because the asset has a low MAC and provides a relatively small contribution to the weighted PSR total for finishing. VLVF and K703 have a relatively high frequency of losses but with a lower weighted PSR impact on Finishing. The quantity of losses is important, as although this report is directed at reliability improvements; procedures are for safety as well as production, and high procedure adherence contributes to a safe and reliable plant.

Inadequate operating procedures were the third largest operating discipline shortfall contributing to PSR losses of 0.08%; this was accumulated from two significant losses¹¹:

HVF container requirements not specified	0.05%
VLVF operating procedures inadequate for grade changes	0.03%

HVF container requirements were not specified within the procedure resulting in a 0.05% PSR loss. The PSR loss was a single occurrence, the procedure would have had to be corrected for the operators to continue the production task, and no further losses were seen.

VLVF operating procedures inadequacies resulted in 0.03% PSR losses. The PSR losses were combined from four occurrences. Repeated losses indicate that the steps within the procedure are safe and

¹¹ There are additional PSR losses that are statistically insignificant (<0.01%)

possible to complete; however, they result in a less than effective way to manage a production grade change resulting in PSR losses.

Lack of operator training was the smallest operator discipline loss category contributing to 0.07% PSR losses. Three PSR losses were associated with this loss category, all caused by operators making mistakes during their training period.

16.2 Research

Coronavirus resulted in PSR impact during 2022 due to operators being unwell and unable to attend the site. Figure 25 shows the daily cases by date of specimen for London (Greater London Authority City Intelligence, 2023). Trends in UK Coronavirus data closely follow London data (Howarth *et al.*, 2021). UK regional coronavirus data is not published as frequently in 2023 as London data and no reliable up to date data is available for the South Wales area (Halford *et al.*, 2022). Figure 25 shows there has been a significant decrease in Coronavirus cases in the second half of 2022 and the beginning of 2023. All the PSR losses from Coronavirus were recorded in the first half of 2022. From this data, it could be surmised that it is less likely to see PSR losses from Coronavirus throughout 2023.

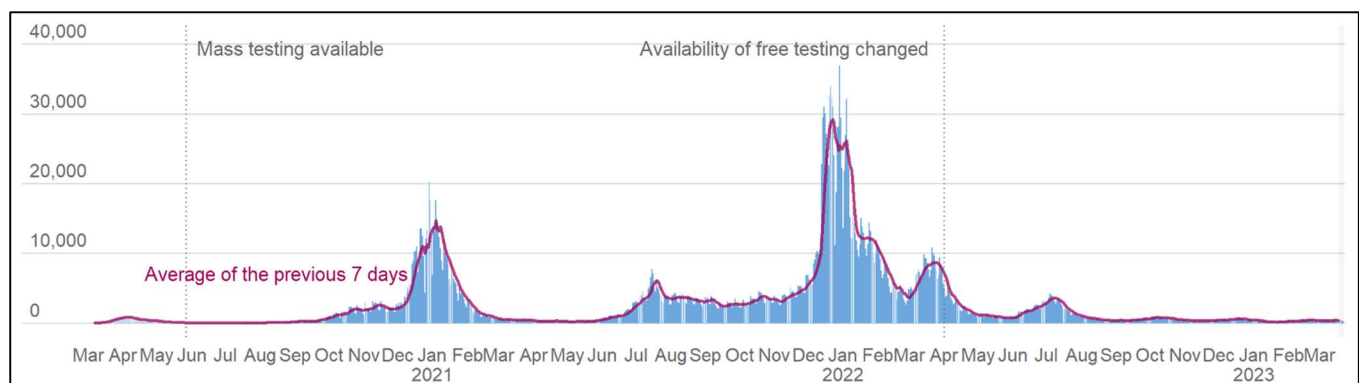


Figure 25 - Daily Coronavirus cases by Date of Specimen (Greater London Authority City Intelligence, 2023)

Dow introduced compulsory procedure use for all maintenance and operations tasks in 2020. A trial period through 2019 allowed for most procedures to be developed and tested; the Dow procedure use policy is attached in Appendix 5. The change to compulsory procedure use was met with resistance from the operations and maintenance teams, illustrated in Figure 26 as a Force Field Analysis diagram (Lewin, 1951).

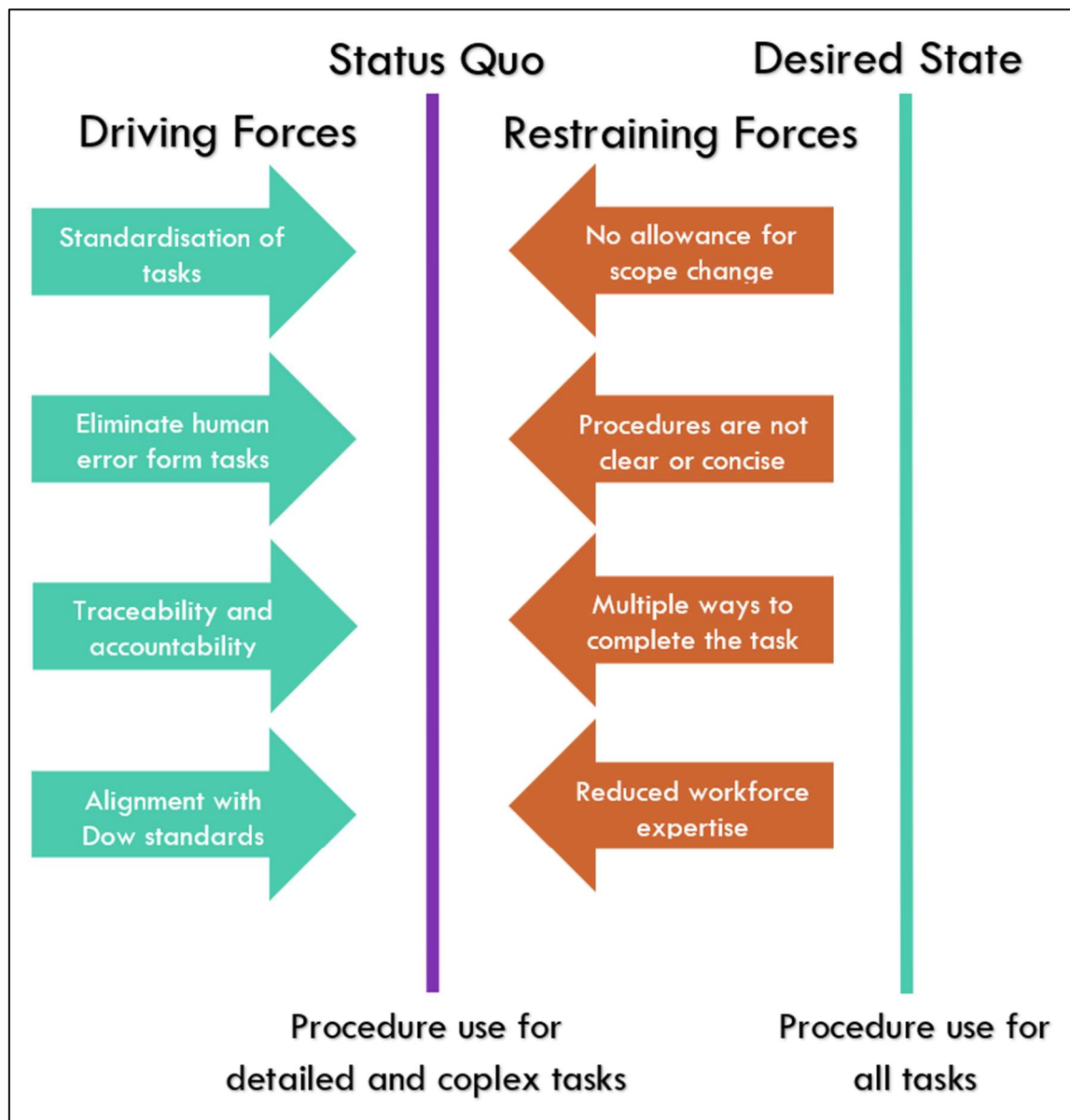


Figure 26 - Force Field Analysis of Procedure Use Policy

Figure 27 illustrates The Change Curve (Kübler-Ross, Wessler and Avioli, 1972); it identifies a model for the seven stages people experience during change. Different operators/groups of operators are at various stages of the change curve. Operators who have not followed procedures will likely resist changes from the procedure use policy; therefore, they are not as far along the change curve.

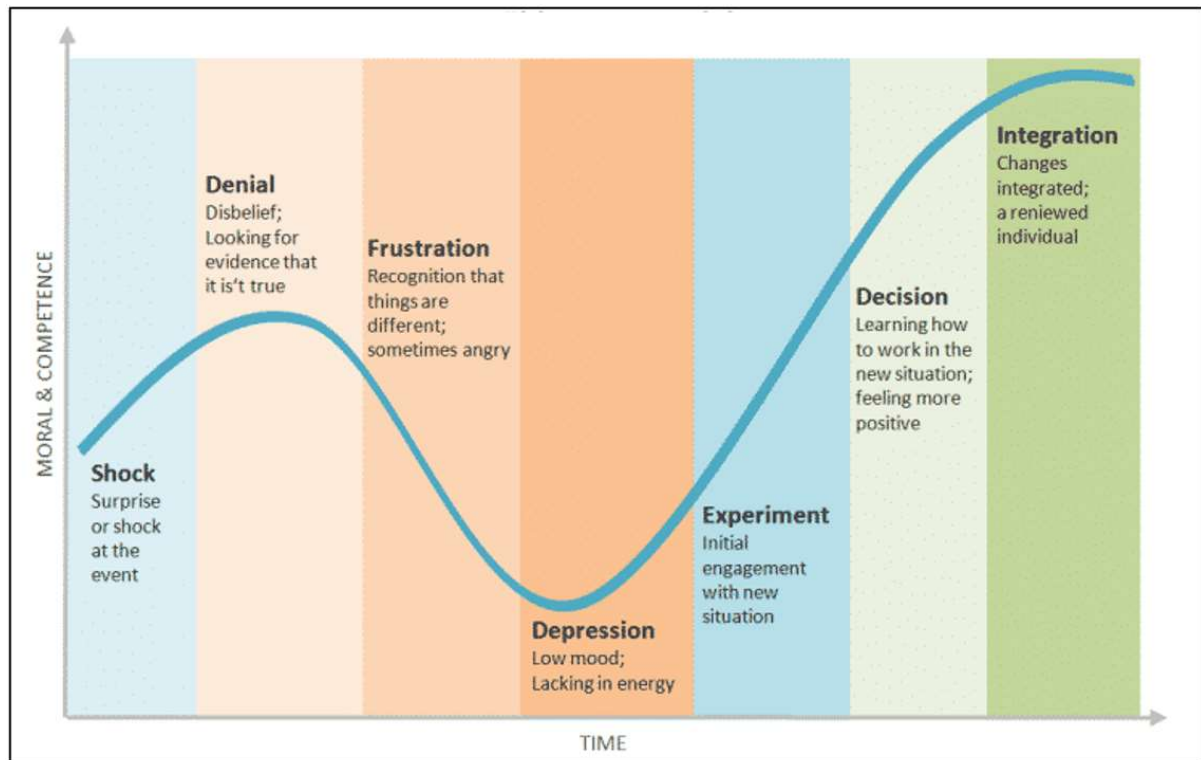


Figure 27 - The Change Curve (Kübler-Ross, Wessler and Avioli, 1972)

The eight-step process to manage change (Kotter, 2012) is illustrated in Figure 28. Kotter's eight-step strategy for change provides a clear description and guidance on the entire change process; it is a strategy to manage the acceptance of the change, not the change itself (Pollack and Pollack, 2015).



Figure 28 - Eight Step Organisational Change Model (Kotter, 2012)

The Eight Step Organisational Change model could be used to promote positive acceptance towards procedure use policy. This change model would increase acceptance of the change and reduce PSR losses due to operators not following procedures.

16.3 Strategy

Below are all the PSR losses associated with operating discipline in descending order. There is a constraint on finance and resource to resolve reliability issues, so the top PSR losses should be addressed to ensure resource is allocated in the areas where most PSR gains are available.

Combined operators not following procedures	0.75%
B383, K1303, K150 and K250 operators shared with and prioritised for W407 and CHU	0.27%
BDMs, HCR, FSR and W407 Covid illness reducing available operator numbers	0.27%
HVF container requirements not specified	0.05%
VLVF operating procedures inadequate for grade changes	0.03%

The assets with the highest PSR impact from operators not following procedures were BDMs, HVF, W422, VLVF and W407, resulting in a combined PSR loss of 0.50%. VLVF also had the highest frequency of PSR losses caused by operators not following procedures. To reduce PSR losses from operators not following procedures, the procedures should be reviewed with the operating team. The eight steps of organisational change model should be followed, and the procedure writers need to involve the operators for these assets to engage and enable the operating team. The procedure writer is most commonly the run plant engineer; they should utilise the operators to review and amend the procedures so that the operations team have ownership of the detail within the procedures. This change should be implemented firstly for VLVF, followed by the BDMs, HVF, W422 and W407. Engaging with the operators will help educate them on the benefits of procedure use and utilise their ideas and experience in creating fit-for-purpose procedures that they have ownership of.

Following the eight steps of change to create an accepting culture of the procedure use policy will not eliminate losses from BDMs, HVF, W422, VLVF and W407 due to operators not using procedures; however, it should reduce the losses to the level of the other assets. The other assets have an average PSR loss of 0.02 % due to operators not following procedures. Therefore, Dow should expect a 0.36% PSR loss for the eighteen assets combined in 2023, which is a 0.39% improvement on the PSR loss in 2022.

Coronavirus resulted in a 0.27% PSR impact during 2022 due to operators being unwell and unable to attend the site. The losses were all seen in the first half of 2022; as the UK Coronavirus infection rate

trend has decreased since 2022, Dow should expect no further PSR losses from operator absence due to Coronavirus.

If the two proposed solutions to reduce operational discipline PSR losses are implemented, the losses should be expected to total 0.99% in 2023, a 0.66% improvement on 2022, illustrated in Figure 29.

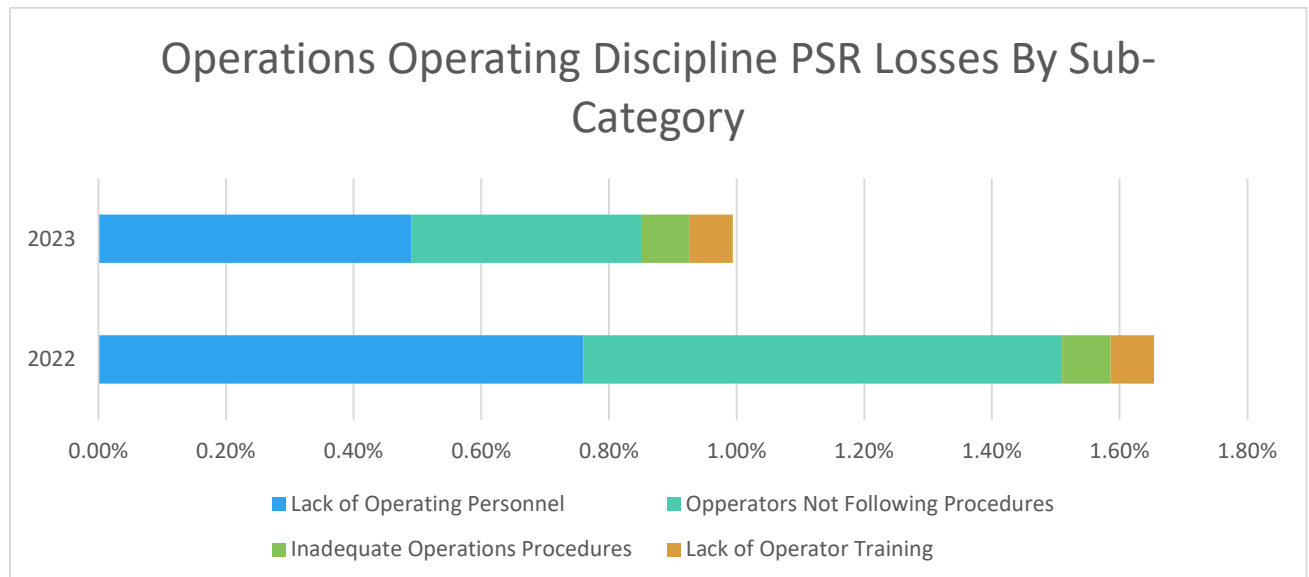


Figure 29 - Decrease in PSR Losses for Operational Discipline if Proposed Solutions are Implemented Successfully in 2023

17 Process Technology

17.1 Data and Statistics

Process Technology was the fifth largest category of PSR losses from January to October 2022, resulting in 1.56% of reliability losses. The process technology category is distributed into sub-categories, illustrated in Figure 30.

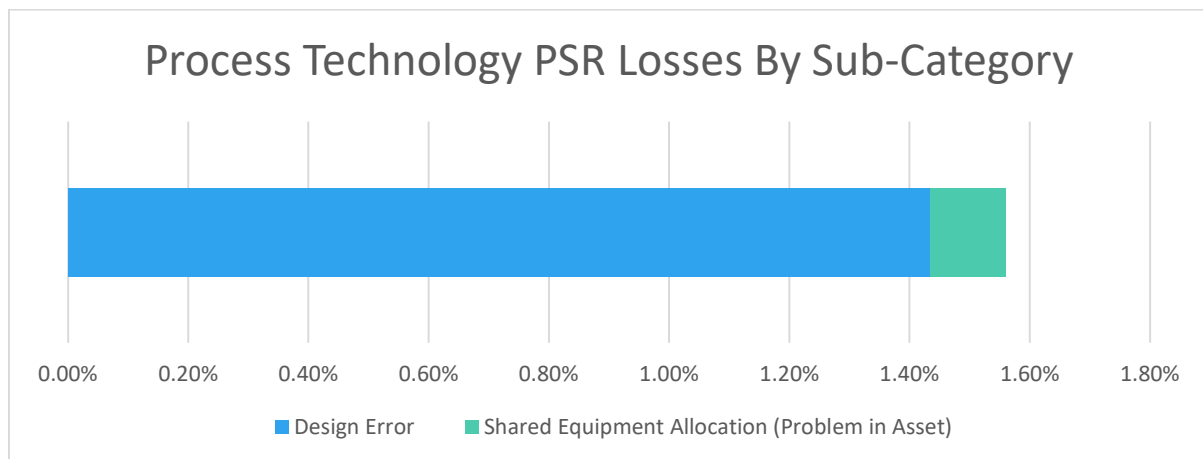


Figure 30 - January to October 2022 Process Technology PSR Loss Sub-Categories

Design error was the largest process technology shortfall contributing to PSR losses of 1.43%; this was accumulated from three significant losses¹²:

Tilts 157 mixer jacket chloride stress corrosion cracking	1.19%
BDM 177 mixer bearing failure - sleeve tolerances too tight	0.17%
Gum Rig 591 pump is not optimal for catalyst duty	0.05%

The 157 tilt mixer (Figure 31) is one of two identical mixers that mix rubber products for the asset Tilts. The 157 mixer supplies half of the asset's production needs. The Tilts are a batch process with a turnaround for cleaning between each batch. When one mixer is offline, it reduces the asset capacity by 50%. The 157 tilt mixer experienced a crack in the mixer jacket. The jacket is a void on the outside of the mixer, where water is flushed through to dissipate heat from the mixer. When operational, the mixer temperature rapidly increases due to friction between the highly viscous product and the blades. The crack in the mixer jacket resulted in a water leak that was unacceptable to continue manufacturing with. The mixer had been subject to historic cracks in its jacket; therefore, extensive fabrication was required to repair the crack. The mixer was removed from plant and transported to an offsite fabrication shop for the repair to be completed. Due to the crack in the mixer jacket, 157

¹² There are additional PSR losses that are statistically insignificant (<0.01%)

mixer was offline for eighty-six days resulting in a 1.19 PSR loss for finishing. When the mixer was rebuilt on site, the bearings were not installed correctly, which resulted in a 0.29% PSR loss; this loss was categorised as equipment failure in Dow AU.



Figure 31 - 157 Tilt Mixer

BDM 177 mixer bearing failure resulted in 0.29% PSR losses. The 177 mixer bearing sleeves are sacrificial bearing components replaced yearly on a preventative maintenance plan. The manufacturer provided out-of-tolerance bearing sleeves; these were unknowingly installed; however, during operation, the bearings heated up and expanded, causing mechanical contact with the out-of-tolerance bearing sleeves. 177 mixer had to be shut down, the bearings removed, and new bearings had to be provided by the manufacturer before the bearing could be reassembled and the mixer recommissioned. Due to the bearing failure, the 177 mixer was offline for eight days resulting in a 0.29% PSR loss.

17.2 Research

During the failure 157 mixer jacket, an RCA was completed. The RCA concluded that the crack was caused by chloride stress corrosion cracking; the RCA summary is available in Appendix 6. This conclusion is supported through independent lab testing on a cross-section of the mixer jacket where the failure occurred; the full report is available in Appendix 7.

Chloride Stress Corrosion Cracking (CSCC) is a form of localized corrosion that can occur in certain metals when exposed to an environment containing chlorides (Rhodes, 1969). This type of corrosion is often difficult to detect and can lead to catastrophic failure of the metal (Truman, 1977). CSCC can occur in ferrous and non-ferrous metals but is most commonly seen in stainless steel and other chromium alloys (Pugh, 1985).

CSCC is often seen in environments combining high stress, high humidity, and high temperatures (Scully, 1968). This type of corrosion can also occur in metals that have been damaged or contain defects (Newman and Procter, 1990). CSCC can occur slowly and remain undetected for many years (Ghosh et al., 2011). The first sign of CSCC is usually a small leak or crack in the metal (Galanti et al., 2021). If left unchecked, CSCC can lead to the complete failure of the metal (Kain, 2011). The main way to prevent CSCC is to use materials resistant to chlorides, such as austenitic stainless steels (Ghosh and Kain, 2010).

17.3 Strategy

The 1.19% PSR loss from the Tilts 157 mixer jacket chloride stress corrosion cracking is the second-largest PSR loss incident in 2022, illustrated in Table 7. CSCC is an irreversible chemical failure mechanism; therefore, the 157 mixer requires replacement. Once the RCA was completed on the 157 mixer, a project was initiated to replace the mixer with a jacket designed from materials known to prevent CSCC. The replacement 157 mixer will arrive on site in May 2023 and should be prioritised for immediate installation. Due to the unknown operating history of the current 157 mixer, it is impossible to predict when the next chloride stress corrosion crack will occur. The last time CSCC occurred on the mixer was in 2018; therefore, it can be assumed there should be no PSR losses from CSCC on the 157 mixer before the installation of the new mixer in May. Dow should expect no PSR losses from the asset Tilts due to 157 mixer jacket failures in 2023 and beyond.

Table 7 - Top Five Finishing PSR Losses January - October 2022

PSR Loss Description	% of PSR Loss
Gum Rig Extended Turnaround due to Poor Execution	1.67%
Tilts 157 mixer jacket chloride stress corrosion cracking	1.19%
No gum from Gum Rig for BDM's and Tilts	0.98%
W407 818 Vac Pump Failures	0.80%
Poor raw material planning resulted in a shortage of 4-2812 catalyst for the BDM's	0.67%

18 Reprocessing and Blending

18.1 Data and Statistics

Reprocessing and Blending was the sixth largest category of PSR losses from January to October 2022, resulting in 0.92% of reliability losses. The reprocessing and blending category is distributed into sub-categories, illustrated in Figure 32.

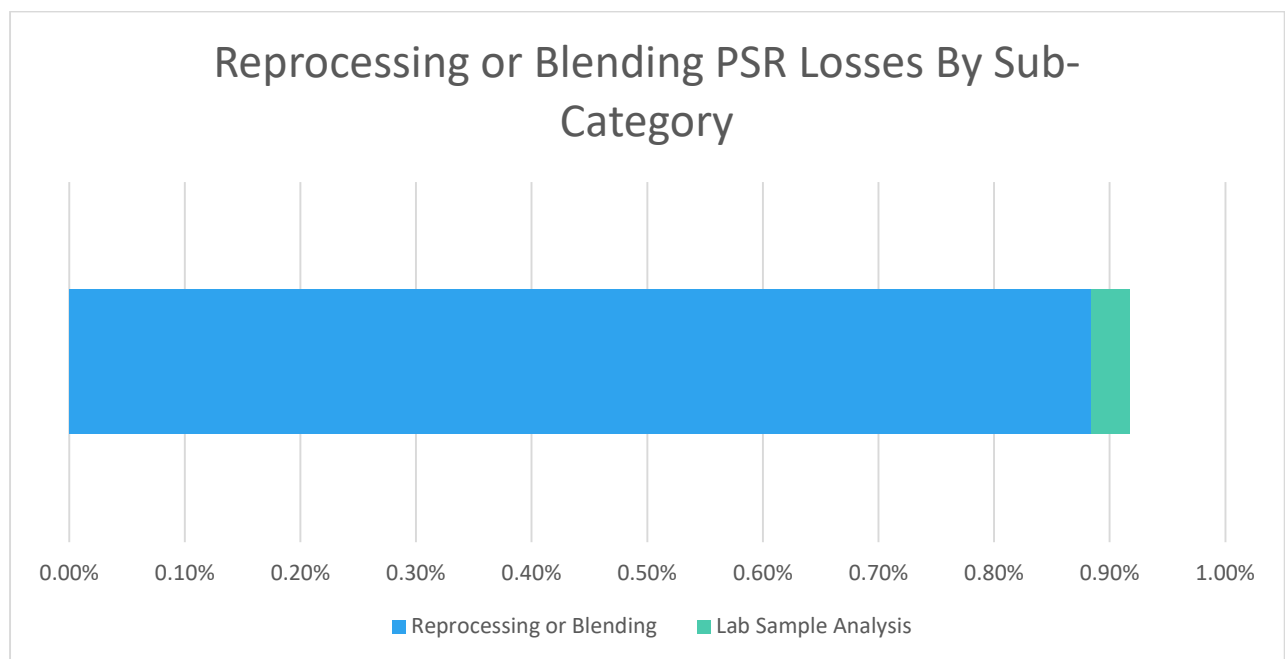


Figure 32 - January to October 2022 Reprocessing or Blending PSR Loss Sub-Categories

Reprocessing or blending was the largest shortfall contributing to PSR losses of 0.88%. There were ninety-five incidences of reprocessing or blending from January to October 2022, all of which had a very low PSR impact. However, if the data is combined by asset, the PSR impact of reprocessing or blending can be seen, illustrated in Figure 33.

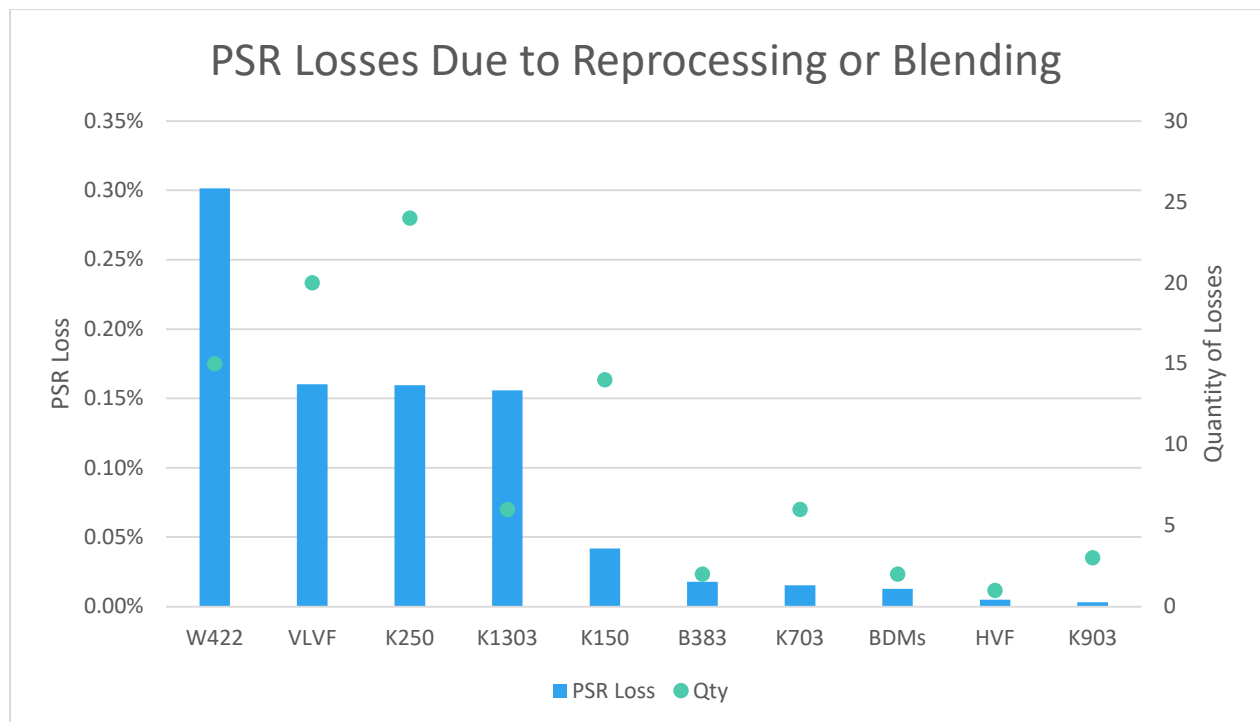


Figure 33 - PSR Losses Due to Reprocessing or Blending by Asset Including Quantity of Losses

Figure 33 illustrates the percentage off loss and the quantity of events each asset has had due to reprocessing or blending. The quantity of events is important because an asset may have a high frequency of events but with a very low PSR impact. K150 has a relatively high frequency of losses but with a lower PSR impact. W422 has the highest PSR impact, although it does not have the highest quantity of reprocessing or blending losses; as it has the highest MAC, losses from this plant have a greater impact.

Lab sample analysis was the second largest reprocessing or blending shortfall contributing to PSR losses of 0.03%. Twenty separate production delays were associated with lab sample analysis from January to October 2022, each with a low PSR impact.

18.2 Research

Reprocessing is treating a batch product of unacceptable quality through repeating production steps to improve the quality of the product (Sharratt, 1997). Blending is the process of mixing a small amount of out-of-specification product with a large amount of in-specification product to ensure the quality of the combined batch is acceptable (French, 2008). Reprocessing and blending are quality

improvement methods to reduce the amount of waste material (French and Disenza, 2006). Reprocessing or blending is a significant problem in process industries for a variety of reasons:

- Set up time
- Resource restrictions
- High cost
- Risk of operational failure
- Lack of original process control
- Practicalities of rework

(Flapper *et al.*, 2002).

Therefore, rather than improving rework management to reduce the time spent reprocessing or blending products, the original cause that prevented the products from meeting its specification should be investigated (Agnihotri and Kenett, 1995). The overall value of reprocessing should also be established to ensure the production time spent reworking products is not more costly than discarding the out-of-specification product (Clegg, Williams and Uzsoy, 1995). Reworking is often an inevitable outcome in complex batch manufacturing processes when out-of-specification partially processed material has received a high production investment (Lee, 1992).

18.3 Strategy

PSR is impacted through reprocessing and blending; however, these are not directly proportional to production losses as rework and blending produces products that meet their specification. For this reason, and the proportionally low PSR impact from reprocessing and blending, it is not an area of improvement where time and resources should be heavily invested.

An RCA could be completed to identify the cause of reprocessing and blending. The operations team should carry out this RCA as they have the best knowledge and understanding of the production process. Minimal recommendations have been made throughout this report for the operations team; therefore, utilising this team for reliability work balances the workload evenly throughout the organisation. W422 should be the asset in which the first RCA in reprocessing a blending should be completed, as it has a relatively high quantity of PSR losses and a high weighting on Finishing PSR. If the outcomes of the W422 RCA are effective, then RCAs on VLVF, K250 and K1303 should be completed, as these have the next highest quantity and PSR losses from reprocessing and blending in 2022. If the outcomes of the W422 reprocessing and blending RCA are ineffective, with no PSR improvement seen, no further RCAs should be completed to ensure time and resource is not wasted. The RCA should be directed to find the root cause of the out-of-specification products requiring reprocessing and blending and should identify low-cost control measures. High-cost solutions would not be supported due to the relatively low PSR impact and return on investment.

The PSR losses for reprocessing and blending are relatively low, and there are cost and resource constraints upon reliability improvements in 2023. The RCA into identifying the cause of out-of-specification products requiring reprocessing and blending should not be prioritised. Therefore, Dow should not expect any PSR improvements in reprocessing and blending in 2023.

19 Logistics

19.1 Data and Statistics

Logistics was the seventh largest category of PSR losses from January to October 2022, resulting in 0.89% of reliability losses. The logistics losses are distributed into sub-categories, illustrated in Figure 34.

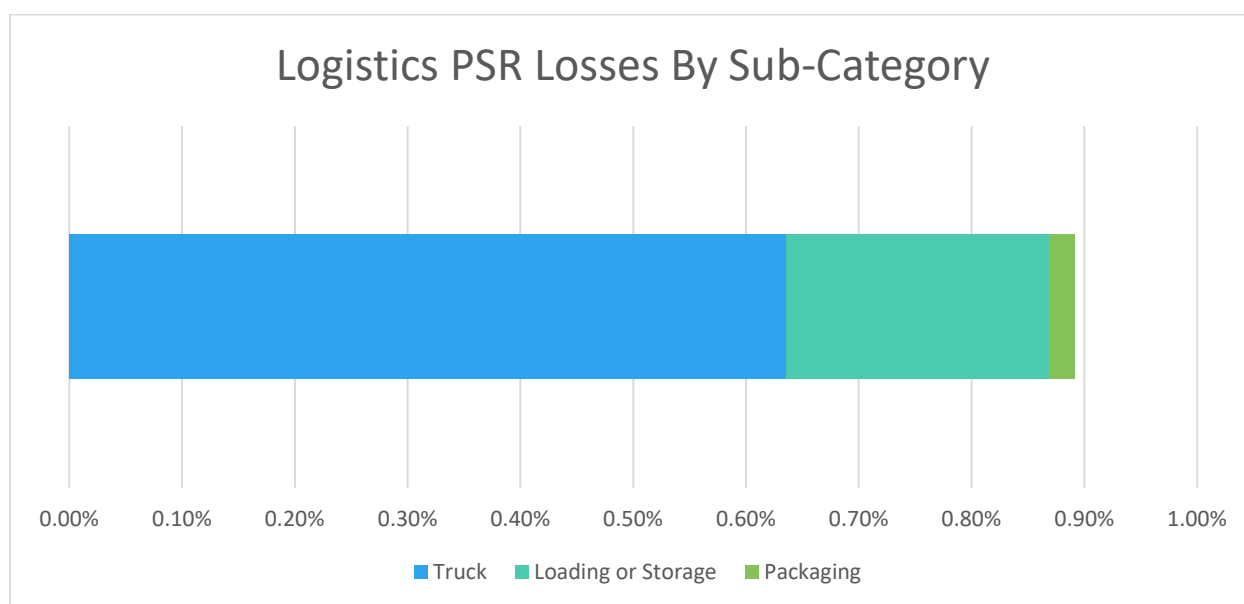


Figure 34 - January to October 2022 Logistics PSR Loss Sub-Categories

Trucks were the largest logistics shortfall contributing to PSR losses of 0.64%; this was accumulated from the following losses¹³:

B383, CHU, K250, W407 shortage of road tankers	0.62%
B383 Forklift truck delays	0.01%

Sixteen instances of road tanker shortages accumulated in 0.62% PSR losses. Dow owns the road tankers, which are managed by the site logistics team. The road tankers are shared with all Dow plants globally and must comply with each county's road and chemical transportation standards. Road tankers are the primary method for off site product distribution, some products are also transported in IBCs or drums, which are transported by trucks controlled by the site logistics team. Batch assets require products to be fully offloaded into their relevant road tanker before the next batch can be manufactured; therefore, tanker delays can quickly cause PSR losses. There are many different road

¹³ There are additional PSR losses that are statistically insignificant (<0.01%)

tankers on site, and each product must be offloaded into the correct tanker. In addition to providing the plant with road tankers, the logistics team connect and disconnect the road tankers from the process. Therefore, delays can occur from limited resources to connect and disconnect tankers.

Forklift trucks are used on most finishing assets to transport raw materials to the process. Forklift trucks are also used to transport finished products packaged in IBCs and Drums to be loaded onto trailers. There is a pool of forklift trucks shared within the finishing plants.

Loading and storage was the second largest logistics shortfall contributing to PSR losses of 0.23%; this was accumulated from forklift tuck breakdowns¹³, which resulted in a 0.06% PSR loss.

19.2 Research

Tanker logistics can be a challenge within a manufacturing site, as there are several factors to consider to maximise efficiency while minimizing cost (Lummus, Krumwiede and Vokurka, 2001). Tankers can transport various liquids and include hazardous materials; therefore, it is important to have a well-designed logistics plan to ensure the safe and efficient transportation of materials (Bokor, 2010).

There are many issues to consider when designing a tanker logistics plan, such as route planning, loading and unloading, and maintenance (Rushton and Saw, 1992). Route planning is critical to ensure tankers travel efficiently around the manufacturing site (Brainard, Lovett and Parfitt, 1996). Loading and unloading must be performed carefully to avoid spills or other accidents (Bonvicini, Leonelli and Spadoni, 1998). Regular maintenance is necessary to keep the tankers in a legal and operable condition to ensure they remain safe (Leonelli, Bonvicini and Spadoni, 2000).

19.3 Strategy

PSR in 2022 was impacted due to logistics; however, the losses have a proportionally low impact; therefore, it is not an area when time and resources should be heavily invested. The site will have a logistics plan/strategy; this should be reviewed by the logistics team using actual PSR loss data to identify shortfalls in the current logistics plan. It should be ensured that the logistics plan considers route planning, loading and unloading, and maintenance. The PSR losses for logistics are relatively low, and there are cost and resource constraints upon reliability improvements in 2023. The review of the site logistics plan should not be prioritised. Therefore, Dow should not expect any PSR improvements from logistics in 2023.

20 Utilities

20.1 Data and Statistics

Utilities were the eighth largest category of PSR losses from January to October 2022, resulting in 0.85% of reliability losses. The utility losses are distributed into sub-categories, illustrated in Figure 35.

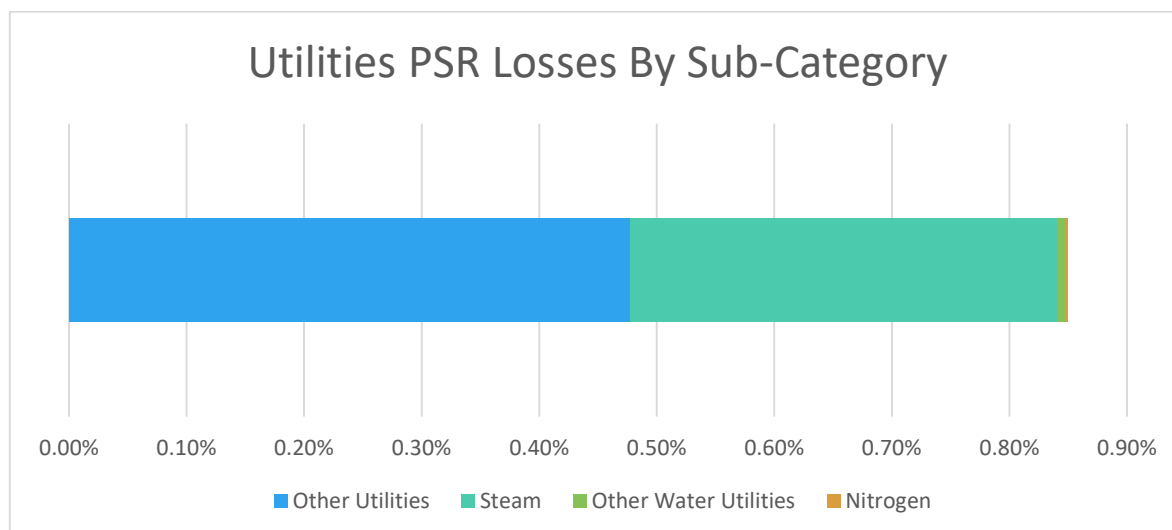


Figure 35 - January to October 2022 Utilities PSR Loss Sub-Categories

Other Utilities subcategory losses were the largest utility shortfall contributing to PSR losses of 0.48%; this was accumulated from the following losses:

HVF, VLVF, W407, W422 Hot oil capacity limiting	0.29%
HVF, VLVF, W407, W422 Hot oil plant trips	0.19%

Hot oil is used in many finishing processes to heat reactors and exchangers. Hot oil is heated in a fired boiler on W322 finishing hot oil plant. Hot oil is preferred to steam in finishing as it can achieve a higher temperature at a lower operational pressure due to its heating efficiency. Of the hot oil PSR impacting events, 0.29% were due to hot oil capacity limiting rates, and 0.19% were due to the hot oil plant tripping. When there is a high demand for hot oil from multiple assets running at MAC, the hot oil plant cannot meet its demand; this caused PSR losses on five occasions in 2022. Production prioritisation has to take place to ensure the plants with the most customer demand are prioritised, and other plants have to reduce rates to match the hot oil plant's capability. There have been twelve trips on the hot oil unit, causing the hot oil unit to shut down. Following legal governance, the hot oil unit has a dedicated Safety Instrumented System (SIS); this instrumentation is designed and maintained to prevent unsafe process operations when unacceptable or dangerous conditions occur.

If process limitations are met, the SIS instrumentation is designed to shut down the hot oil unit's production safely. In 2022 these limitations were achieved, and the SIS systems have correctly shut down the hot oil unit causing PSR losses on downstream assets.

The second largest subcategory contributing to utilities PSR losses was steam. The gum rig incurred a 0.36% PSR loss due to the Barry site steam maintenance turnaround from overrunning. Turnarounds are dedicated time in the production schedule when the process is taken offline to complete essential, often regulatory, maintenance. The site steam turnaround is included in the major site turnaround every two years. The steam system is often a critical path within the turnaround as steam is required to prepare other plants for maintenance and start-up plants post-maintenance safely. The Gum Rig utilises steam to heat the gum reactor; it has a steam jacket used to initiate the chemical reaction inside.

The remaining utility subcategories, other water utilities and nitrogen, have caused PSR losses that are statistically insignificant (<0.01%).

20.2 Research

The W322 Hot Oil Plant has had decreasing performance since 2013 (Jones, 2022); the Hot Oil Plant burner outlet pressure is representative of the plant's efficiency, the decrease in efficiency is illustrated in Figure 36.

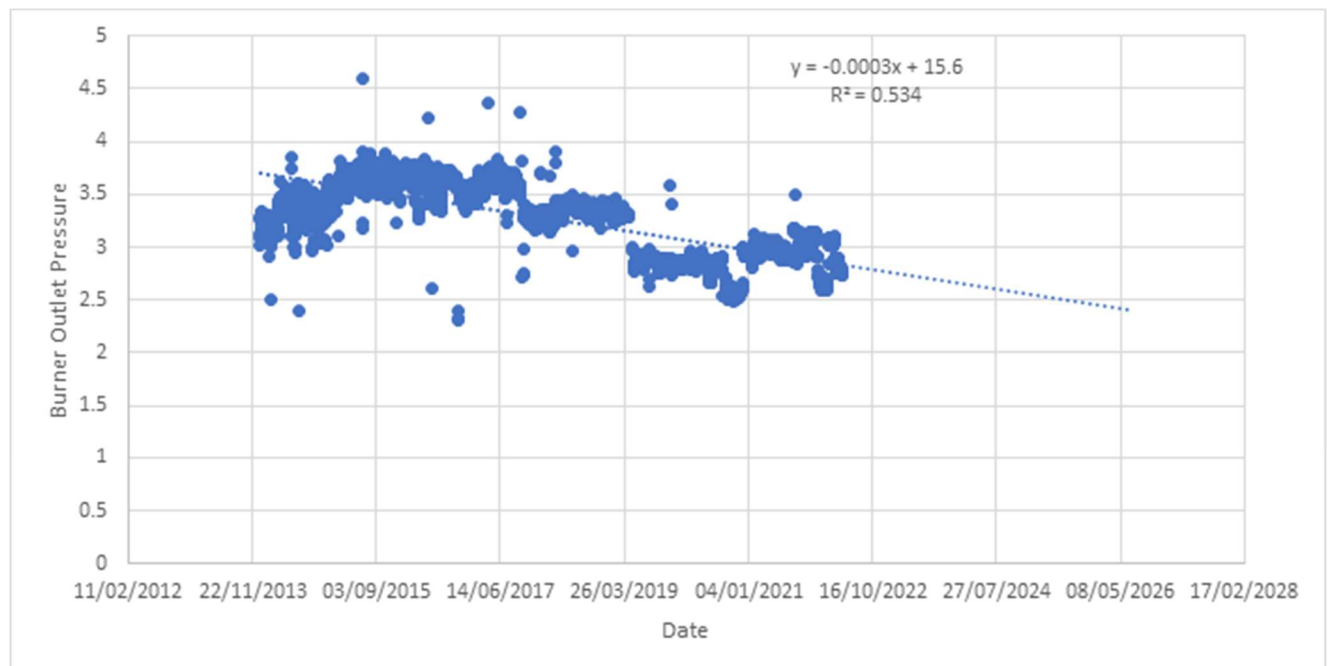


Figure 36 - W322 Hot Oil Plant Burner Outlet Pressure (Halasz, 2022)

The rate of heat transfer in a fired boiler can be influenced by many factors, including:

- Shell and tube size and geometry
- Flow configuration
- Burner control and temperature
- Process media selection
- Process media fouling

(Abd, Kareem and Naji, 2018)

The boiler and hot oil have not changed; hot oil fouling is the most likely cause of decreasing heat transfer and performance. Hot oil fouling can occur from viscosity changes, water contamination, solid contamination, and accumulation of wear debris (Johnson and Spurlock, 2010). Lubrication analysis involves sampling and analysing oil to understand the lubrication condition (Van de Voort, Sedman and Pinchuk, 2011). Lubrication analysis provides a laboratory report on the sample's condition, including lubricant properties and wear debris (Soliman, 2020). Lubrication analysis could be used to confirm if hot oil fouling is the cause of decreased performance from the W322 Hot Oil Plant. Lubrication analysis could also help to identify the cause of the contamination of the hot oil.

If the hot oil has fouled, the cause of the fouling will need to be resolved before the hot oil is returned to its original condition. To return the hot oil to its original condition, it could be drained and replaced, filtered clean, or a combination of the two.

20.3 Strategy

In 2022 PSR was impacted through utility losses; however, the losses have a proportionally low impact; therefore, it is not an area when time and resources should be heavily invested. As W322 Hot Oil Plant is a utility for finishing, it remains online throughout the year without any planned downtime; therefore, any solutions would have to be implemented during a W322 Hot Oil Unit turnaround. W322 has a turnaround scheduled every four years, the next of which is in 2024. Therefore, solutions to resolve the losses associated with the Hot Oil Plant cannot be implemented in 2023 and do not align with this report's scope. Investigation into the causes of hot oil fouling should take place throughout 2023; this will be included in the recommendations of this report.

21 Change Management

This report has identified nine areas for targeted PSR improvement in 2023:

- Root Cause Analysis into Gum Rig post-turnaround start-up delays
- Raw material supplier contract suitability review and diversification
- Root Cause Analysis into raw material coordination systems
- Project to replace 818 vacuum pump
- Stock addition of Barwell components susceptible to fatigue cracking and implementation of 2022 ERS
- ERA for Ibex MOG 2030X gear pumps and Renold Carter gearbox reducers
- Project to replace 157 mixer
- Project to replace obsolete PLCs
- Rewrite procedures with operator engagement

These changes must be implemented proficiently to achieve employee engagement and maximum benefits from the recommendations. It is widely accepted that engaged employees are essential for effective change management (Proctor and Doukakis, 2003). Engaged employees are more likely to be aware of and support changes that are being made (Bordia *et al.*, 2011). Employees are also more likely to be willing to help implement changes when engaged from the start of the process (Fedor and Herold, 2004). Engaged employees are able to communicate the need for and benefits of change to other employees (Davis and Fifolt, 2018). Engaged employees are more likely to be able to effectively adapt to changes and provide feedback on how effective the change is once implemented; this feedback is essential in ensuring that changes are successfully implemented and have the desired effect (Bankar and Gankar, 2013).

21.1 Costs

Each recommendation will have a financial cost associated with it. It is not within the scope of this report to establish the cost of the recommendations; however, the cost has a significant determination if each recommendation will be supported. Therefore, a budget cost for each solution should be identified. Estimating a budget cost is the process of judging the overall cost of completing a task without investing too much time and detail into the scope; the budget cost provides an estimated cost using prior experience and minimal consultation (Jackson, 2002).

When considering any investment, it is important to understand the potential return on investment (ROI) (Friedlob and Plewa Jr, 1996). ROI allows you to weigh the costs and benefits of the investment and make an informed decision about whether or not it is worth undertaking (Phillips, 1994).

Many different methods can be used to calculate ROI. The most common is to take the total gains from the investment and divide them by the total costs; this will give you a percent figure that can be used to compare different investments (Erdogmus, Favaro and Strigel, 2004).

In the case of Dow Finishing, the total gains from the investment are the PSR improvement from implementing the recommendation. ROI can be used to rank the solutions proposed in this report by their greatest PSR return for cost invested.

The proposals should be prioritised by ROI as the solution with the greatest PSR gain may have a high cost to implement; greater PSR gains could be received though completing multiple less costly solutions.

21.2 Leadership and Management

Recommendations from this report include Root Cause Analysis into historical PSR losses. To maximise the success of the RCA, the best RCA leader should be selected. Three recommendations have been made for projects to replace obsolete equipment. The best project manager should be established to maximise the project's success. Table 8 states the differences between management and leadership as defined by Kotterman (2006, p.15).

Table 8 - Differences Between Management and Leadership (Kotterman, 2006)

Process	Management	Leadership
Vision Establishment	- Plans and budgets - Develops process steps and set timelines - Displays an impersonal attitude about the vision and goals	- Sets the direction and develops the vision - Develops strategic plans to achieve the vision - Displays a very passionate attitude about the vision and goals
Human Development and Networking	- Organises and staffs - Maintains structure - Delegates responsibility - Delegates authority - Implements the vision - Establishes policy and procedures to implement the vision - Displays low emotion - Limits employee choices	- Aligns organisation - Communicates the vision, mission, and direction - Influences the creation of coalitions, teams, and partnerships that understand and accept the vision - Displays drive, high emotion - Increases choices
Vision Execution	- Controls processes - Identifies problems - Solves problems - Monitors results - Takes a low-risk approach to problem-solving	- Motivates and inspires - Energises employees to overcome barriers to change - Satisfies basic human needs - Takes a high-risk approach to problem-solving
Vision Outcome	- Manages vision order and predictability - Provides expected results consistently to leadership and other stakeholders	Promotes useful and dramatic changes, such as new products or approaches to improving labour relations

The RCA leaders will be key in driving the direction and success of the RCA team. The RCA requires a leader rather than a manager as it is a people-driven process. The proposed projects require a manager rather than a leader, as there are many formal steps and constraints within Dow that must be followed; the project manager must ensure the team is directed through the process.

21.3 Team Roles

Creating the appropriate team demographic is essential increasing a successful team to implement the recommendations of this report. The team members provide the knowledge and resources to make the team effective (Lupuleac, Lupuleac and Rusu, 2012). Each team member has a role; their attributes, personality and behaviour directly benefit the team (Pearce and Sims Jr, 2002).

Belbin's team roles (2012) are a useful framework for understanding and assessing team members' interpersonal skills and behaviours. Belbin's model identifies nine different team roles that can be useful in different situations, these roles are:

- Plant: creative, generates new ideas and solutions
- Resource Investigator: curious, seek new opportunities and information
- Coordinator: ensures that the team runs smoothly and effectively
- Shaper: challenges others, promotes discussion and debate
- Monitor Evaluator: logical, objective and dispassionate; provide critical analysis
- Team Worker: supportive, cooperative and good at maintaining relationships
- Implementer: practical, turns ideas into actions and gets things done
- Completer Finisher: diligent, seeks perfection and attention to detail
- Specialist: expert in a particular area, can be relied upon for detailed knowledge

(Belbin, 2012)

When forming the RCA and project teams, Belbins team roles should be considered to provide a well-rounded team to meet the team's goals. As well as the proposed RCAs and projects, other recommendations from this report will require teams to be set up; the raw material supplier contract suitability review and diversification, and rewriting procedures with operator engagement. These teams should also be aligned with Belbins team roles.

21.4 Resource

This report has identified nine recommendations for PSR improvements in 2023. Three recommendations are people-driven and require a relatively large resource commitment to complete indicated in Table 9. Table 9 also provides the number of operators currently running the asset associated with each solution. The information provided in Table 9 is sourced from the organisational charts in Appendix 8 and 9.

Table 9 - Personnel for Resource-Constrained Solutions

	RCA into Gum Rig post-turnaround start-up delays	RCA into raw material coordination systems	Rewrite procedures with operator engagement
Asset Specific Resource	Gum Rig	BDM's	VLVF
Operators Trained in the Asset	5	17	5
Operators Available	2	7	2
Leader or Manger	1	1	1
Operators From Other Assets	2	2	2
Roles From the Operators Organisation	2	1	2
Roles From the Maintenance Organisation	1	1	1

Belbins team roles identify eight roles to make a successful team. The available operators specific to the asset should be used to fulfil the roles they are naturally suited to. The leader/manger should also be allocated to the role they best suit. As Table 9 illustrates, the remaining team should be built from operators not trained on the specific asset and employees from the operations and maintenance organisation. The employees chosen from the operations and maintenance organisation should be allocated to the teams based on their natural fit in Belbin's team roles, not their plant knowledge or experience. The operators from other assets should also be chosen based on their fit in Belbin's team roles; ideally, they would include one experienced and one inexperienced operator.

For the proposed projects, the site engineering department will allocate a project manager. The project managers are responsible for receiving adequate time commitments from team members with the support of their leaders. Project support and reliability work are built into all engineers' time allocation.

The project to replace 157 mixer started in 2022, the design work has been completed, and now the project is awaiting mixer delivery. The mixer manufacturer will complete the mixer's installation and commissioning, requiring less input from the project team. Therefore, only two projects remain to be resourced.

The project to replace the 818 vacuum pump will require a project manager and an extensive team, including a range of engineering disciplines. The operations and maintenance team from W407 will also have to support the project; therefore, they should not be involved in any other reliability recommendations.

The project to replace obsolete PLCs will require a project manager and technical team from various electrical and instrumentation engineering disciplines. There will be little input from plant operators and the finishing maintenance and operations team.

Both projects should utilise contract resources from the equipment manufacturer for installation and commissioning, and additional technical support can be utilised offsite from other Dow sites. The project manager should resource the projects appropriately to meet the deadlines set out within this report. If it is impossible to meet these deadlines (due to lead times and additional project constraints) additional reliability solutions should be found to meet the 2023 finishing reliability goals to compensate for the projects inability to deliver the results in 2023.

The main resource required to complete an ERA on the Ibex MOG 2030X gear pumps and Renold Carter gearbox reducers is the reliability engineer, supported by the W422 finishing maintenance and operations team. CEC can be used to facilitate the administrative elements of the ERA and ensure the plant teams' time is utilised on the technical elements of the ERA.

Both the ERA on the Ibex MOG 2030X gear pumps, Renold Carter gearbox reducers, and the Stock addition of Barwell components susceptible to fatigue cracking will result in parts requiring on-site store holding. The parts will likely hold a value greater than \$5,000 and require offsite financial approval. A business case will have to be established by the Reliability Engineer for each item costing over \$5,000; this report contains sufficient detail alongside the proposed ROI calculations to complete a good business case.

ROI calculations can be used to rank the priority of the reliability recommendations if resource constraints prevent progress. The reliability recommendations must be correctly prioritised to meet the 2023 reliability goals.

Once the nine reliability recommendations are resourced, if there is an additional resource, the two additional recommendations that require no financial support can be completed:

- W422 RCA could be completed to identify the cause of reprocessing and blending
- Review the site logistics plan

22 2023 Reliability Strategy

From January to October 2022, Barry Finishing reliability was 81.5% compared to its goal of 85.4%; therefore, a 3.9% PSR gap closure is required to meet the 2023 reliability goal. Thirteen areas of improvement have been identified throughout this report, nine of which are actionable in 2023; the remaining improvements were made in 2022 or will occur naturally without the any action. Table 10 summarises the recommendations made within this report and quantifies the PSR improvements to be expected in 2023.

Table 10 - 2023 PSR Improvement Recommendations

Loss Category	2022 Loss Description	Reliability Improvement Strategy	2022 PSR Loss	2023 PSR Improvement
Raw Material Shortages	Gum Rigs' inability to provide a reliable supply of Gum for BDM's and Tilts	RCA into Gum Rig post-Turnaround start-up delays	0.98%	0.25%
	Vendor supplied raw material shortages from Isalchem, SilPhos, Peroxide and ETCH	Supplier contract suitability review and diversification	0.85%	0.21%
	Raw material planning for 4-2812 catalyst for the BDM's	RCA into raw material coordination systems	0.67%	0.17%
Equipment Failure and Maintenance	W407 818 Vacuum Pump Failures	Project to replace 818 vacuum pump	0.80%	0.40%
	Compounding HCR Low Pressure Barwell Failures	Stock addition of Barwell components susceptible to fatigue cracking and implementation of 2022 ERS	0.31%	0.31%
	W422 237 pump and 235 pump failures	ERA for Ibex MOG 2030X gear pumps and Renold Carter gearbox reducers	0.51%	0.51%
	Tilts 157 Mixer bearing failure	Project to replace 157 mixer	0.29%	0.29%
	W422 and VLVF PLC failures	Project to replace obsolete PLCs	0.19%	0.05%
	BDM 177 Mixer lid seal failures	Resolved in 2022 RCA	0.22%	0.22%
Budgeted Turnaround	Gum Rig extended turnaround due to poor execution	RCA into Gum Rig post-Turnaround start-up delays	1.67%	1.23%
Operating Discipline	Combined operators not following procedures	Rewrite procedures with operator engagement	0.75%	0.39%
	Covid illness reducing available operator numbers	Natural reduction in the number of Covid cases and increased population resilience	0.27%	0.27%
Process Technology	Tilts 157 mixer jacket chloride stress corrosion cracking	Replacement 157 Mixer	1.19%	1.19%

The recommendations throughout this report will result in a total PSR improvement of 5.49% compared to the 3.9% PSR gap closure required to meet the 2023 reliability goal. Therefore, there is a potential 1.59% extra PSR improvement. This additional PSR improvement will allow flexibility if additional funding or resource constraints are applied to the reliability initiatives. The extra PSR improvement can also buffer for unforeseen PSR losses.

Two further recommendations were made:

- W422 RCA could be completed to identify the cause of reprocessing and blending
- Review site logistics plan

These recommendations would reduce frequent but low PSR-impacting events, and this would not only help the plant's reliability but remove disruption and stress among employees. These two solutions are of lesser priority than the nine primary recommendations and should be implemented if cost and resource constraints allow.

23 Conclusion

The start of the report sets out aims and objectives; the report's success can be established by comparing if the recommendations satisfy the aims and objectives.

This report aimed to create a reliability strategy for Dow Silicones Barry Finishing, providing clear direction on achieving the 2023 reliability goals. The report identified thirteen areas for PSR improvement with nine actionable recommendations for 2023.

The objectives of this report are:

- Close the 3.9% PSR gap between 2022 performance and the 2023 goal
- Identify a strategy to achieve the 2023 reliability goals using 2022 AU data to support the strategy
- Identify a strategy that meets the financial and resource constraints of Barry Finishing
- Identify a strategy that aligns with Dow practices and can be implemented seamlessly
- Implement a process that can be repeated to produce a high-quality facility reliability strategy each year

The recommendations throughout this report will result in a total PSR improvement of 5.49% compared to the 3.9% PSR gap closure detailed in the objectives. Therefore, there is a potential 1.59% extra PSR improvement than set by the objectives of this report.

The report used 2022 Dow AU data to ensure the strategies address the historical losses with the greatest PSR impact. All strategies have the potential PSR return detailed; considerations are provided for PSR losses that will take longer than a year for the solutions to be fully effective.

The report identified the financial and resource constraints upon the reliability strategy. With these constraints in place, the report researched how it can most effectively implement the recommendations to maximise return on finance and people resource.

This report has highlighted the value of establishing the correct manager, leader and team to complete each recommendation. The report understands resource constraints, but teams should be established using Belbins team roles where possible. Leaders should be assigned to RCAs and Managers for projects, as each requires a different approach to achieve success.

The report identifies employee engagement as key to building a positive attitude towards reliability and utilising the range of employee knowledge and experience to maximise the potential of the recommendations. The recommendation that requires extensive team engagement is rewriting the

operating procedures to reduce PSR losses from operators not following procedures. Kotters eight-step process to manage change should be utilised to maximise employee buy-in and engagement to create solutions.

The scope identified resources as a constraint upon the report. As illustrated in Table 11, the recommendations can be categorised as requiring no resource to complete or a low or high resource to complete. The report took the existing organisational structure and allocated the resource appropriately to the solutions requiring low and high resources. The report first aligned the resource based on necessary experience and roles, then composed the remaining team using Belbin's team roles and balancing the workload across the whole organisation.

Table 11 - Levels of Resource Requirement for Each Proposed Solution

No Resource Requirements	Small Resource Requirements	Large Resource Requirements
- Natural reduction in the number of Covid cases and increased population resilience - BDM 177 Mixer lid seal failures resolved in 2022 RCA	- Supplier contract suitability review and diversification - Stock addition of Barwell components susceptible to fatigue cracking and implementation of 2022 ERS - ERA for Ibex MOG 2030X gear pumps and Renold Carter gearbox reducers	- RCA into Gum Rig post-Turnaround start-up delays - RCA into raw material coordination systems - Project to replace 818 vacuum pump - Project to replace 157 Mixer - Project to replace obsolete PLCs - RCA into Gum Rig post-Turnaround start-up delays - Rewrite procedures with operator engagement

As well as resource constraints, there are financial constraints upon the report's recommendations. It is not within the scope of this report to establish the cost of the recommendations. The report has identified that establishing the budget cost of each solution is essential before implementation. Once budget costs are established, Return On Investment calculations will be used to rank the solutions. If finances do not allow for all of the recommendations to be implemented, the ROI scores will ensure the finance is invested into the solutions that will return the most PSR per dollar invested.

All recommendations within this report have been made to align with Dow practices and can be implemented seamlessly. The report uses the existing organisational structure as a foundation for resource allocation for reliability solutions. The report has repeatedly referred to and referenced Dow standards to ensure its recommendations are aligned to allow for effective implementation.

The report has implemented a process that can be repeated to produce a high-quality facility reliability strategy each year. Early in the report, a strategy was established to review data analysis for each PSR loss category, followed by research and recommendations for the greatest PSR losses. This process can be replicated for future reliability strategies.

In conclusion, this report meets the aims and objectives set out at the start of the report. It has also identified constraints to work within and set guidelines for managing those constraints and maximising financial and resource return. However, the only way to establish if the recommendations made within this report are successful is through implementation. If the recommendations are implemented and provide a PSR increase of 3.9% in 2023 and meet the 85.4% PSR goal, then the report will be a complete success.

24 Implementation

The first stage in implementing the strategy is to get budget costs. Budget costs will allow the ROI calculations to be completed and each recommendation ranked by PSR improvement v's cost invested. Understanding each recommendation's budget cost will also help identify how the strategy fits within Dow's current financial constraints. Although each solution will have a high financial return on investment once implemented, the current spending constraints may prevent all solutions from being implemented in 2023.

The second stage in implementing the reliability strategy is to present it to senior site leaders. The strategy should be summarised into a presentation with one information slide for each recommendation. If the site leaders support the recommendations, they will provide resource to implement each recommendation.

The site leaders, Reliability Engineer and the team members that are aligned to each solution will work to establish a schedule for implementing the solutions. The team members will have the reliability solution they are aligned to embedded into their personal goals to provide incentive and accountability for the reliability improvements.

Once the teams are formed, certain solutions will be implemented in less than a month, whereas others will take the full year. The variation in implementation time has been accounted for in the expected return on PSR throughout the year. This report has made recommendations that will provide a return greater than the 2023 PSR goal; therefore, compromises can be made for financial, resource and time constraints, and the reliability goal can still be achieved.

25 Recommendations for Further Work

This report has identified one long-term solution that can be added to the Multi-Generational Plan (MGP). Tri shortages from Basics supplying the CHU resulted in a 0.54% PSR loss. Although Basics have its own reliability goals and strategy to achieve those goals, there is potential to hold a level of Tri as safety stock to alleviate production interruptions from Basics. Calculations could be made using historical data to identify the safety stock level that could be held to absorb any production variations from Basics. This calculation should show the appropriate size storage tank, safety requirements, and distribution system. Due to complexity of the work and likely duration, this recommendation should form part of the Multi-Generational Plan (MGP). It would take several years to design and implement a storage tank, pipeline and control systems to manage and balance the Tri supply from Basics to Finishing. This solution will likely require a relatively high and long-term financial investment compared to other recommendations. To justify the investment in Tri storage, further historical PSR data should be analysed to identify if the losses are a long-term trend or just a short-term anomaly.

26 References

- Abd, A.A., Kareem, M.Q. and Naji, S.Z. (2018) 'Performance analysis of shell and tube heat exchanger: Parametric study', *Case studies in thermal engineering*, 12, pp. 563–568.
- Adams, N. (1972) 'Fatigue crack closure at positive stresses', *Engineering Fracture Mechanics*, 4(3), pp. 543–554.
- Afzali, P., Keynia, F. and Rashidinejad, M. (2019) 'A new model for reliability-centered maintenance prioritisation of distribution feeders', *Energy*, 171, pp. 701–709.
- Agnihothri, S.R. and Kenett, R.S. (1995) 'The impact of defects on a process with rework', *European Journal of Operational Research*, 80(2), pp. 308–327.
- Andersen, B. and Fagerhaug, T. (2006) *Root cause analysis: simplified tools and techniques*. Quality Press.
- Atkins, A.G., Atkins, T. and Escudier, M. (2013) *A dictionary of mechanical engineering*. Oxford University Press.
- Baker, K.R., Magazine, M.J. and Nuttle, H.L. (1986) 'The effect of commonality on safety stock in a simple inventory model', *Management Science*, 32(8), pp. 982–988.
- Ballard, P. *et al.* (1995) 'High cycle fatigue and a finite element analysis', *Fatigue & Fracture of Engineering Materials & Structures*, 18(3), pp. 397–411.
- Bankar, S. and Gankar, S. (2013) 'Employee engagement and change management', *Journal of Commerce and Management Thought*, 4(2), pp. 313–321.
- Basri, E.I. *et al.* (2017) 'Preventive maintenance (PM) planning: a review', *Journal of Quality in Maintenance Engineering*, 23(2), pp. 114–143.
- Belbin, R.M. (2012) *Team roles at work*. Routledge.
- Bokor, Z. (2010) 'Logistics Costing in Manufacturing Companies', *LOGI-Scientific journal on transport and logistics*, 1(1), pp. 5–13.
- Bonvicini, S., Leonelli, P. and Spadoni, G. (1998) 'Risk analysis of hazardous materials transportation: evaluating uncertainty by means of fuzzy logic', *Journal of Hazardous Materials*, 62(1), pp. 59–74.
- Bordia, P. *et al.* (2011) 'Haunted by the past: Effects of poor change management history on employee attitudes and turnover', *Group & Organization Management*, 36(2), pp. 191–222.
- Brainard, J., Lovett, A. and Parfitt, J. (1996) 'Assessing hazardous waste transport risks using a GIS', *International Journal of Geographical Information Systems*, 10(7), pp. 831–849.
- Burkhardt, M. (2021) *Impacts of natural disasters on supply chain performance*. KIT Scientific Publishing.
- Callioni, G. *et al.* (2005) 'Inventory-driven costs', *harvard business review*, 83(3), pp. 135–141.

- Carbone, T.A. and Tippet, D.D. (2004) 'Project risk management using the project risk FMEA', *Engineering management journal*, 16(4), pp. 28–35.
- Card, A.J., Ward, J.R. and Clarkson, P.J. (2012) 'Beyond FMEA: The structured what-if technique (SWIFT)', *Journal of Healthcare Risk Management*, 31(4), pp. 23–29.
- Cassanelli, G. *et al.* (2006) 'Failure analysis-assisted FMEA', *Microelectronics Reliability*, 46(9–11), pp. 1795–1799.
- Chiozza, M.L. and Ponzetti, C. (2009) 'FMEA: a model for reducing medical errors', *Clinica chimica acta*, 404(1), pp. 75–78.
- Christopher, M. and Holweg, M. (2011) "'Supply Chain 2.0": Managing supply chains in the era of turbulence', *International journal of physical distribution & logistics management*, 41(1), pp. 63–82.
- Cleaver, M. (2023) 'Finishing Assets not included in the site Turnaround'.
- Clegg, A.J., Williams, D.J. and Uzsoy, R. (1995) 'Production planning for companies with remanufacturing capability', in: *Proceedings of the 1995 IEEE International Symposium on Electronics and the Environment ISEE (Cat. No. 95CH35718)*, IEEE, pp. 186–191.
- Coleman, I. (2023) 'Typical Mitigating Actions as part of an ERS'.
- Cooper, M.C. and Ellram, L.M. (1993) 'Characteristics of supply chain management and the implications for purchasing and logistics strategy', *The international journal of logistics management* [Preprint].
- Cox, A. (1999) 'Power, value and supply chain management', *Supply chain management: An international journal* [Preprint].
- Craig, R.W. (2002) 'A methodology for addressing support equipment obsolescence', *IEEE aerospace and electronic systems magazine*, 17(5), pp. 20–25.
- Croxton, K.L. *et al.* (2001) 'The Supply Chain Management Processes', *The International Journal of Logistics Management*, 12(2), pp. 13–36. Available at: <https://doi.org/10.1108/09574090110806271>.
- Davis, M. and Fifolt, M. (2018) 'Exploring employee perceptions of Six Sigma as a change management program in higher education', *Journal of higher education policy and management*, 40(1), pp. 81–93.
- Davis, T. (1993) 'Effective supply chain management', *Sloan management review*, 34, pp. 35–35.
- Dillon, R.E. (1990) 'Some simple steps to inventory reduction', *Production and Inventory Management Journal*, 31(1), p. 62.
- Doggett, A.M. (2005) 'Root cause analysis: a framework for tool selection', *Quality Management Journal*, 12(4), pp. 34–45.
- Dow (2022a) '2022 Finishing Asset Capacity'.
- Dow (2022b) *Silicones, Silicone-Organic Hybrids and Silanes*. Available at: <https://www.dow.com/en-us/product-technology/pt-silicone-hybrids-silanes.html> (Accessed: 25 December 2022).

Doyen, L. and Gaudoin, O. (2011) 'Modeling and assessment of aging and efficiency of corrective and planned preventive maintenance', *IEEE Transactions on Reliability*, 60(4), pp. 759–769.

Dubey, S.Y.D. (1967) 'Normal and Weibull distributions', *Naval Research Logistics Quarterly*, 14(1), pp. 69–79.

Duffuaa, S.O. and Ben Daya, M. (2004) 'Turnaround maintenance in petrochemical industry: practices and suggested improvements', *Journal of Quality in maintenance Engineering*, 10(3), pp. 184–190.

ECO Clean Room Ram Extruders (2022) Barwell Global Ltd. Available at: <https://barwell.com/products/eco-clean-room-ram-extruders/> (Accessed: 14 March 2023).

Eggert, L. and Hofmann, A. (2016) 'Managing supply chain disruption risks through insurance solutions: current practices and challenges', *International Journal of Management and Decision Making*, 15(2), pp. 154–166.

Ellram, L.M. (1991) 'Supply-chain management: the industrial organisation perspective', *International Journal of Physical Distribution & Logistics Management* [Preprint].

Erdogmus, H., Favaro, J. and Strigel, W. (2004) 'Return on investment', *IEEE software*, 21(3), pp. 18–22.

Fawcett, S.E., Ellram, L.M. and Ogden, J.A. (2007) *Supply chain management: From vision to implementation*. Pearson Prentice Hall Upper Saddle River, NJ.

Fedor, D.B. and Herold, D.M. (2004) 'Effects of change and change management on employee responses: an overview of results from multiple studies', in. *Tappi Fall Technical Conference*, pp. 3–1.

Flapper, S.D.P. et al. (2002) 'Planning and control of rework in the process industries: a review', *Production Planning & Control*, 13(1), pp. 26–34.

Fracarolli Nunes, M., Lee Park, C. and Paiva, E.L. (2020) 'Can we have it all? Sustainability trade-offs and cross-insurance mechanisms in supply chains', *International Journal of Operations & Production Management*, 40(9), pp. 1339–1366.

Fredendall, L.D. and Hill, E. (2000) *Basics of supply chain management*. CRC Press.

French, M.L. (2008) 'Improving sustainability through effective reuse of product returns: minimizing waste in a batch blending process environment', *Journal of Cleaner Production*, 16(15), pp. 1679–1687.

French, M.L. and Discenza, R. (2006) 'Returns in process industries: a managerial perspective', *Management Research News*, 29(12), pp. 769–781.

Friedlob, G.T. and Plewa Jr, F.J. (1996) *Understanding return on investment*. John Wiley & Sons.

Gertsbakh, I. and Gertsbakh, I.B. (2000) *Reliability theory: with applications to preventive maintenance*. Springer Science & Business Media.

Goddard, P.L. (2000) 'Software FMEA techniques', in. *Annual Reliability and Maintainability Symposium. 2000 Proceedings. International Symposium on Product Quality and Integrity (Cat. No. 00CH37055)*, IEEE, pp. 118–123.

Greater London Authority City Intelligence (2023) 'Coronavirus (COVID-19) Weekly Update - London Datastore', March. Available at: <https://data.london.gov.uk/dataset/coronavirus--covid-19--cases?resource=151e497c-a16e-414e-9e03-9e428f555ae9> (Accessed: 29 March 2023).

Halasz, K. (2022) 'W322 Hot Oil Performance'.

Halford, F. *et al.* (2022) 'Understanding reported COVID-19 cases in England following changes to testing, between November 2021 and April 2022', *medRxiv*, pp. 2022–06.

Hall, W. (2023) 'Finishing Maintenance Budgets 2022 and 2023'.

Head, C. (2021) 'Dow Reliability Introduction Training'.

Head, C. (2022) 'Q3 2022 Consumer Solutions Webcast'. *Consumer solutions webcast*, August.

Head, C. (2023) 'Typical Reduction in PSR Impact After Solutions are Implimented'.

Hematyar, S. and Chaharsooghi, K. (2014) 'Coordinating a supply chain with customer returns and two-period newsboy problem using insurance contract', *International Journal of Materials, Mechanics and Manufacturing*, 2(3), pp. 202–209.

'Homepage - DALMEC- Industrial Manipulators and Material Handling - Manual lifts for the ergonomic handling of loads in weightless condition. Dalmec zero gravity balancers' (2021). Available at: <https://www.dalmec.com/>, <https://www.dalmec.com/> (Accessed: 19 March 2023).

Howarth, A. *et al.* (2021) 'Trends in healthcare utilisation during COVID-19: a longitudinal study from the UK', *BMJ open*, 11(7), p. e048151.

Hughes, T.F. (1984) 'Objectives of an effective inventory control system', *American journal of hospital pharmacy*, 41(10), pp. 2078–2085.

Jackson, S. (2002) 'Project cost overruns and risk management', in. *Proceedings of Association of Researchers in Construction Management 18th Annual ARCOM Conference, Newcastle, Northumber University, UK*, pp. 1–10.

Jacobs, F.R. (2007) 'Enterprise resource planning (ERP)—A brief history', *Journal of operations management*, 25(2), pp. 357–363.

Johnson, M. and Spurlock, M. (2010) 'Strategic oil analysis: Instrument-based on-site lubricant analysis', *Tribology & lubrication technology*, 66(7), pp. 26–27.

Jones, L. (2022) 'W322 - Hot Oil Site Visit & Chem Clean'.

Jones, L. (2023) 'Asset Value Averages'. Dow Internal.

Kochak, A. and Sharma, S. (2015) 'Demand forecasting using neural network for supply chain management', *International journal of mechanical engineering and robotics research*, 4(1), pp. 96–104.

Kotter, J.P. (2012) *Leading change*. Harvard business press.

Kotterman, J. (2006) 'Leadership versus management: What's the difference', *The Journal for Quality and Participation*, 29(2), pp. 13–17.

- Kübler-Ross, E., Wessler, S. and Avioli, L.V. (1972) 'On death and dying', *Jama*, 221(2), pp. 174–179.
- Lai, C.-D., Murthy, D. and Xie, M. (2006) 'Weibull distributions and their applications', in *Springer Handbooks*. Springer, pp. 63–78.
- Lambert, D.M. (1992) 'Developing a customer-focused logistics strategy', *International Journal of Physical Distribution & Logistics Management* [Preprint].
- Lambert, D.M. and Cooper, M.C. (2000) 'Issues in supply chain management', *Industrial marketing management*, 29(1), pp. 65–83.
- Latino, R.J. et al. (2006) *Root cause analysis: improving performance for bottom-line results*. CRC press.
- Lee, H.L. (1992) 'Lot sizing to reduce capacity utilization in a production process with defective items, process corrections, and rework', *Management Science*, 38(9), pp. 1314–1328.
- Lee, H.L. (2002) 'Aligning supply chain strategies with product uncertainties', *California management review*, 44(3), pp. 105–119.
- Lenahan, T. (2011) *Turnaround, shutdown and outage management: Effective planning and step-by-step execution of planned maintenance operations*. Elsevier.
- Leonelli, P., Bonvicini, S. and Spadoni, G. (2000) 'Hazardous materials transportation: a risk-analysis-based routing methodology', *Journal of hazardous Materials*, 71(1–3), pp. 283–300.
- Levin, M.A. and Kalal, T.T. (2003) *Improving product reliability: strategies and implementation*. John Wiley & Sons.
- Lewin, K. (1951) 'Field theory in social science: selected theoretical papers (Edited by Dorwin Cartwright.).'
- Lu, Y. et al. (2016) 'Towards the automated verification of weibull distributions for system failure rates', in. *Critical Systems: Formal Methods and Automated Verification: Joint 21st International Workshop on Formal Methods for Industrial Critical Systems and 16th International Workshop on Automated Verification of Critical Systems, FMICS-AVoCS 2016, Pisa, Italy, September 26-28, 2016, Proceedings 21*, Springer, pp. 81–96.
- Lummus, R.R., Krumwiede, D.W. and Vokurka, R.J. (2001) 'The relationship of logistics to supply chain management: developing a common industry definition', *Industrial management & data systems*, 101(8), pp. 426–432.
- Lummus, R.R. and Vokurka, R.J. (1999) 'Defining supply chain management: a historical perspective and practical guidelines', *Industrial management & data systems* [Preprint].
- Lupuleac, S., Lupuleac, Z.-L. and Rusu, C. (2012) 'Problems of assessing team roles balance-Team design', *Procedia Economics and Finance*, 3, pp. 935–940.
- McCue, I. (2021) *All About ERP, Oracle NetSuite*. Available at: <https://www.netsuite.com/portal/resource/articles/erp/what-is-erp.shtml> (Accessed: 14 March 2021).
- Mikulak, R.J., McDermott, R. and Beauregard, M. (2017) *The basics of FMEA*. CRC press.

- Monk, E. and Wagner, B. (2012) *Concepts in enterprise resource planning*. Cengage Learning.
- Morrison, L. (2020) *Engineering News - Pump manufacturer reinforces petrochemical offering rebranding*, *Engineering News*. Available at: <https://www.engineeringnews.co.za/print-version/pump-manufacturer-enforces-trademark-on-petrochemical-offering-2009-03-20> (Accessed: 17 March 2023).
- Murthy, D.N.P., Rausand, M. and Østerås, T. (2008) *Product reliability: specification and performance*. Springer.
- Newman Jr, J.C., Phillips, E.P. and Swain, M. (1999) 'Fatigue-life prediction methodology using small-crack theory', *International Journal of fatigue*, 21(2), pp. 109–119.
- Nicholas, T. (1999) 'Critical issues in high cycle fatigue', *International Journal of Fatigue*, 21, pp. S221–S231.
- Patterson, K.A., Grimm, C.M. and Corsi, T.M. (2003) 'Adopting new technologies for supply chain management', *Transportation Research Part E: Logistics and Transportation Review*, 39(2), pp. 95–121.
- Pearce, C.L. and Sims Jr, H.P. (2002) 'Vertical versus shared leadership as predictors of the effectiveness of change management teams: An examination of aversive, directive, transactional, transformational, and empowering leader behaviors.', *Group dynamics: Theory, research, and practice*, 6(2), p. 172.
- Peck, H. (2006) 'Reconciling supply chain vulnerability, risk and supply chain management', *International journal of logistics: Research and applications*, 9(2), pp. 127–142.
- Phillips, J.J. (1994) *Measuring return on investment*. American Society for Training and Development.
- Pinder III, J.E., Wiener, J.G. and Smith, M.H. (1978) 'The Weibull distribution: a new method of summarizing survivorship data', *Ecology*, 59(1), pp. 175–179.
- Pollack, J. and Pollack, R. (2015) 'Using Kotter's eight stage process to manage an organisational change program: Presentation and practice', *Systemic Practice and Action Research*, 28(1), pp. 51–66.
- Price, C.J. and Taylor, N.S. (2002) 'Automated multiple failure FMEA', *Reliability Engineering & System Safety*, 76(1), pp. 1–10.
- Proctor, T. and Doukakis, I. (2003) 'Change management: the role of internal communication and employee development', *Corporate Communications: An International Journal*, 8(4), pp. 268–277.
- Pugh, E. (1985) 'Progress toward understanding the stress corrosion problem', *Corrosion*, 41(9), pp. 517–526.
- Pyttel, B., Schwerdt, D. and Berger, C. (2011) 'Very high cycle fatigue—Is there a fatigue limit?', *International Journal of fatigue*, 33(1), pp. 49–58.
- Reid, R.D. (2005) 'FMEA—something old, something new', *Quality Progress*, 38(5), pp. 90–93.
- Rhodes, P. (1969) 'Mechanism of chloride stress corrosion cracking of austenitic stainless steels', *Corrosion*, 25(11), pp. 462–472.

- Rinne, H. (2008) *The Weibull distribution: a handbook*. CRC press.
- Robitaille, D. (2010) *Root cause analysis*. Paton Professional.
- Rooney, J.J. and Heuvel, L.N.V. (2004) 'Root cause analysis for beginners', *Quality progress*, 37(7), pp. 45–56.
- Rushton, A. and Saw, R. (1992) 'A methodology for logistics strategy planning', *The International Journal of Logistics Management*, 3(1), pp. 46–62.
- Sharratt, P.N. (1997) *Handbook of batch process design*. Springer Science & Business Media.
- Slack, N. et al. (2006) *Operations and Process Management*. Prentice Hall.
- Soliman, M.H.A. (2020) *Machinery Oil Analysis & Condition Monitoring: A Practical Guide to Sampling and Analyzing Oil to Improve Equipment Reliability*. Mohammed Hamed Ahmed Soliman.
- Stadtler, H. (2008) 'Supply chain management—an overview', *Supply chain management and advanced planning*, pp. 9–36.
- Swanson, L. (2001) 'Linking maintenance strategies to performance', *International journal of production economics*, 70(3), pp. 237–244.
- Tallon, W.J. (1993) 'The impact of inventory centralization on aggregate safety stock: the variable supply lead time case', *Journal of Business Logistics*, 14(1), p. 185.
- Tan, K.C. (2001) 'A framework of supply chain management literature', *European Journal of Purchasing & Supply Management*, 7(1), pp. 39–48. Available at: [https://doi.org/10.1016/S0969-7012\(00\)00020-4](https://doi.org/10.1016/S0969-7012(00)00020-4).
- Tan, K.C. (2002) 'Supply chain management: practices, concerns, and performance issues', *Journal of Supply Chain Management*, 38(4), pp. 42–53.
- Thoman, D.R., Bain, L.J. and Antle, C.E. (1969) 'Inferences on the parameters of the Weibull distribution', *Technometrics*, 11(3), pp. 445–460.
- Tomkins, B. (1968) 'Fatigue crack propagation—an analysis', *Philosophical magazine*, 18(155), pp. 1041–1066.
- Tomlin, B. (2006) 'On the value of mitigation and contingency strategies for managing supply chain disruption risks', *Management science*, 52(5), pp. 639–657.
- Truman, J. (1977) 'The influence of chloride content, pH and temperature of test solution on the occurrence of stress corrosion cracking with austenitic stainless steel', *Corrosion Science*, 17(9), pp. 737–746.
- Van de Voort, F., Sedman, J. and Pinchuk, D. (2011) 'An overview of progress and new developments in FTIR lubricant condition monitoring methodology', *Journal of ASTM International*, 8(5), pp. 1–14.
- Wald, H. and Shojania, K.G. (2001) 'Root cause analysis', *Making health care safer: a critical analysis of patient safety practices*, 51.
- Walker, B. (2021) 'Equipment Reliability Strategy Development and Implementation'.

Wallace, D. (2023) *"Pruning" Your Inventory: Setting MRO Stocking Levels, LOE Life Cycle Engineering*. Available at: <https://www.lce.com/Pruning-Your-Inventory-Setting-MRO-Stocking-Levels-1232.html> (Accessed: 26 November 2021).

Williams, P.M. (2001) 'Techniques for root cause analysis', in. *Baylor University Medical Center Proceedings*, Taylor & Francis, pp. 154–157.

Wilson, R. (2020) *FMEA: An Analysis Method to Mitigate Risk, AuditComply*. Available at: <https://www.auditcomply.com/2020/01/29/fmea-an-analysis-method-to-mitigate-risk/> (Accessed: 14 March 2023).

27 Appendix

27.1 Appendix 1 – AU Data loss categories and subcategories

Category Description	Sub-Category Description
Lack of Demand	
	1.01 External Lack of Demand
	1.03 Alternate Material Allocation
	1.05 LOD for Asset Not Staffed 24-7
Product Mix	
	2.01 Low Capacity Product
	2.02 Feed Slate
	2.03 Operating Conditions Optimization
	2.04 Transition Loss (normal losses only)
	2.05 Product Sequence Break
	2.06 Product Development (including R&D Test Runs)
	2.07 Over MAC (i.e. High Capacity Product)
	2.08 Capacity Product Adjustment
Budgeted Turnaround	
	3.01 Scheduled Maintenance Turnaround
	3.02 Shutdown / Clear / Start-up (for Budgeted Turnaround)
	3.03 Extended Turnaround due to Discovery
	3.04 Extended Turnaround due to Poor Execution
	3.05 Opportunistic Maintenance Turnaround during LOD
	3.06 Element (Catalyst) Change during Turnaround
	3.07 Opportunistic Element (Catalyst) Change during LOD
	3.08 Process Cleaning during Turnaround
	3.09 Opportunistic Process Cleaning during LOD
Equipment Failure	
	4.01 Rotating Equipment
	4.02 Piping / Gaskets / Valves
	4.03 Vessels / Tanks / Boilers / Exchangers
	4.04 Instrumentation
	4.05 Electrical
	4.06 Analyzers
	4.07 Maintenance Not Following Procedures
	4.08 Maintenance Lack of Training
	4.09 Maintenance Inadequate Procedures
	4.10 Lack of Maintenance Personnel
Operating Discipline	(deals with Operations Personnel)
	5.01 Not Following Procedures

	5.02 Lack of Training
	5.03 Inadequate Procedures
	5.04 Lack of Operating Personnel
	5.06 Pending RCI
Reprocessing or Blending	
	6.01 Reprocessing or Blending
	6.02 Lab Sample Analysis
	6.03 Over MAC
Process Variability	
	7.01 Seasonal (i.e. ambient air temperature impact)
	7.02 Acute Weather (i.e. normal rain, etc.)
	7.03 Expected Element (Catalyst) Life Decay
	7.04 Abnormal Process Fouling
	7.06 Statistically Insignificant Variation
	7.07 Over MAC (i.e. expected fluctuations)
	7.08 SAP Reconciliation
	7.11 Expected Process Fouling
Process Technology	
	8.01 Installation Never Performed at Design
	8.03 Shared Equipment Allocation (Problem in Asset)
	8.04 Over MAC
	8.05 Design Error
Process Control	
	9.01 Hardware
	9.02 Software Deficiency
Capital Projects	
	10.01 Turnaround for Capital Installation
	10.02 Shutdown / Clear / Start-up (for Capital Installation)
	10.03 Reduced Rates for Capital Installation
	10.04 Unplanned Extended Turnaround for Capital Project
	10.05 Opportunistic Capital Project during LOD
Severe Weather and Unusual Emergencies	Mediation is at Site level
	11.01 Severe Weather (i.e. hurricane, typhoon)
	11.02 Unusual Emergency (Outside Asset Control)
Utilities	
	12.01 Electric Power
	12.02 Steam
	12.03 Natural Gas and Other Fuels
	12.04 Condensate and Demineralized Water
	12.05 Other Water Utilities
	12.06 Air
	12.07 Nitrogen

	12.08 Other Utilities
Environmental	
	13.01 Permit Limited
	13.02 Waste Water Treatment
	13.03 Vent Limited
	13.04 Liquid Wastes
	13.05 Solids or Bulk
Logistics	
	14.01 Loading or Storage
	14.02 Rail
	14.03 Truck
	14.04 Marine
	14.05 Packaging
Raw Material Shortage or Availability	Does not include utilities (air , N2, fuel gas as utility)
	15.01 Vendor Supplied Material Shortage
	15.02 Vendor Supplied Material Quality
	15.05 Chronic Internal Supplied Raw Material Shortage
	15.06 Acute Internal Supplied Raw Material Shortage
	15.07 Internal Supplied Raw Material Quality
	15.09 RM Planning Coordination
Product Transfer Limitations	
	16.01 Product Downstream Restriction
	16.03 Pipeline Limitations Outside Site
	16.04 Pipeline Limitations Within Site
	16.07 By-Product Downstream Restriction
	16.08 Product Planning Coordination
Design Capacity Imbalance	
	17.01 Upstream Design Capacity Imbalance
	17.02 Downstream Design Capacity Imbalance

27.2 Appendix 2 – Flow Valve 5089

DOW CORNING LTD				Rev	Details	Chkd	Appr	Date
Instrument Data Sheet				A	FOR PURCHASE			9.3.00
Control Valve				B	AS BUILT			
				C	AS INSTALLED			28.02.01

1	EQ ID	TAG NUMBER	PTN	FV 5098407 BI	FV 5098 F6	REV
2	BLDG	PROJ NO	PO NO	W407	H096	600006001
3	EQUIP DESC	804 Catalyst dilution tank combined exit flow				
4	CONN TO EQ ID	P&ID DWG	804 BDC 00090382			
5	LINE/NOZZLE SIZE	LINE NO	LINE SPEC	25mm	040	PSS12W
6	FLUID	STATE	D4 cyclical Liquid			
7	HEALTH HAZARD	CORROSIVE	No No			
8	OPER FLOW UNITS	OPER FLOW LIMIT	Kg/h 0-20			
9	MIN FLOW	NORM FLOW	MAX FLOW	3	10	20
10	TEMP UNITS	TEMP LIMITS	DEG C -10-80			
11	MIN TEMP	NORM TEMP	MAX TEMP	20	25	30
12	INLET PRESS UNIT	PRESS LIMITS	Barg 0-15			
13	MIN PRESS	NORM PRESS	MAX PRESS	10	10	10
14	PRESS DROP UNITS	DROP LIMIT	Bar 1			
15	MIN DROP	NORM DROP	MAX DROP	5/7	5/7	5/7
16	VAPOUR PRESS UNITS	NORM VP	MAX VP	mbar	1.3	2.7
17	VISC UNITS	NORM VISC	VISC LIMITS	cP	10	5-25
18	BASE SP GR	MIN SP GR	NORM SP GR	NA	0.900	0.951
24	CRIT TEMP UNITS	CRITICAL TEMPERATURE	DEG C 313			
25	CRIT PRESS UNITS	CRITICAL PRESSURE	Bar 12.4			
26	MOLECULAR WEIGHT	SP HEAT RATIO Cp/Cv	894 1.05			
29	VALVE DUTY					
30	MANUFACTURER	MODEL NO	FISHER ROSEMOUNT 241778F			
31	BODY TYPE (STYLE)	BODY RATING CLASS	BAUMANN/GLOBE CLASS 300			
32	CONN SIZE	RATING	CONN TYPE	25mm	ANSI 300	RF FLG
33	BODY/BONNET MATL	LINING MATERIAL	316 ST.ST.			
34		GASKET MATERIAL				
35	FLANGE FINISH	FLOW ACTION TO	125-250 CLA OPEN			
36	BODY SPECIAL FEATURES					
37	TRIM SIZE	TRAVEL	FLOW CHARACTERISTIC	5/16"	1/4"	MOD=1
38	TRIM STYLE (FORM)	PACKING MATERIAL	177 EPASEAL TRIPLE			
39	SEAT MATERIAL	PLUG MATERIAL	RULON NITRINIC 60			
40	DIAPHRAGM MATERIAL	BELLOWS MATERIAL				
41	GUIDING TYPE	NO OF INTERNAL PORTS	SINGLE			
42	ANSI LEAKAGE CLASS	MAX SOUND LEVEL dBA	IV <50			
43	Cv MIN	Cv NORM	Cv MAX	0.0029	0.0079	0.0014
44	RATED Cv	RATED FL	0.05			
45	TRIM SPECIAL FEATURES					
46	ACT MPGR	MODEL NO	SIZE	FISHER ROSEMOUNT	FS9000-AA6LS/R	12
47	ACTUATOR TYPE	MOUNTING ARRANGEMENT	SYSTEM 9000 TOP			
48	SERVICE TYPE	SIZING FACTOR %				
49	CLOSE AT - UNITS	OPEN AT - UNITS				
50	FAIL ACTION	AMB TEMP LIMITS	CLOSE			
51	HOUSING MATERIAL	ACCESSORIES				
52	TRANSDUCER MPGR	TRANS MODEL NUMBER	FISHER ROSEMOUNT FS5040-110-HCT001			
53	CALIB UNITS	CALIB FROM	CALIB TO	mA	4	20
54	OUTPUT UNITS	OUTPUT FROM	OUTPUT TO	BARG	0.2	1.0
55	AIR SUPPLY UNITS	AIR SUPPLY LIMITS	BARG 4.1			
56	TRANSDUCER TYPE	OPTIONS	I TO P / POSITIONER			
57	FILTER REG	GAUGES	BY-PASS	FISHER 67AFR	YES	NO
58	TUBING MATERIAL	ELECTRICAL ENTRY	PVC COVERED COPPER 20mm			
59	ELECTRICAL CERT	INGRESS PROTECTION	IP65			
60	ZONE	GAS GROUP	TEMP RATING	ZONE 2	IIA	T3
61	QUALITY	SAFETY CRITICAL	ENVIRONMENTAL	YES	YES	
FOR COMPLETION INSTRUCTIONS SEE EMTN DOCUMENT NO CV.HLP 13.400.042						

DOW CORNING BARRY PLANT - PROPRIETARY

File Name: FV 5098 W407 F6.DOC
 Dow Corning Template File: 06_DataSheet_Control_Valve.doc

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Author :- P.A.Argyle

27.3 Appendix 3 – 818 Vac Pump SAP Failure Data

Date	QTR	Cost	Maintenance WO Type	WO Text	Floc	Description	Note	Equipment Type	End Date	WFO	Planner	Priority	Cost Centre
30/01/2018	Q1-2018	£ -	2030	RO7	HAZBEM/CLAND	HS10-00W007-000001-FS-0818-P1	VAC PUMP	302753949 HOOK & CLAW DRY VACUUM PUMP - LEYBOLD	38.12.2017	18.12.2017	G01	3	4302
25/06/2018	Q3-2018	£ 124.06	2030	RO7	Install earth clip on V2-818	HS10-00W007-000001-FS-0818-V01	VACUUM PUMP VENT CONDENSER	302538990 VACUUM PUMP VENT CONDENSER	25.08.2018	25.08.2018	W07	1	4302
03/09/2018	Q3-2018	£ 6,971.62	2030	RO7	@ REPLACE LP SEALS ON P1-818	HS10-00W007-000001-FS-0818-P2	VAC BOOSTER PUMP	302745326 VACUUM PUMP BOOSTER	30.08.2018	28.06.2019	W07	4	4302
24/09/2018	Q3-2018	£ 124.06	2030	RO7	P2-818 oil pot require top up	HS10-00W007-000001-FS-0818-P2	VAC BOOSTER PUMP	302745326 VACUUM PUMP BOOSTER	26.09.2018	26.09.2018	W07	1	4302
18/11/2018	Q4-2018	£ 187.36	2030	RO7	818 vac pump oil pot	HS10-00W007-000001-FS-0818-P1	VAC PUMP	302753949 HOOK & CLAW DRY VACUUM PUMP - LEYBOLD	26.12.2018	26.12.2018	W07	3	4302
25/03/2019	Q1-2019	£ 158.68	2030	RO7	lag drain line on 818 vac pump	HS10-00W007-000001-FS-0818-P1	VAC PUMP	302753949 HOOK & CLAW DRY VACUUM PUMP - LEYBOLD	25.03.2019	25.03.2019	W07	3	4302
17/09/2019	Q3-2019	£ 270.70	2030	RO7	REPLACE SPLIT O RING ON W007 P1-818	HS10-00W007-000001-FS-0818	VAC PUMP ASSEMBLY	302743724 VACUUM PUMP CONDENSER	17.09.2019	17.09.2019	W07	3	4302
15/07/2020	Q3-2020	£ -	2030	RO7	W/SHOP REELS OF 818 P2 FROM PREV TEC	HS10-00W007-000001-FS-0818-P2	VAC BOOSTER PUMP	302745326 VACUUM PUMP BOOSTER	31.12.2020	31.12.2020	ME7	3	4302
04/03/2021	Q1-2021	£ -	2030	RO7	INSPECT ZONE 12 TRACE HEATING	HS10-00W007-000001-FS-0818	VAC PUMP ASSEMBLY	302743724 VACUUM PUMP CONDENSER	05.03.2021	05.03.2021	W07	1	4302
11/03/2021	Q1-2021	£ 5,249.36	2030	RO7	Remove lagging on P1-818 discharge	HS10-00W007-000001-FS-0818-P1	VAC PUMP	302753949 HOOK & CLAW DRY VACUUM PUMP - LEYBOLD	13.03.2021	13.03.2021	W07	3	4302
14/04/2021	Q1-2021	£ 210.17	2030	RO7	P1-818 PULLING HIGH AMPS	HS10-00W007-000001-FS-0818-P1	VAC PUMP	302753949 HOOK & CLAW DRY VACUUM PUMP - LEYBOLD	13.06.2021	13.06.2021	W07	1	4302
18/06/2021	Q3-2021	£ 491.84	2030	RO7	FAULT FINDING ON P1-818	HS10-00W007-000001-FS-0818-M1	VAC PUMP MOTOR	302755135 P1-818m	18.06.2021	18.06.2021	W07	1	4302
01/07/2021	Q3-2021	£ -	2030	RO7	W007-818-P1 upgrade to MET (ROU)	HS10-00W007-000001-FS-0818-P1	VAC PUMP	302753949 HOOK & CLAW DRY VACUUM PUMP - LEYBOLD	31.05.2022	31.05.2022	PT7	4	4302
27/04/2021	Q3-2021	£ 16,214.06	2030	RO7	@Service P1-818 vac pump	HS10-00W007-000001-FS-0818-P1	VAC PUMP	302753949 HOOK & CLAW DRY VACUUM PUMP - LEYBOLD	18.06.2021	08.08.2021	W07	3	4302
27/12/2021	Q4-2021	£ 525.40	2010	COO	@12M, External visual inspection	HS10-00W007-000001-FS-0818-EP01	BELLOWS - 150-P-014APSIOW	302638555 BELLOWS - 150-P-014APSIOW	06.10.2021	27.10.2021	W07	3	4302
28/12/2021	Q4-2021	£ 938.50	2030	RO7	P1-818 - Air breather disconnected	HS10-00W007-000001-FS-0818	VAC PUMP ASSEMBLY	302743724 VACUUM PUMP CONDENSER	26.12.2021	26.12.2021	W07	1	4302
10/01/2022	Q1-2022	£ 12,616.56	2030	RO7	Service P1-818 vac pump - replace seal	HS10-00W007-000001-FS-0818-P1	VAC PUMP	302753949 HOOK & CLAW DRY VACUUM PUMP - LEYBOLD	02.12.2021	10.01.2022	W07	2	4302
21/01/2022	Q1-2022	£ 14,009.80	2030	RO7	Remove and service P1-818	HS10-00W007-000001-FS-0818-P1	VAC PUMP	302753949 HOOK & CLAW DRY VACUUM PUMP - LEYBOLD	14.01.2022	21.01.2022	W07	E	4302
24/01/2022	Q1-2022	£ 6,340.43	2030	RO7	scaffold and lagging support for 818 vac	HS10-00W007-000001-FS-0818	VAC PUMP ASSEMBLY	302743724 VACUUM PUMP CONDENSER	24.01.2022	24.01.2022	CO7	E	4302
25/01/2022	Q1-2022	£ 7,352.41	2030	RO7	Troubleshooting P2-818	HS10-00W007-000001-FS-0818-P1	VAC PUMP	302753949 HOOK & CLAW DRY VACUUM PUMP - LEYBOLD	20.01.2022	25.01.2022	W07	E	4302
04/02/2022	Q1-2022	£ 17,216.51	2030	RO7	Remove and Repair P1-818	HS10-00W007-000001-FS-0818-P1	VAC PUMP	302753949 HOOK & CLAW DRY VACUUM PUMP - LEYBOLD	11.01.2022	13.01.2022	W07	E	4302
08/06/2022	Q2-2022	£ -	2030	RO7	W007-818 Vac Pump Flush off	HS10-00W007-000001-FS-0818	VAC PUMP ASSEMBLY	302743724 VACUUM PUMP CONDENSER	30.06.2022	30.06.2022	W07	3	4302
14/06/2022	Q2-2022	£ 509.34	2010	COO	@ 12M P1-818 BPO1 BELLOWS External in	HS10-00W007-000001-FS-0818-EP01	BELLOWS - 150-P-014APSIOW	302638555 BELLOWS - 150-P-014APSIOW	12.07.2022	12.10.2022	W07	3	4302
16/06/2022	Q2-2022	£ 340.51	2030	RO7	Remove spool piece on 818 vent	HS10-00W007-000001-FS-0818-P2	VAC BOOSTER PUMP	302745326 VACUUM PUMP BOOSTER	15.08.2022	16.08.2022	W07	1	4302
26/10/2022	Q4-2022	£ 1,290.99	2030	RO7	(NW) Re-install the original P818 Vac Pu	HS10-00W007-000001-FS-0818-P1	VAC PUMP	302753949 HOOK & CLAW DRY VACUUM PUMP - LEYBOLD	30.10.2022	30.10.2022	G20	4	4302
19/12/2022	Q4-2022	£ 538.30	2030	RO7	Refit P1-818 Vac Pump	HS10-00W007-000001-FS-0818-P1	VAC PUMP	302753949 HOOK & CLAW DRY VACUUM PUMP - LEYBOLD	12.12.2022	30.12.2022	W07	3	4302
30/12/2022	Q4-2022	£ 21,786.09	2030	RO7	P1-818 Service Gearbox	HS10-00W007-000001-FS-0818-P1	VAC PUMP	302753949 HOOK & CLAW DRY VACUUM PUMP - LEYBOLD	12.12.2022	30.12.2022	W02	3	4302
12/01/2023	Q1-2023	£ 7,870.51	2030	RO7	W007 - Remove and service P1-818	HS10-00W007-000001-FS-0818-P1	VAC PUMP	302753949 HOOK & CLAW DRY VACUUM PUMP - LEYBOLD	14.08.2022	27.01.2023	CO7	3	4302
12/01/2023	Q1-2023	£ 14,387.44	2030	RO7	Change out P1-818	HS10-00W007-000001-FS-0818-P1	VAC PUMP	302753949 HOOK & CLAW DRY VACUUM PUMP - LEYBOLD	11.01.2023	12.01.2023	W07	E	4302
27/01/2023	Q1-2023	£ 8,545.64	2030	RO7	W007 - P1-818 Rebuild	HS10-00W007-000001-FS-0818-P1	VAC PUMP	302753949 HOOK & CLAW DRY VACUUM PUMP - LEYBOLD	16.01.2023	30.03.2023	W02	3	4302
07/02/2023	Q1-2023	£ -	2010	COO	12M, External visual inspection	HS10-00W007-000001-FS-0818-EP01	BELLOWS - 150-P-014APSIOW	302638555 BELLOWS - 150-P-014APSIOW	14.07.2023	11.08.2023	PO7	3	4302
02/03/2023	Q1-2023	£ 1,743.99	2030	RO7	w007 - replace p1-818 vac pump	HS10-00W007-000001-FS-0818	VAC PUMP ASSEMBLY	302743724 VACUUM PUMP CONDENSER	27.02.2023	03.03.2023	W07	2	4302
04/03/2023	Q1-2023	£ 902.18	2030	RO7	W007 - P1-818 vent blockage	HS10-00W007-000001-FS-0818-V01	VACUUM PUMP VENT CONDENSER	302538990 VACUUM PUMP VENT CONDENSER	03.03.2023	03.03.2023	W07	1	4302
17/03/2023	Q1-2023	£ 14,127.01	2030	RO7	W007 Service and Replace P1-818	HS10-00W007-000001-FS-0818-P1	VAC PUMP	302753949 HOOK & CLAW DRY VACUUM PUMP - LEYBOLD	15.03.2023	15.03.2023	W07	1	4302

General Business

27.4 Appendix 4 – Barwell Quote for Parts Susceptible to Fatigue Cracking

barwell global ltd

Unit 1, 9 Burrel Road,
St. Ives,
Cambridgeshire,
PE27 3LE
England
VAT Number GB 943412340
Tel: 01480 832650
email: jseaman@barwell.com

Customer Address	DOWUK
DOW SILICONES UK LIMITED	
CARDIFF ROAD	
BARRY	
CF63 2YL	
Great Britain	

Quotation Valid for 30 days
Quotation Number 0000034358
Your Ref
Date 24/10/2022
All Amounts in Pound Sterling
Your VAT Number GB 134 023 713
Terms 30 Days from End of Month
Estimated Despatch Currently Ex Stock
Despatch By Not Included, charged extra

Deliver To
Customer Address

Item Code	Description	Quantity	Unit	Unit Price	Total
19500	C3 FRONT BARREL - TWIN BASE.	1	Each	10450.00	10450.00

Our minimum order value is £50.00 which will be charged for all orders of less than this value.

BANK DETAILS:-
 BARCLAYS BANK PLC
 BENET STREET BUSINESS CENTRE
 P.O.BOX 2, CAMBRIDGE, CB2 3PZ
 SORT CODE:- 20-17-22
 SWIFT CODE:- BUKBGB22
 SWIFT CODE:- BUKBGB22
 SWIFT CODE:- BUKBGB22

ACCOUNT
 GBP ACCOUNT NO. 43409821
 EUR ACCOUNT NO. 52016633
 USD ACCOUNT NO. 46380277
IBAN
 GB73 BUKB 2017 2243 4098 21
 GB19 BUKB 2017 2252 0166 33
 GB77 BUKB 2017 2246 3802 77

TOTAL NET	Pound Sterling	10450.00
TOTAL VAT	Pound Sterling	2090.00
TOTAL GROSS	Pound Sterling	12540.00

Registered Office: Unit 1, 9 Burrel Road, St. Ives, Cambs, PE27 3LE, England.
 Registered In England No. 06517461, VAT Registration No. GB 943 4123 40, EORI No. GB 943 4123 40 000
 SUBJECT TO BARWELL GLOBAL LTD TERMS & CONDITIONS OF QUOTATION/SALE (see www.barwell.com)

Page 1 of 1

27.5 Appendix 5 - Dow Procedure Use Policy

Procedure Use Policy – Barry Operations

Scope and Purpose	This Procedure Use Policy defines expectations and requirements associated with the Procedure management system for the Barry Site, Basics & Fostering Operations and Logistics and Analytical Procedures document the step by step instructions followed in Barry to safely, effectively and efficiently perform work. This policy applies for all employees and contractors who perform work using procedures. It does not apply to Maintenance or R&D experimental/laboratory tasks, which are covered under separate policies to be found in WebEDMS. This policy document meets the requirement defined in the Operating Discipline Management System (ODMS) 05.03.04 L1 specifically section F.
Key Requirements of Procedure Use	All employees must: - Follow procedures as written or stop and escalate if the procedure cannot be followed as written. - Carry and complete procedures when required to do so. - Be involved in the development and ownership of procedures which apply to their role and initiate procedure updates as improvement opportunities are determined. - Create applicable procedures when needed. - Be trained on the job and authorized to use procedures relevant to their role prior to independently performing work. - Complete applicable refresher training to ensure they have the skills and knowledge needed to understand and adhere to the procedures for their role. - Create a field procedure when a procedure does not exist, following the Non-Existent Procedure (First Use-Single Use Process). - Participate in procedure audits as requested. - Revise procedures as required.

General Business

DOW RESTRICTED

Procedure Use

- We allow multiple users to sign on the same procedure copy as long as they stay in reference distance whilst performing the task.
- We allow partnership for sign off of procedures when hazards create a barrier that prevents the person performing the task from signing (examples, using walkie-talkies or a communication system for someone inside to sign the steps as someone outside performs them).
- When the task requires restrictive PPE or due to adverse weather, we allow groups of steps to be completed without signing each one with all steps being marked complete after the additional hazard condition is removed.
- Procedures which are passed from shift to shift will be marked with a line after the last step performed. The person passing the task will initial above the line and the person picking up the task will initial below the line.
- When more than one work team is involved in the completion of a task, each work team will have procedures which represent the steps they perform, and clear communication must be completed for each handoff of the task.
- Procedures must not be printed more than 72 hours in advance of being used. This requirement may be waived by the FWGL during Turnaround activity.

The workflow [Procedures vs Permits](#) expands on the ODMS 05.03.04 L2 process to clarify when a procedure can be used in place of a permit and vice-versa.

Emergency Procedure Requirements

- Definition:** Procedure associated with a planned response to a specific type of incident/unplanned event relevant to Maintenance owned assets.
- Personnel following Emergency Procedures shall:**
- Be knowledgeable of existing Emergency procedures.
 - Be trained on relevant Emergency procedures, through Emergency Incident Response drills and emergency plan reviews, specifically the Barry Emergency Response Team (BERT) training coordinated by the site ESS team.
 - Use good judgment, training and skills to bring the emergency under control.
 - Obtain and follow emergency procedures during the emergency if time permits, or as soon as the situation is brought under control.
 - Know where and how to locate Emergency Procedures.
- Example:** Emergency Spill Response

General Business

DOW RESTRICTED

Procedure Creation	Procedures are tools that, when properly followed, ensure safe and consistent execution of the task. We create procedures when it brings value to the company and the procedure user to do so. In Barry, procedures are created according to the ODMS 05.03.04 L1 Policy, including but not limited to the following types of tasks: - Any high risk (critical) tasks. - Tasks which require consistency or collective knowledge to safely, effectively and efficiently perform work. - Tasks for immediate response to emergency situations and for planned activities preparing for or following emergencies. Barry site may identify specific tasks to be exempt from needing a procedure. These tasks must meet one or more of the following criteria: - Be low or minimal risk (safety, health, environmental, and reliability) - Create significantly increased risk if a procedure is used when performing the task. - Covered by a certification (i.e. forklift operation), local regulations, Notified Body, or Dow requirements. The FWGL has final Approval of all items on the Exemption List. The Facility Procedure Exemption List can be found in the Barry WebEDMS.
Risk Assessment	If a risk assessment has been written for the task, the procedure must reference the risk assessment. Either the risk assessment or the procedure can then be used as the controlling document to manage the risks of the activity as documented by the risk assessment. To use the procedure as the controlling document for this activity providing the following conditions are met: - All risk assessment mitigations have been copied into the procedure into appropriate sections with signatures to confirm each mitigation is in place. - Risk assessment number is referenced on the procedure within the scope section. - The risk assessments has been verified after the first use as per site risk assessment policy. If the procedure is not going to be used as the controlling document the procedure must instruct the procedure user to print and carry the risk assessment in conjunction with the procedure. Each risk assessment mitigation must then be signed to ensure that the mitigations are all in place prior to continuing the procedure.
Inter-Business Inter-Function	If a procedure involves steps which are totally or partially performed by any group outside the department, special steps must be built into procedures to ensure safe completion, such as: - Communicate with the person(s) or group. - Confirm step status & completion.

General Business

DOW RESTRICTED

Procedure availability	The master electronic copy of all procedures which are approved for use are located in the Facility file share under approved procedures and are linked in WebEDMS. Infrequently used procedures must be kept in the relative file share but are not required to be linked to WebEDMS. Controlled hardcopies are maintained for: - Immediate Response/Emergency procedures which must be accessible during a power failure. They are located in each control room or galleyhouse. It is at the discretion of the Facility to keep hardcopies of non-immediate response procedures. If controlled hardcopies are kept they must, at minimum: - Include indication they are a controlled hardcopy - Include a reference to the master electronic version - Be updated, following the management of change process, when changes are made.
Risk and the Carry and Complete Requirements	The task risk is defined following the L2 Procedure Process. Site and Facility Criticality tools are available to aide determination of the overall risk. The tool is not mandatory but recommended. Risk is used to identify the carry and complete requirements for that task. Tasks that are deemed carry and complete every time include: - Tasks with high risk steps where the steps must be signed every time - Tasks where the risk is moderate but there is value in the procedure being carried and completed into the field (key to operations) - As determined by Facility Leader Note that all maintenance procedures are required to be at the job site while the task is being performed.
Procedure Formats	Procedures and work instructions are documented in a format that helps the user understand and perform the task. Approved templates at the Barry Site are available in webEDMS and at the following location: LINK\ASDOW\101\BARR_SiteCpsApproved\0503_04_ProcedureTemplates & Tools

General Business

DOW RESTRICTED

27.6 Appendix 6 – 157 Mixer RCA

W115-157 MIXER JACKET CRACK LER

• What? - Extended UPE from jacket failure on 500 gal sigma blade mixer 157 • When? - Unplanned outage 03/31/22-08/24/2022 • Where? - Barry Finishing Elastomers • Significance? - \$2,379,000 Loss - 1220MT Production Loss - 28.5% PSR Loss	• Incident Summary - During prep for a planned chemical clean of Mixer 157 jacket a small pinhole leak was discovered. Upon inspection it was noticed that a 7" crack had formed near a previous repair near the lift cylinder. • Key Findings - 2018 similar failure occurred, and replacement was recommended however not acted upon. Mixer had passed required integrity testing to continue operation and pinhole leaks not considered a high safety risk. - Chloride content in the flowing cooling water is relatively low. Typically, this is not high risk for Stress Corrosion Cracking. However, chloride content can be concentrated locally when jacket is drained, and mixer is hot giving required conditions for SCC. - Mixer was commissioned in 1978 but second hand to Dow. Historical cleaning methods poorly documented and could be an additional contributor to SCC. - Metallurgical testing confirmed presence of Stress Corrosion Cracking ultimately contributing to end of life of this mixer. Failures will continue until replaced. • Corrective Actions - Prevent no flow jacket condition when mixer is hot (keep water flowing) to manage chloride concentration. Procedural and hardware/programming to be installed. (plant) - Review options, decide on replacement strategy, and set timeline for replacement due to end of life failure mode (business)
--	---



E&AT: 50796
IM:



3/31/2023

1

27.7 Appendix 7 – R-Tech

This report is Copyright © R-TECH Materials Limited

Examination of a failed compound mixer section

Report Number: M22094
Date: 11/05/2022
Proforma No.: 4513196639
Customer: Dow Silicones UK LTD
Customer Contact: Tomos Rowlands

R-TECH MATERIALS

Report by: James McConnell
 Consultant Metallurgist

Reviewed by: Sarah Bagraff C.Eng. MIMMM
 Director Consultancy Services

Testing House, Fawley Industrial Estate, Margen, Port Talbot, SA2 8PE, UK
 T: +44(0)1496 738 030 E: info@r-techmaterials.co.uk W: www.r-techmaterials.co.uk

R-TECH MATERIALS

Executive Summary

R-TECH Consultants Ltd received a failed welded patch from Dow Silicones UK Ltd, with the request to confirm both the chemical composition and cause of failure. The patch consisted of two welded stainless steel plate sections, side A corresponding to the original vessel metal and side B the repair insert. The following conclusions arose from this assessment:

- 1) Failure of the welded patch is thought to be attributable to Chloride Stress Corrosion Cracking (CLSCC).
- 2) CLSCC was confined to the original vessel metal (side A) and was apparent at both the internal and external surfaces. Analysis was unable to determine at which surface (internal or external) CLSCC had originally initiated or the origin of the chloride bearing species.
- 3) Temperature is a key indicator for susceptibility to CLSCC. As temperatures increase beyond 60°C, very small levels of chloride (~1 – 50ppm) can initiate CLSCC.
- 4) The stress threshold required for crack initiation can vary from 10 to 70% of the yield strength depending on the alloy, chloride content and temperature.⁽¹⁾ The welded patch was associated with high residual stresses, which can be of the order of the tensile strength of the steel.
- 5) Side A exhibited evidence of sensitisation, however no intergranular attack was observed during the investigation.
- 6) The chemical composition of side A complied with AISI Stainless Steel grade 321.
- 7) The chemical composition of side B complied with AISI Stainless Steel grade 317.
- 8) The recorded hardness for both sides A & B satisfied with the maximum value stated by the relevant standard.

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 TMR-03 Rev. 02

F4N F4 For Nuclear

R-TECH MATERIALS

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F4N F4 For Nuclear

R-TECH MATERIALS

1. Introduction

R-TECH Consultants Ltd received a failed welded patch from Dow Silicones UK Ltd, with the request to confirm both the chemical composition and cause of failure. It was understood that the welded patch had been removed from a compound mixer vessel and was suspected to be comprised of stainless steel, although the specific grades were unknown. The patch, in the as-received condition, can be seen in figure 1.1 – 1.3. The patch was divided across the weld into sections A & B by the client; side A corresponded with the original vessel metal, whilst side B was the thicker repair insert.

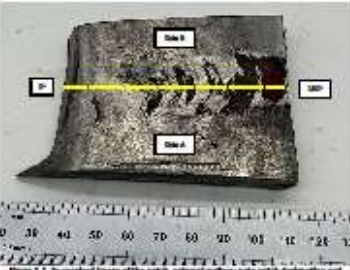


Figure 1.1. As-received image of the patch, external surface note patch designation and orientation.

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F4N F4 For Nuclear

27.8 Appendix 8 – Elastomers Operator Structure

A Shift		B Shift		C Shift		D Shift		E Shift	
W115									
Gunning	Operator 1	Gunning	Operator 15	Gunning	Operator 30	Gunning	Operator 45	Gunning	Operator 59
Colmec	Operator 2	Colmec	Operator 16	Colmec	Operator 31	Colmec	Operator 46	Colmec	Operator 60
Colmec	Operator 3	Colmec	Operator 17	Colmec	Operator 32	Colmec	Operator 47	Colmec	Operator 61
Tilts	Operator 4	Tilts	Operator 18	Tilts	Operator 33	Tilts	Operator 48	Tilts	Operator 62
177	Operator 5	177	Operator 19	177	Operator 34	177	Operator 49	177	Operator 63
277	Operator 6	277	Operator 20	277	Operator 35	277	Operator 50	277	Operator 64
W205									
CTM355	Operator 7	CTM355	Operator 21	CTM355	Operator 36	CTM355	Operator 51	CTM355	Operator 65
CTM355	Operator 8	CTM355	Operator 22	CTM355	Operator 37	CTM355	Operator 52	CTM355	Operator 66
CTM FSR	Operator 9	CTM FSR	Operator 23	CTM FSR	Operator 38	CTM FSR	Operator 53	CTM FSR	Operator 67
CTM FSR	Operator 10	CTM FSR	Operator 24	CTM FSR	Operator 39	CTM FSR	Operator 54	CTM FSR	Operator 68
BDM 1	Operator 11	BDM 1	Operator 25	BDM 1	Operator 40	BDM 1	Operator 55	BDM 1	Operator 69
BDM 2	Operator 12	BDM 2	Operator 26	BDM 2	Operator 41	BDM 2	Operator 56	BDM 2	Operator 70
BDM 3	Operator 13	BDM 3	Operator 27	BDM 3	Operator 42	BDM 3	Operator 57	BDM 3	Operator 71
BDM 4	Free	BDM 4	Operator 28	BDM 4	Operator 43	BDM 4	Free	BDM 4	Free
KIT PREP	Operator 14	KIT PREP	Operator 29	KIT PREP	Operator 44	KIT PREP	Operator 58	KIT PREP	Operator 72
Day Workers									
Dow									
Adesco									
Dep Lead Op									
S-Lot									
S-Lot									
KR-Smalis 1									
KR-Smalis 2									
CTM145/95									
Operator 73									
Operator 74									
Operator 75									
Operator 76									
Operator 77									

27.9 Appendix 9 - Polymers Operator Structure

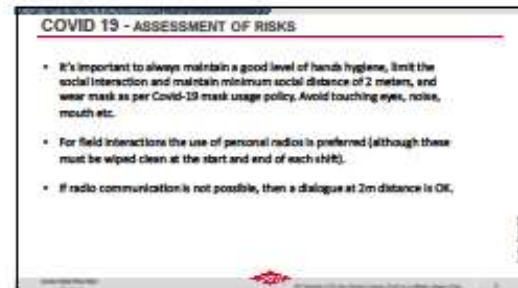
Process Areas	A Shift	B Shift	C Shift	D Shift	E Shift
Seat A					
W322, W404, W405, W406, W422	Operator 1	Operator 2	Operator 3	Operator 4	Operator 5
Seat B					
VLVF, HVF, 1107, GIC	Operator 6	Operator 7	Operator 8	Operator 9	Operator 10
Vinyl					
K250, 383, W407	Operator 11	Operator 12	Operator 13	Operator 14	Operator 15
Batch					
CHU, K1303	Operator 16	Operator 17	Operator 18	Operator 19	Operator 20
Blending					
419, 183/283, K150	Operator 21	Operator 22	Operator 23	Operator 24	Operator 25
W307					
K903, K703, K941, W309	Operator 26	Operator 27	Operator 28	Operator 29	Operator 30

27.10 Appendix 10 – Dow Barry Site Covid-19 Policy

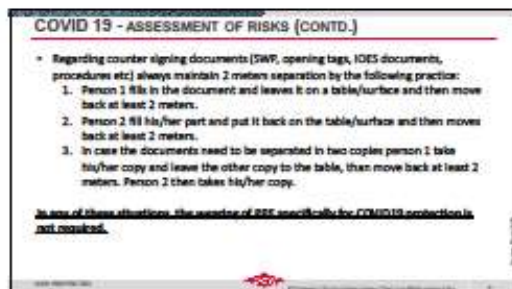
11/04/2023



1



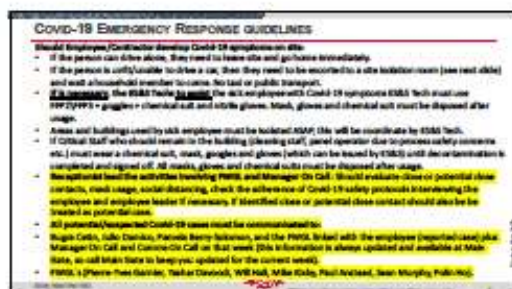
2



3



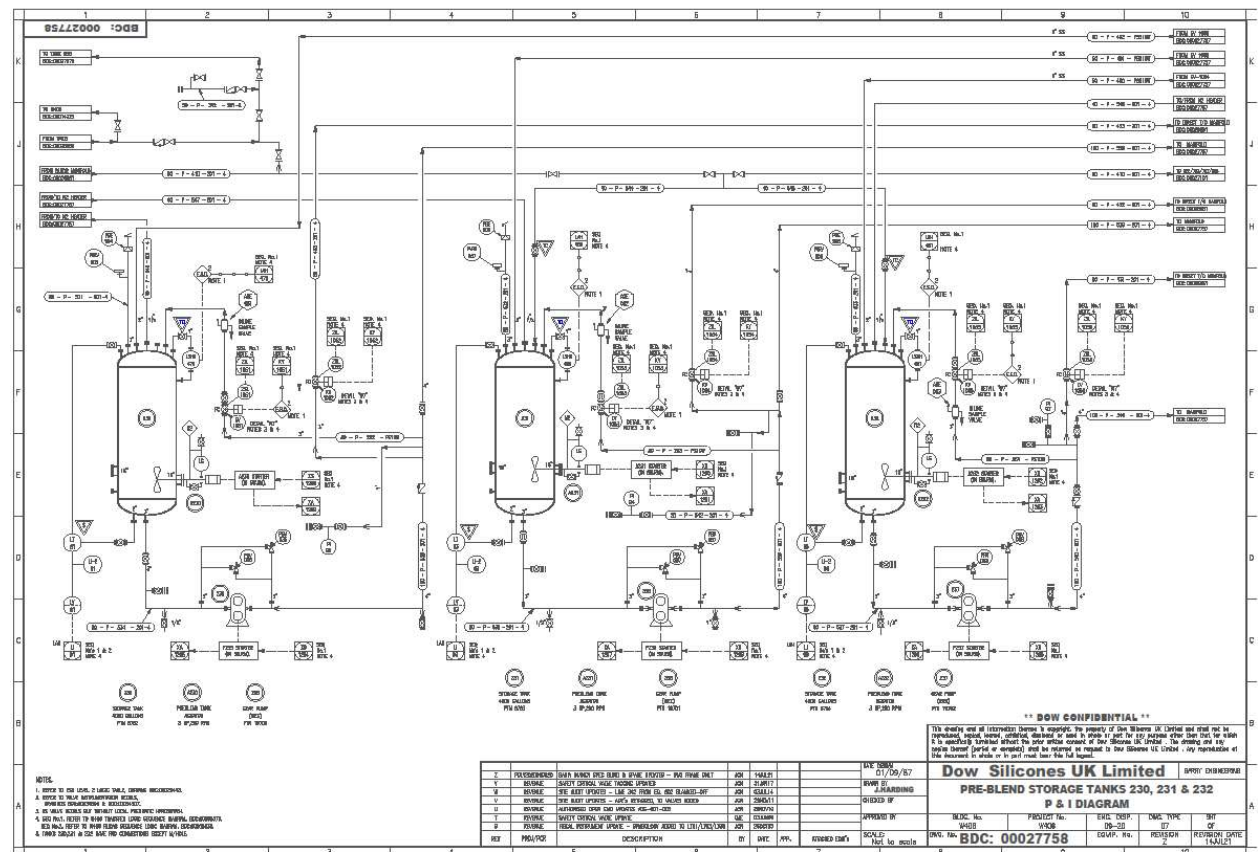
4



5



6

[illegible]

27.12 Appendix 12 - Confined Space Entry Summary of Requirements



Confined Space Entry

LIFE Rules



PROTECTING PEOPLE
AND OUR PLANET

Definition "Confined Space"

Difficult to get into.
Difficult to get out of.

Both are Confined Spaces

small entrance



large open top



Required Documents

CSE Procedure, CSE SWP

Procedure

Confined Space Entry Procedure

This procedure is a safe system of work and must be followed in its entirety.

Procedure No.	1001	1002	1003
Revision No.	1	2	3
Revision Date	10/10/10	10/10/10	10/10/10
Revision Reason	Initial version	Minor changes	Major changes

Secondary Approver Required

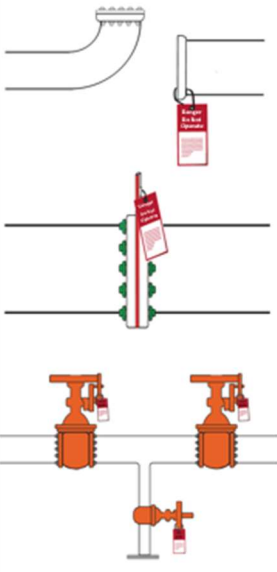
CSE SWP



Before Anyone Goes In

Prepare the Space

Isolate



Ventilate



Test Air



Prepare the People

Safety Attendant



✓	Trained
✓	Maintains "Line of Sight"
✓	Or 2-Way Communication
✓	Maintains Entrant Log
✓	Monitors Safety Equipment

Entrant



✓	Trained
✓	Maintains "Line of Sight"
✓	Or 2-Way Communication
✓	Notify Safety Attendant of Entry/Exit
✓	Knows Hazards

Rescue Member



✓	Trained
✓	Emergency Equipment Available
✓	Rescue Plan
✓	Can Communicate with Safety Attendant