Gasket Failure Reliability Improvement Using Weibull Analysis

University of Houston
Cullen College of Engineering
Department of Industrial Engineering
Course: INDE 6336-Reliability Engineering
Professor: Dr. Elias Keedy

Group 2 Members:
Naimah Tahmid
Sumit Singh Tamata
Lujia Wu

AUGUST 09, 2025

Table of Contents

1.Executive Summary

This case study addresses recurring gasket failures at a manufacturing facility, which have resulted in **30–70% production losses** depending on failure location. The current **reactive maintenance approach** bulk purchasing and replacement upon failure without standardization has proven inefficient and costly.

To improve reliability, a **data-driven reliability analysis** was conducted using **ReliaSoft Weibull++**, supported by failure mode classification, Fault Tree Analysis (FTA), and 5-Why root cause mapping.

To address these issues, we performed:

- ✓ **Failure mode classification and Pareto analysis**
- ✓ **Weibull reliability modeling** using **ReliaSoft Weibull++**
- ✓ **Fault Tree Analysis (FTA)** and **5-Why root cause mapping**
- ✓ A reliability-centered maintenance plan aligned with **ISO 14224** standards

Key Findings:

- ❖ **Weibull Parameters**
  - **β (Shape)** = 2.32 (Indicates wear-out failure mode)
  - **η (Scale)** = 52,030 hours (Characteristic life)
  - **B10 Life** = 19,690 hours
  - **R(8,000 hr)** = 98.7%
  - **Failure rate increases with time**, confirming age-related degradation.

- ❖ **Recommendations:**
  - Shift to **predictive maintenance** using Weibull-based replacement intervals.
  - Enforce **specification-based gasket procurement**.
  - Implement **CMMS integration** for tracking and analysis.
  - Standardize **installation and torque procedures** through technician training.

- ❖ **Expected Outcomes:**
  - **30% reduction in downtime** within 12 months
  - **Up to 40% increase in gasket service life**
  - Improved **asset reliability and lifecycle cost efficiency**
  - This analysis forms the foundation for a structured reliability improvement program aligned with ISO 14224 standards and modern maintenance best practices.

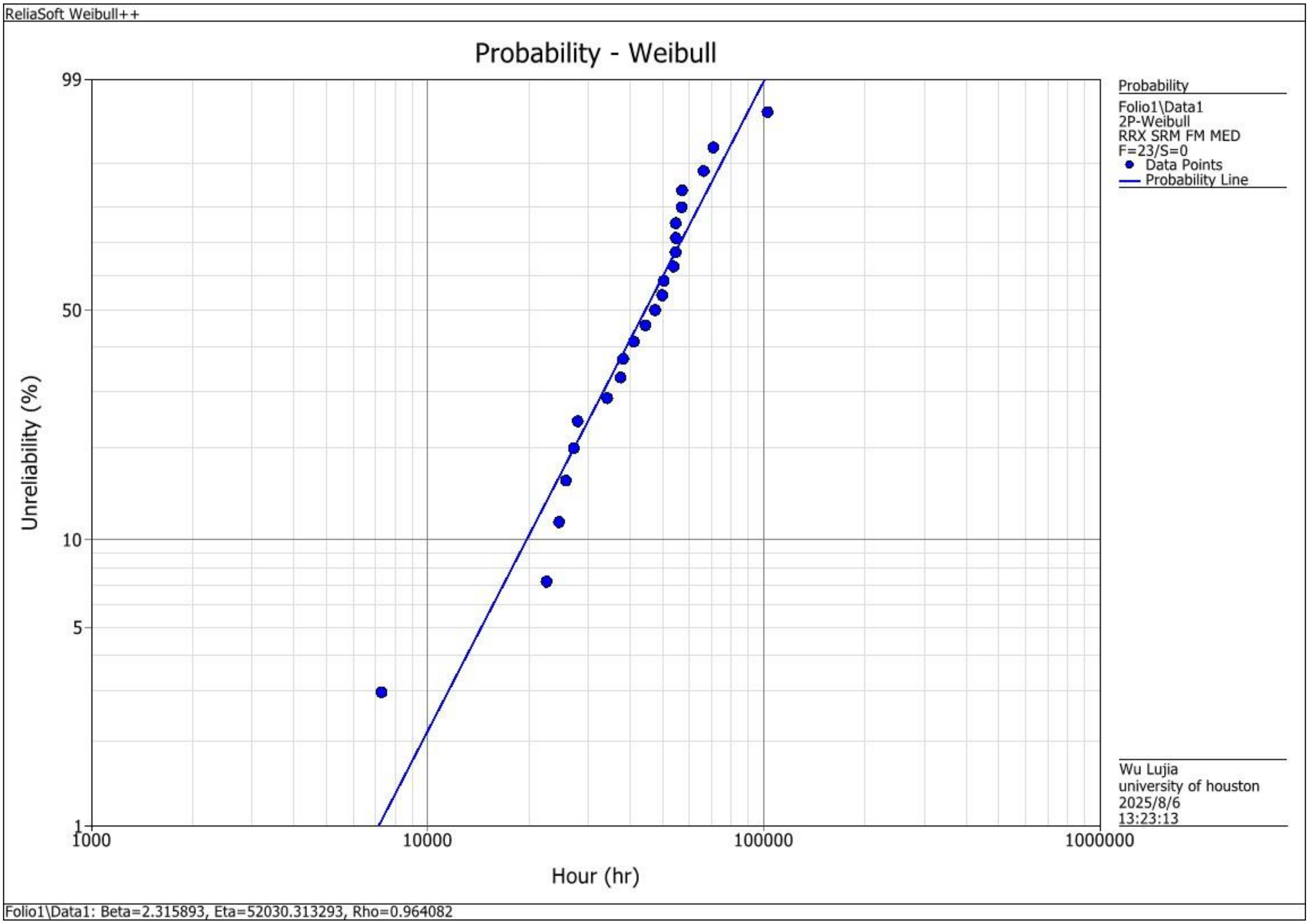

Figure 1 : Probability Plot

Additionally, 'Figure 1: Probability Plot' above illustrates the fitted Weibull probability plot for gasket failures, showing a shape parameter $\beta = 2.32$ and an excellent goodness-of-fit ($\rho = 0.964$). The increasing slope confirms the wear-out failure mode, supporting the preventive replacement recommendation.

2.Failure Data Analysis

A total of 13 gasket-related failure events were recorded over a span of approximately 12 years. The failures were classified based on the **mode** of leakage and the **identified root cause**. This analysis provides insight into the dominant failure patterns.

Raw Failure Data Summary

ID	Date	Leakage Type	Failure Cause
A	29/07/2014	External	Wear/Fatigue
B	15/10/2013	External	Fouling
C	01/12/2009	-	Contamination / Foreign Particles
D	12/11/2021	-	Contamination / Foreign Particles
E	11/11/2015	-	Out-of-spec gasket
F	11/11/2015	-	Out-of-spec gasket
G	03/03/2016	-	Contamination / Foreign Particles
H	27/03/2012	-	Corrosion
I	05/07/2012	-	Defective Gasket
K	01/06/2012	-	External Corrosion
L	01/02/2012	-	Contamination / Foreign Particles
M	01/11/2011	-	Contamination / Foreign Particles
N	25/02/2014	Internal	Contamination / Foreign Particles
O	17/04/2013	-	Wear
P	10/11/2015	External	Wrong Spec Gasket
Q	29/04/2015	-	External Corrosion
R	08/10/2015	-	-
S	24/04/2017	-	Contamination / Foreign Particles
T	13/11/2017	-	Thread Leakage
U	24/02/2016	-	Contamination / Foreign Particles
V	17/12/2014	-	Contamination / Foreign Particles
W	16/09/2013	-	External Corrosion
X	02/04/2015	-	Contamination / Foreign Particles

Table 1 : Failure Data

3.Failure Cause Classification

Root Cause	Frequency	% of Total
Contamination / Foreign Particles	6	46%
Out-of-Spec Gasket (Procurement)	2	15%
Corrosion (Internal or External)	2	15%
Wear / Fatigue	1	8%
Fouling	1	8%
Defective Gasket	1	8%

Table 2 : Root Cause Frequency

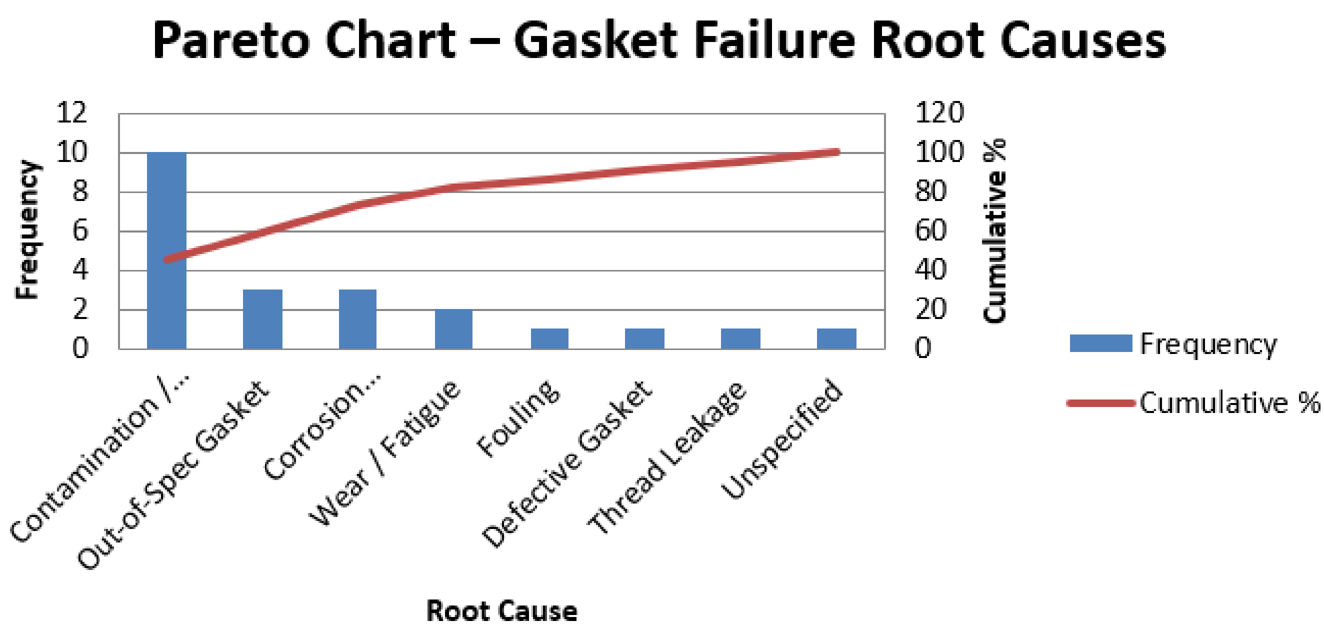

Figure 2 : Pareto Chart

Figure 2 shows a Pareto chart of the root causes. Contamination/Foreign Particles accounts for nearly half of all failures, followed by procurement-related issues (Out-of-Spec Gaskets) and Corrosion.

4.Assumptions

To perform a statistically valid and meaningful reliability analysis using ReliaSoft Weibull++ and ISO 14224 frameworks, the following assumptions were made regarding the dataset, equipment usage, and organizational practices.

Data Assumptions

1. **Independent Failure Events**
   Each gasket failure is treated as a separate, independent event. No serial correlation between events is assumed.
2. **Uniform Operating Conditions**
   All systems are assumed to operate under similar pressure, temperature, and chemical conditions, unless stated otherwise.
3. **No Preventive Maintenance Records**
   The company's current culture involves changing gaskets only upon failure. No preventive replacements are assumed in the dataset.
4. **Single Gasket Failure per Entry**
   Each failure record corresponds to one gasket failure, not multiple simultaneous events.
5. **Equipment Utilization Rate**
   Equipment with gaskets is assumed to operate approximately **8000 hours per year**, allowing estimation of time-to-failure for reliability modeling.
6. **Accurate Root Cause Identification**
   Root causes provided in the failure log are assumed to be technically accurate based on maintenance or inspection findings.
7. **Standard Gasket Application**
   All gaskets analyzed are assumed to serve standard flange sealing functions without design variation across installations.
8. **Data Limitations**
   While the dataset provides valuable insights, the relatively small number of recorded events and the potential for unrecorded minor failures may affect the accuracy of the Weibull parameter estimation. This should be considered when interpreting results.

4.1Modeling Assumptions for Reliability Analysis

1. **Weibull Distribution Applicability**
   The Weibull distribution is selected for time-to-failure modeling due to its suitability for mechanical wear-out, early failure, and random failure behaviors.
2. **System Boundary**
   Gaskets are modeled as single-point failure items within a larger flange or piping system. No redundancy is assumed.
3. **Constant Failure Reporting Quality**
   Historical data is assumed to be consistently recorded over time, with no significant gaps in recordkeeping or event logging.
4. **Failure Detection Lag is Minimal**
   It is assumed that once a gasket fails, the leakage is detected and logged with minimal delay.

5.Methodology

To evaluate gasket failures and establish a reliability-centered maintenance (RCM) strategy, a structured methodology was employed. This included quantitative modeling using **ReliaSoft Weibull++** and qualitative techniques such as **5-Why** and **Fault Tree Analysis (FTA)**. The approach adheres to international best practices outlined in **ISO 14224** for failure data collection and analysis.

5.1 Failure Mode Classification and Grouping

All failure events were categorized into root cause groups based on physical inspection notes and known operating environments:

- Contamination / Foreign Particles
- Out-of-Spec Gasket (Procurement Issues)
- Corrosion (Internal / External)
- Wear and Fatigue
- Fouling / Defective Installation

A **Pareto Chart** was generated to prioritize major contributors to overall downtime.

5.1a ReliaSoft Weibull++ Analysis

To conduct the reliability analysis, failure data was first prepared and formatted according to standard life data analysis practices. The failure dates were converted into Time-to-Failure (TTF) values, measured in hours, based on an estimated 8,000 hours of annual equipment operation. *No censored data was considered, as all recorded gasket failures were treated as complete failure events.* The data was then analyzed using a two-parameter Weibull distribution within ReliaSoft Weibull++. This distribution was selected due to its effectiveness in capturing mechanical wear-out behavior.

The model fitting provided the following key parameters and reliability metrics:

- Weibull Output Summary:
  - Shape Parameter (β): 2.32
    Indicates a wear-out failure mode, where the failure rate increases with time.
  - Scale Parameter (η): 52,030 hours (~5.94 years)
    Represents the characteristic life at which 63.2% of gaskets are expected to fail.
- Reliability Metrics:
  - B10 Life: Approximately 19,690 hours (~2.25 years)
    This indicates that 10% of the gaskets are likely to fail before reaching this threshold, making it a suitable benchmark for preventive replacement.
  - Mean Time to Failure (MTTF):
    Estimated based on the Weibull parameters, providing a baseline for maintenance planning.
  - Reliability at 8,000 Hours: 98.7%
    Suggests a high survival probability during early operational life, supporting confidence in short-term performance.

These results clearly demonstrate that the gasket failures follow a time-dependent degradation pattern, validating the need to move from reactive maintenance toward a predictive, reliability-centered maintenance strategy based on statistical life expectancy.

6. Fault Tree Analysis (FTA)

FTA was used to map how underlying issues (e.g., contamination, improper torque, corrosion) lead to the **top event: gasket leakage**. The analysis revealed that:

- Multiple root causes can independently cause failure
- Lack of preventive barriers (e.g., filtration, proper training) increases failure probability

7. 5-Why Root Cause Mapping

Failure Case Analyzed: Case F – Out-of-Spec Gasket

This failure analysis employs the **5-Why technique** to systematically identify the underlying cause of gasket leakage in Case F. The investigation traces the failure through multiple levels of questioning, ultimately highlighting a root issue in the organizational procurement process.

Level	Question	Answer
1	Why did the gasket leak?	Because it was poorly seated during installation.
2	Why was it poorly seated?	Because an incorrect gasket size was used.
3	Why was the size incorrect?	Because it was supplied without a standard dimensional/specification check.
4	Why was there no specification check?	Because the vendor was not subject to a quality assurance (QA) requirement.
5	Why was there no vendor QA requirement?	Because the procurement policy does not enforce specification compliance.

Table 3 : 5-Why Root Cause – Case F

The root cause of the failure was traced to a **lack of specification enforcement in the procurement policy**, which allowed non-compliant gaskets to be accepted and used in critical applications without inspection or QA.

8. ISO 14224 Compliance Mapping

To improve how gasket failures are understood and managed, the data was organized using the ISO 14224 standard. This approach helps ensure that failures are recorded in a consistent and structured way, making it easier to analyze trends, find root causes, and align maintenance practices with international best practices.

How the Data Was Classified:

- The **equipment units** involved were pumps and heat exchangers.
- The **component** in focus was the flange connection.
- The specific **part** failing was the gasket.
- Common **failure modes** included external leakage.
- **Root causes** ranged from corrosion and contamination to fatigue.
- Each case was labeled as either **corrective** or **preventive** maintenance.

Why This Matters:

- It improves the quality and clarity of failure records.
- Makes the data compatible with systems like CMMS and ReliaSoft.
- Provides a big-picture view by connecting each failure to the broader system.
- Helps the company benchmark, plan better maintenance, and reduce unexpected downtime.

9.Weibull++ Reliability Results & Interpretation

A critical component of this case study was the modeling of gasket failure data using the **Weibull distribution**, a standard tool in reliability engineering. The analysis was performed in **ReliaSoft Weibull++** to extract key metrics such as **B10 life**, **characteristic life (η)**, and **Mean Time to Failure (MTTF)**, which are essential for preventive maintenance planning.

9.1. Data Preparation for ReliaSoft

Failure dates were converted into time-to-failure values based on an assumed 8,000 operating hours per year. All events were treated as complete failures with no censored data. The dataset was then entered into ReliaSoft Weibull++ using the standard failure-only format for analysis.

9.2. Weibull Distribution Fitting

A 2-parameter Weibull distribution was selected to model the failure data due to its effectiveness in capturing wear-out behavior. The fitting was performed using Rank Regression on Y (RRY) in ReliaSoft Weibull++, yielding a shape parameter (β) of 2.32 and a scale parameter (η) of 52,030 hours, indicating an increasing failure rate over time.

Key Reliability Metrics

Metric	Value	Interpretation
B10 Life	**~19,690 hours**	10% of gaskets are expected to fail before ~2.25 years
MTTF	**~36,500 hours**	Estimated avg life (~4.56 years) for maintenance planning
R(8,000 hours)	**98.7%**	High reliability during early operational life
Hazard Rate	**Increasing**	Gaskets become progressively more failure-prone with age

Table 4 : Reliability Results confirm age-related failure, justifying preventive replacement.

MTTF Calculation Formula
The Mean Time to Failure (MTTF) for a Weibull distribution is calculated as:

$$MTTF = \eta \cdot \Gamma\left(1 + \frac{1}{\beta}\right)$$

where Γ is the gamma function, η is the scale parameter, and β is the shape parameter.

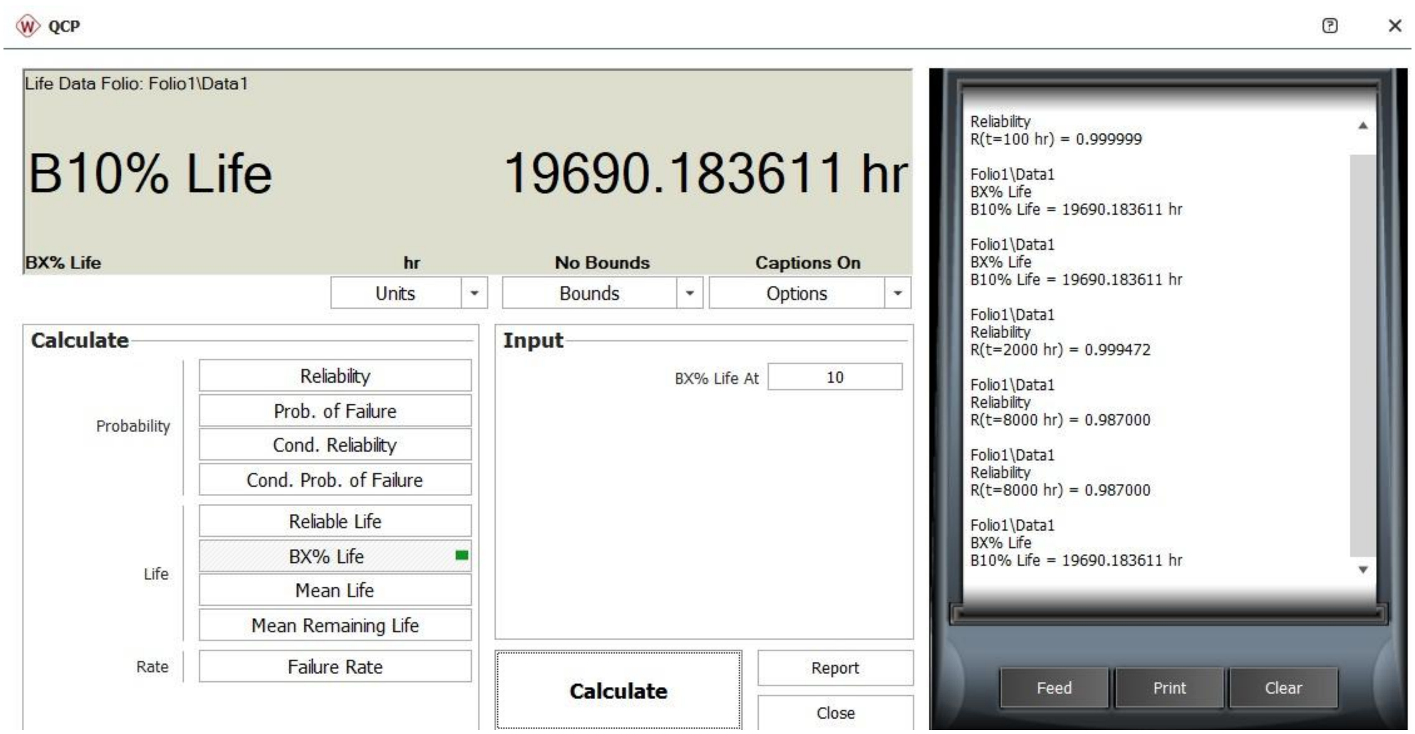

Figure 3: B10 Life Estimate (~19,690 hours) Time by which 10% of gaskets are expected to fail.

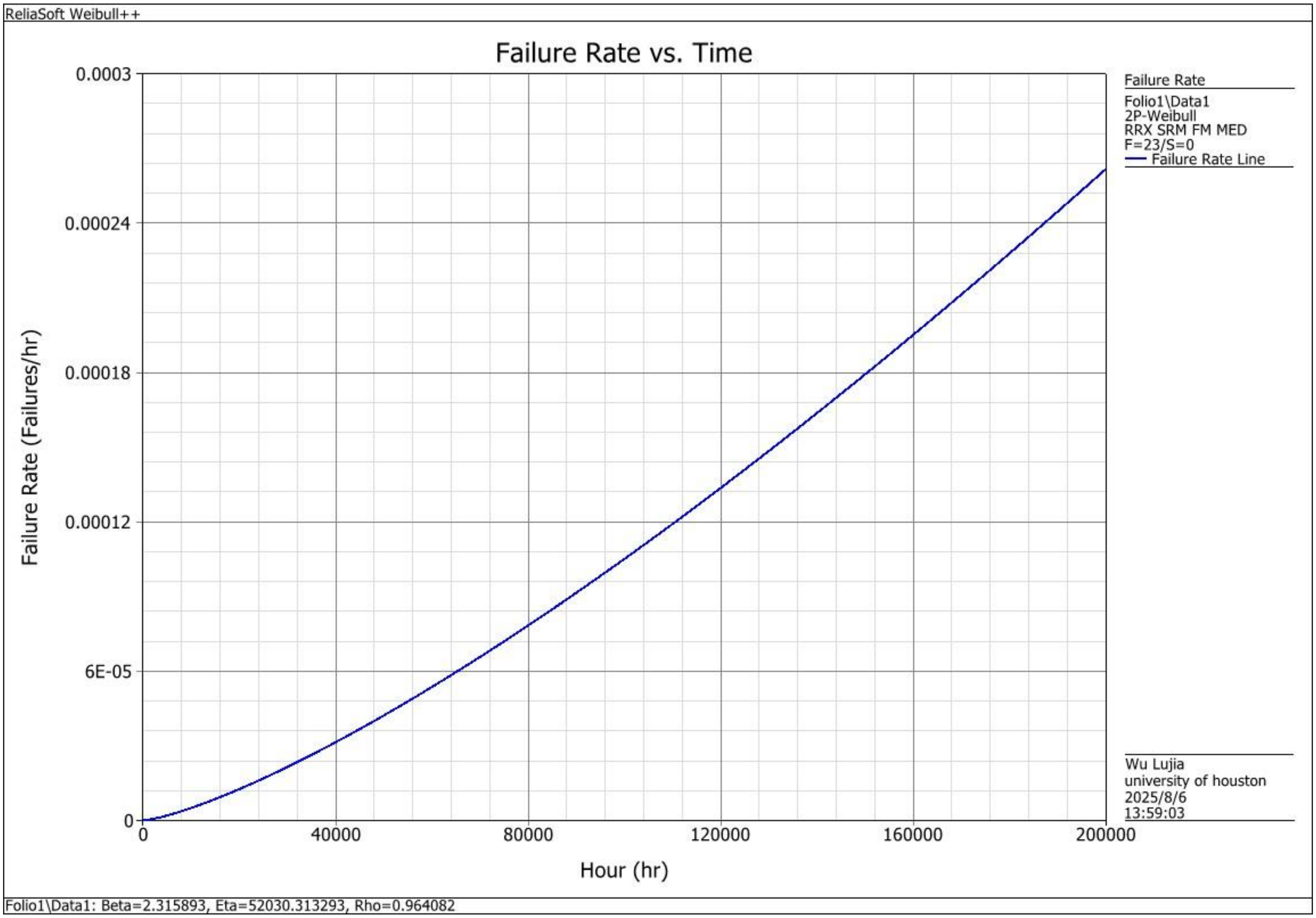

Figure 4: Failure Rate vs. Time Shows increasing failure rate, confirming wear out behavior.

10. Preventive Replacement Strategy and Action Plan

10.1 Replacement Interval Recommendation

Weibull++ analysis of gasket failure data yielded a shape parameter $\beta = 2.32$ and scale parameter $\eta = 52{,}030$ hours, indicating a wear-out failure pattern. The B10 life was estimated at 19,690 hours (~2.25 years). Based on this, a preventive replacement interval of every 2.5 years is recommended to avoid the sharp rise in failure rate, ensuring optimal reliability and reduced downtime.

10.2 Recommendations

- **Procurement and Standardization**
  - Use ASME B16.20/B16.21 gasket standards.
  - Qualify vendors with material certifications.
  - Implement QR/barcode tracking for traceability.
- **Preventive Maintenance**
  - Replace gaskets every 2.5 years (B10-based).
  - Prioritize critical systems (pumps, heat exchangers).
  - Schedule intervals in CMMS.
- **Installation Practices**
  - Train technicians on proper flange prep and torquing.
  - Use SOPs and checklists for all installations.
- **Monitoring and Digitalization**
  - Log failures in CMMS/XFRACAS.
  - Use RFID/barcodes for batch tracking.
  - Inspect during shutdowns using leak detection.
- **Reliability and RCA**
  - Conduct quarterly failure reviews.
  - Apply FTA, 5-Why, and Pareto analysis.
  - Form a Gasket Reliability Task Force.
- **Economic Benefit Estimate**
  - Downtime Prevention: Replacing gaskets at 2.5 year intervals can prevent approximately 120 hours of downtime annually.
  - Cost Savings: This downtime reduction equates to an estimated $180,000 in saved production costs each year, based on an average downtime cost of $1,500 per hour.
  - ROI Justification: The projected savings strengthen the business case for preventive replacement and justify initial implementation costs.

10.3 Implementation Timeline

A phased implementation plan is proposed to ensure the successful execution of the gasket reliability improvement strategy. The approach is spread over a 2-year timeline, starting with planning and standardization, followed by staff training, system integration, preventive maintenance rollout, and long-term optimization through audits and refinements.

Phase	Duration	Activities
Phase 1	Month 1–3	Form team, finalize SOPs, standardize gaskets
Phase 2	Month 4–6	Train staff, digitize history, set up CMMS
Phase 3	Month 7–12	Start preventive replacement, monitor trends
Phase 4	Year 2	Audit progress, refine intervals, expand scope

Table 5: Implementation Timeline and Key Activities

11. Conclusion

The analysis of gasket failure incidents revealed that a significant majority were due to contamination, procurement of out-of-spec gaskets, corrosion, and wear-related issues, most of which are predictable and preventable. The organization's reactive maintenance approach and lack of vendor quality assurance contributed to repeated breakdowns, leading to substantial production losses.

By implementing reliability-centered practices, standardizing procurement, digitizing maintenance history, and adopting preventive strategies, the facility can significantly enhance equipment reliability and reduce downtime. Tools like Weibull analysis, fault tree mapping, and ISO 14224 classification have provided a structured understanding of failure patterns and laid the foundation for informed decision-making.

Moving forward, a disciplined implementation of CMMS, training, and periodic audits as outlined in the action timeline will be essential to drive sustainable reliability improvements and build a culture of proactive asset management.

To ensure continuous improvement, the facility should track clear and measurable targets such as achieving a Mean Time Between Failures (MTBF) of at least 40,000 hours for gasket-related incidents, maintaining gasket reliability R (8,000 hours) at or above 98%, and reducing contamination-related failures to no more than 25% of total gasket failures within two years.

References

- https://www.maintenanceandengineering.com/2017/09/01/reliability-and-maintenance-data-improvement-based-on-iso-14224/
- https://help.reliasoft.com/documents/version2021/UG_Weibull21.pdf
- Montgomery, D. C., & Runger, G. C. (2018). *Applied Statistics and Probability for Engineers* (7th ed.). Wiley.
- University of Houston – INDE 6336 Course Notes, Chapter 7 & Chapter 10 (2025). *The Journey Organizational Growth Toward Reliability*.
- ISO 14224:2016. Petroleum, petrochemical and natural gas industries — Collection and exchange of reliability and maintenance data for equipment. International Organization for Standardization, Geneva, Switzerland.