Assignment Guidance and Front Sheet

This front sheet for assignments is designed to contain the brief, the submission instructions, and the actual student submission for any WMG assignment. As a result the sheet is completed by several people over time, and is therefore split up into sections explaining who completes what information and when. Yellow highlighted text indicates examples or further explanation of what is requested, and the highlight and instructions should be removed as you populate 'your' section.

This sheet is only to be used for components of assessment worth more than 3 CATS (e.g. for a 15 credit module, weighted more than 20%; or for a 10 credit module, weighted more than 30%).

To be completed by the student(s) prior to final submission:

Your actual submission should be written at the end of this cover sheet file, or attached with the cover sheet at the front if drafted in a separate file, program or application.

Student ID or IDs for group work	**e.g. 1234567**

To be completed (highlighted parts only) by the programme administration after approval and prior to issuing of the assessment; to be consulted by the student(s) so that you know how and when to submit:

Date set	6th January 2025
Submission date (excluding extensions)	**3rd February 2025 by 12 pm UK time**
Submission guidance	Tabula link
Marks return date (excluding extensions)	3rd March 2025
Late submission policy	If work is submitted late, penalties will be applied at the rate of **5 marks per University working day** after the due date, up to a **maximum of 10 working days** late. After this period the mark for the work will be reduced to 0 (which is the maximum penalty). "Late" means **after the submission deadline time as well as the date** – work submitted after the given time even on the same day is counted as 1 day late. For **Postgraduate** students only, who started their **current course before 1 August 2019**, the daily penalty is **3 marks** rather than 5.
Resubmission policy	If you fail this assignment or module, please be aware that the University allows students to remedy such failure (within certain limits). Decisions to authorise such resubmissions are made by Exam Boards. Normally these will be issued at specific times of the year,

	depending on your programme of study. More information can be found from your programme office if you are concerned. **If this is already a resubmission attempt, this means you will not be eligible for an additional attempt. The University allows as standard a maximum of two attempts on any assessment (i.e. only one resubmission). Students can only have a third attempt under exceptional circumstances via a Mitigating Circumstances Panel decision.**

To be completed by the module owner/tutor prior to approval and issuing of the assessment; to be consulted by the student(s) so that you understand the assignment brief, its context within the module, and any specific criteria and advice from the tutor:

Module title & code	WM9F8-15 Quality, Reliability and Maintenance
Module owner	Jane Marshall
Module tutor	Jane Marshall
Assessment type	Lifetime Data Analysis
Weighting of mark	20%

Assessment brief

A propylene plant pump, which is used as a feed pump, is a key component in a refinery plant. Two of the key components of the pump have been failing thus affecting the plant availability. To identify an appropriate maintenance strategy to keep the plant at 100% availability the following data requires analysis. The two key components in this pump are – the seal and the bearing.

Component	Failure Time (days)
Bearing	1516
Bearing	2800
Bearing	3276
Bearing	4078

Bearing	4629
Seal	4650
Seal	4772
Seal	4915
Seal	4953
Seal	5300
Bearing	5411
Seal	5488

a) Use appropriate plotting techniques to identify the lifetime distribution and estimate and discuss the implications of the shape and scale parameters for the seals and bearings.

b) Using the estimates obtained draw and interpret the Reliability Function. You should also discuss the assumptions of the method and how it is used.

c) Recommend and discuss a suitable reliability testing method for each of the failure modes based on your analysis.

20 marks

You should refer to data and information from journals or books to support your answer.

The word limit for this work is maximum of 800 words + 10%.

Word count	800
Module learning outcomes (numbered)	**1. Develop a critical understanding of Quality Management theories** **2. Analyse lifetime data to measure reliability performance**

	3. Develop a conceptual understanding of maintenance philosophies. **4. Investigate the role of equipment asset management in an engineering business** **5. Evaluate how quality, reliability and maintenance tools are applied. to aid customer satisfaction** **6. Reflect on how the module enhances the product quality, reliability and maintenance of an engineering business**
Learning outcomes assessed in this assessment (numbered)	2
Marking guidelines	
Academic guidance resources	Module moodle, book list (on moodle), University Library databases

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List of Abbreviations

ALT – Accelerated Life Testing
HALT – Highly Accelerated Life Testing
IID – Independently and Identically Distributed
(R(t)) – Reliability Function
h - Hazard Rate
(H(t)) – Cumulative Hazard
B – Beta
η - eta

Introduction

The propylene plant feed pump is necessary for maintaining refinery operations by ensuring a steady supply of feedstock. However, frequent failures in the seal and bearing have made 100 percent plant availability difficult. To overcome this issue, Weibull plotting technique has been used to identify failure patterns and estimate key parameters shape (β) and scale (η). The shape parameter displays how the failure rate changes overtime whereas, scale parameter tells typical lifespan of an item before failing (Shailesh 2018). Based on bathtub curve, different shape (β) parameters describes failure patterns. Where **β < 1** failure decreases over time, which expressed as infant mortality. **β = 1,** where failure rate remains constant and when **β > 1** the failure rate increase over time which indicates items are more likely to fail as they age (Arrospide, Bikandi et al. 2017). While the scale parameter (η) marks the characteristic life, which is the point where 63.2 items are expected to fail.

This analysis explores the implementation of Weibull analysis to understand failure patterns and lifetime distribution. It also examines reliability function, reliability curves and highlights key assumptions. For the last part, it provides recommendations for reliability testing strategies.

Implications of parameters and reliability function

The below image shows how reliability analysis was done for seals and bearings using Weibull plotting technique. The failure times were arranged in ascending order. Then reverse ranks were given to these times to get the values of hazard rate using formula $h = \frac{1}{reverse\ rank}$ where, n = total set which is 12 and i is pump number. After that cumulative hazard was calculated by adding up hazard rates for each failure time that is cumulative addition.

All failures					
Data sorted by rank (earliest failure to latest failure)					
Pump number	Age at failure	Failure mode	Reverse rank	Hazard (h)	Cumulative hazard
1	1516	Bearing	12	0.0833	0.0833
2	2800	Bearing	11	0.0909	0.1742
3	3276	Bearing	10	0.1000	0.2742
4	4078	Bearing	9	0.1111	0.3854
5	4629	Bearing	8	0.1250	0.5104
6	4650	Seal	7	0.1429	0.6532
7	4772	Seal	6	0.1667	0.8199
8	4915	Seal	5	0.2000	1.0199
9	4953	Seal	4	0.2500	1.2699
10	5300	Seal	3	0.3333	1.6032
11	5411	Bearing	2	0.5000	2.1032
12	5488	Seal	1	1.0000	3.1032

Table 1. All failures by rank

Bearing Failure							
Data sorted by rank (earliest failure to latest failure)							
Pump number	Age at failure	Failure mo	Reverse rank	Hazard (h)	Cumulative hazard	Log cumulative hazard	Log age at failure
1	1516	Bearing	12	0.0833	0.0833	-1.0792	3.1807
2	2800	Bearing	11	0.0909	0.1742	-0.7588	3.4472
3	3276	Bearing	10	0.1000	0.2742	-0.5619	3.5153
4	4078	Bearing	9	0.1111	0.3854	-0.4141	3.6104
5	4629	Bearing	8	0.1250	0.5104	-0.2921	3.6655
6	5411	Bearing	2	0.5000	1.0104	0.0045	3.7333

Table. 2 Bearing Failure by Rank

Seal Failure							
Data sorted by rank (earliest failure to latest failure)							
Pump number	Age at failure	Failure mode	Reverse rank	Hazard (h)	Cumulative hazard	Log cumulative hazard	Log age at failure
6	4650	Seal	7	0.1429	0.1429	-0.8451	3.6675
7	4772	Seal	6	0.1667	0.3095	-0.5093	3.6787
8	4915	Seal	5	0.2000	0.5095	-0.2928	3.6915
9	4953	Seal	4	0.2500	0.7595	-0.1195	3.6949
10	5300	Seal	3	0.3333	1.0929	0.0386	3.7243
12	5488	Seal	1	1.0000	2.0929	0.3207	3.7394

Table 3. Seal Failure by Rank

Above tables (2,3) display different failures for pumps independently for bearing and seal. The age of failure is arranged in ascending order and each failure is assigned a reverse rank.

The reverse rank starts from 12 which gives the value of n that is 12. And it decreases further by 1 for next coming failures. Also, the hazard rate (h) $h = \frac{1}{reverse\ rank}$ Displays conditional probability of failure.

Furthermore, the cumulative hazard is calculated by sequentially adding the previous hazard values.

For instance, From above table (table 3) 0.1429 + 0.1667 = 0.3095.

Afterwards, those cumulative hazard values are further turned in Log Cumulative Hazard log10 (H(t)).

Statistical analysis of data (Bearing)

Regression statistics	
Multiple R	0.9723
R Square	0.9455
Adjusted R Sq	0.9318
Standard Erro	0.0516
Observations	6

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	0.1845	0.1845	69.3434	0.00113632
Residual	4	0.0106	0.0027		
Total	5	0.1951			

	Coefficients	Standard Erro	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	3.7890	0.0380	99.6690	0.0000	3.6834	3.8945	3.6834	3.894519433
X Variable 1	0.5099	0.0612	8.3273	0.0011	0.3399	0.6799	0.3399	0.679850287

Table 4. Statistical Analysis of data (Bearing)

Statistical analysis of data Pump (Seal)

Regression statistics	
Multiple R	0.9600
R Square	0.9216
Adjusted R S	0.9020
Standard Err	0.0086
Observations	6

ANOVA					
	df	SS	MS	F	Significance F
Regression	1	0.0035	0.0035	47.0464	0.00236555
Residual	4	0.0003	0.0001		
Total	5	0.0038			

	Coefficients	Standard Erro	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	3.7144	0.0041	900.3760	0.0000	3.7029	3.7258	3.7029	3.725805764
X Variable 1	0.0639	0.0093	6.8590	0.0024	0.0380	0.0897	0.0380	0.089710182

Table 5. Statistical Analysis of Data (Seal)

Above both charts describe statistical analysis for both Bearing and Seal. The Reliability Function is used to calculate component's failure free operation probability until time (t).

Using Weibull Analysis, we can interpret the Reliability Function, which identifies trends of failure over time. $R(t) = e - \left(\frac{t}{\eta}\right) \boldsymbol{\beta}$

From above calculation of regression statistics, we used R^2 we interpreted that how model fits with data. R^2 = 0.9216 shows a perfect model fit for reliability predictions.

Same calculation was performed for bearing and the R^2 value came for bearing is 0.9455 (from table 4).

Reliability function for Pump (Bearing)	
From Statistical analysis	
beta	1.9613
eta	6151.3629

Table 6. Reliability Function of Bearing.

The above tables talk about the reliability function R(t) of bearing. After observing the reliability curve for bearing, the shape parameter **β** is 1.9613. Since **β** is greater than 1 which indicates that the failure rate increases over the time (wear out failure). This can happen because of wear and tear of material or its degradation over the time of usage. However, the data obtained after regression shows scale parameter η = 6151.3629 which 62.3% will fail (O'Connor and Kleyner 2011). This trend of bearing requires preventive maintenance to avoid any damage.

Reliability function for Pump (seal)	
From Statistical analysis	
beta	15.6592
eta	5180.2653

Table 7. Reliability Function of Seal

For seal, as displayed in the reliability curve (given below) for seal, there's a sudden decline in the pattern. Since the value is way more than 1, it can be interpreted that the seal is in sharp wear out failure, where the failure rate rapidly increases as the seal ages. While the scale parameter for seal shows that 63.2% percent seals will fail after approximately 5180.2653 days. It can be said that seal has lesser life span as compared to bearing.

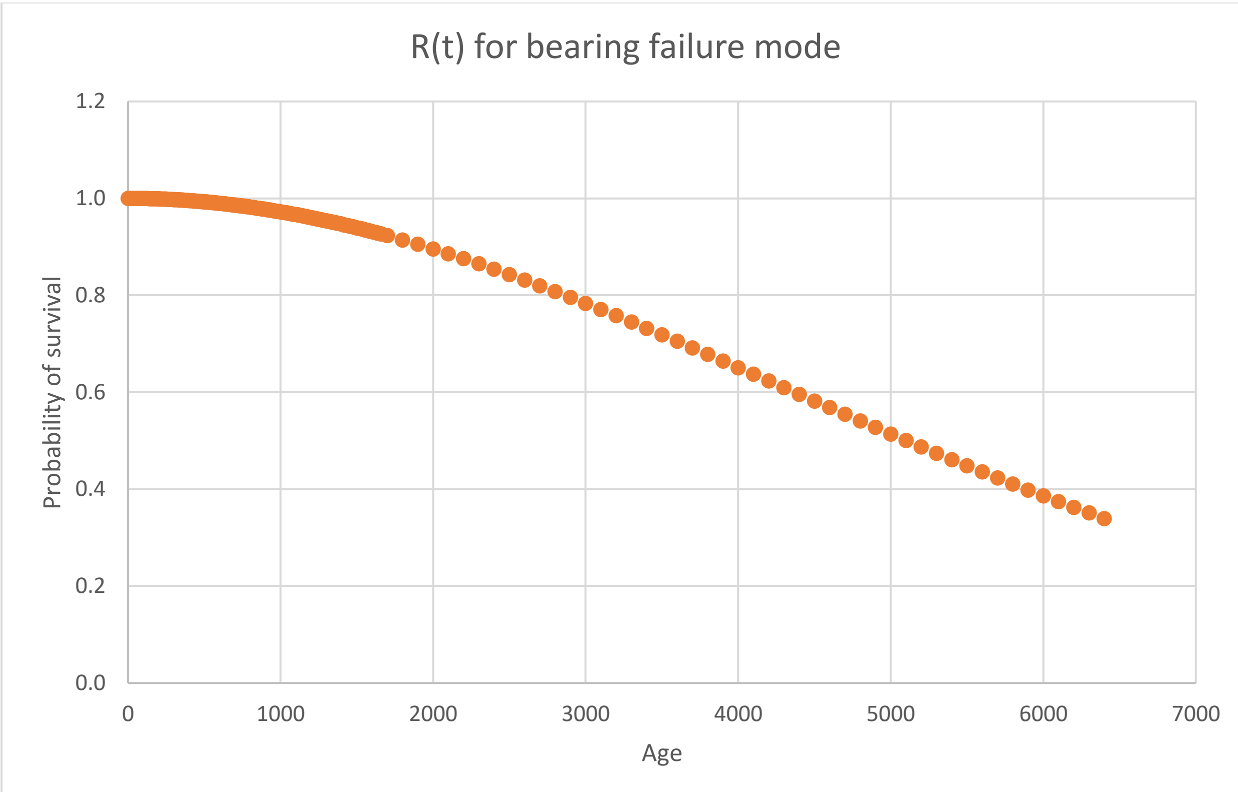

Fig. 1 Lifetime Distribution of Bearing Failure

Above plotted graph (fig.2) shows, how likely a bearing is to keep working overtime. On the X axis, bearing's operating time that is Age. While on the Y axis, Probability of survival (Dolas, Jaybhaye et al. 2014). At initial stage, probability of survival is high closer to 100 percent, but as time passes it decreases which shows bearing is more likely to fail. This downward trend explains that, failures become more common as the bearing gets older.

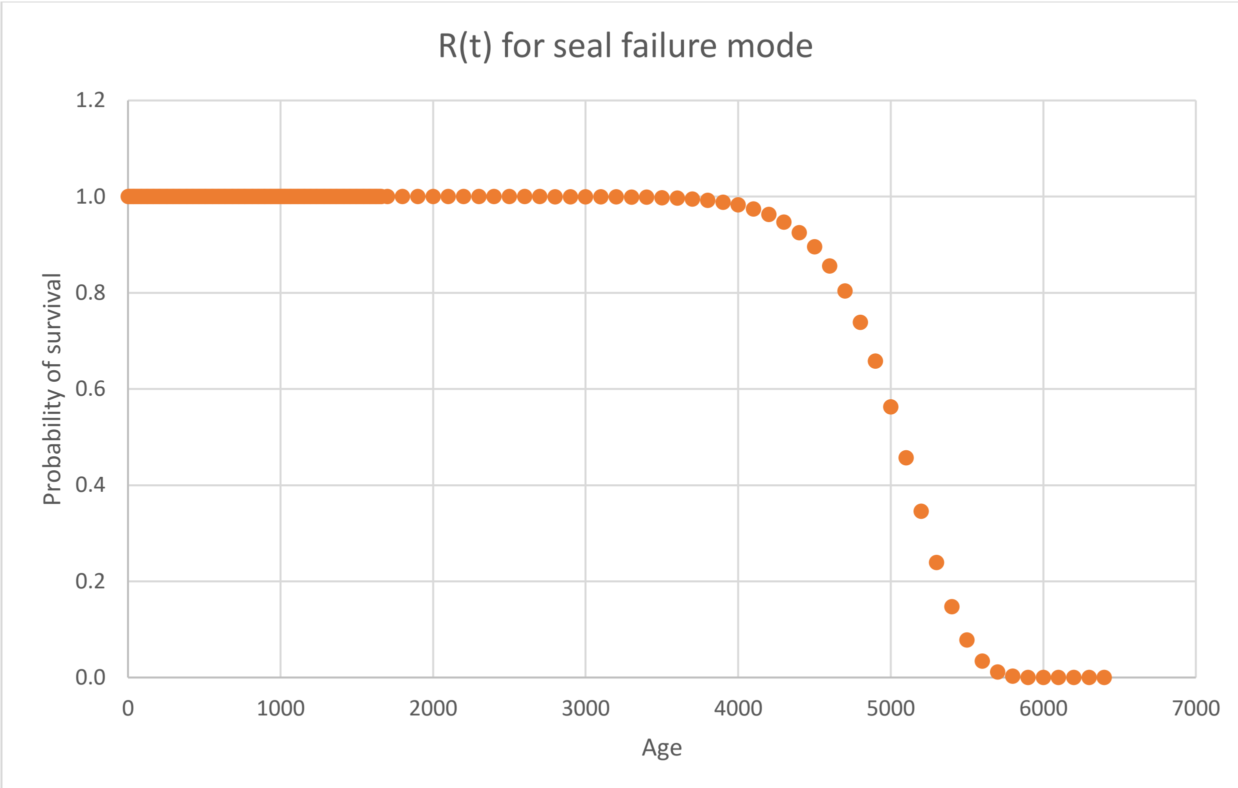

Fig. 2 Lifetime Distribution of seal failure

The above graph shows the life time distribution of the seal. As we can see, the probability of survival is high at the initial stage without any early failures. However, from 4000 days (age) above in graph, there's a sudden drop in the reliability which shows seal has suddenly failed and not gradually. This can be said as sudden degradation failure and not wear out failure (Chen, Yu et al. 2018). The Weibull shape parameter which is **β = 15.65** shows that failure has happened suddenly.

Assumptions of the Weibull Method

In the above Weibull analysis, the Independently and Identically Distributed (IID) assumption ensures accurate reliability predictions. The basic concept of IID is, the failures of one part don't affect the other one. That concludes, bearing failures don't affect seal failures. For the identical distributions, one component operates under same condition and experiences same failure as of other (Arafeh, Hammoud et al. 2022). Below are some assumptions mentioned for Weibull Analysis.

1. Failures are Independent – For seal, the failure is sudden and for bearing failure is gradual.
2. Consistent Operating Conditions – Both of the parts had similar operating condition.
3. Single Dominant Failure Mode – For both parts, failures occurred due to wear out which are not random.
4. Sufficient Sample Size for accuracy - (Khalili and Kromp 1991)

Recommendations for Reliability Test

Based on the results, which displayed high failure rates for both bearing and seal, it is necessary to take immediate solutions.

1. **Bearing** – To address the reliability concerns of the bearing, **Accelerated Life Testing** (ALT) is the recommended method. From the analysis, we came up with the conclusion that bearing is in wear out failure mode where the failure rate increases as the bearing ages. ALT can simulate real world conditions which includes, higher loads, faster speed to test how bearing performs over the time. Using models like Arrhenius or Coffin-Monson can help to set high stress levels during testing. It's important to monitor failure causes like material fatigue or poor lubrication. These tests will help to understand and identify the weak points and can provide improvement methods (Silverman 2006). This testing method is perfectly suitable for wear out failure mode.

2. **Seal** – For seal, Highly Accelerated Life Testing (HALT) is the recommended approach to overcome its weakness. Seal experiences sudden degradation failure as shown by its **β** value. To overcome this failure, HALT is recommended approach which exposes seal to extreme test conditions like sudden temperature changes or instant variation in pressure to identify its weaknesses. These extreme conditions simulate how does the seal perform in real life situations. After failures occur a detailed root cause analysis is carried out to identify the origin of the problem occurred. The problem could be design limitations, environmental factors or material of the product itself. After identifying the problem, improvements are suggested by HALT. Also, by applying higher stress levels HALT can simulate the time of failure in shorter version (Silverman 2006). HALT mainly used for sudden degradation failure modes.

REFERENCES

Arafeh, M., et al. (2022). Independent and identically distributed (IID) data assessment in federated learning. GLOBECOM 2022-2022 IEEE Global Communications Conference, IEEE.

Arrospide, E., et al. (2017). Mechanical properties of polymer-optical fibres. Polymer Optical Fibres, Elsevier**:** 201-216.

Chen, Y., et al. (2018). "A failure mechanism cumulative model for reliability evaluation of a k-out-of-n system with load sharing effect." IEEE Access **7**: 2210-2222.

Dolas, D., et al. (2014). "Estimation the system reliability using Weibull distribution." International Proceedings of Economics Development and Research **75**(29): 144-148.

Khalili, A. and K. Kromp (1991). "Statistical properties of Weibull estimators." Journal of materials science **26**: 6741-6752.

O'Connor, P. and A. Kleyner (2011). Practical reliability engineering, john wiley & sons.

Shailesh, K. (2018). An example on estimating Weibull scale (eta) and shape (beta) parameters from sample failure data. 2018 4th International Conference on Applied and Theoretical Computing and Communication Technology (iCATccT), IEEE.

Silverman, M. (2006). HALT vs. ALT: when to use which technique? RAMS'06. Annual Reliability and Maintainability Symposium, 2006., IEEE.