Analysis of Wind Turbine Failure

Business Problem:

Unplanned failure of wind turbine engines is leading to huge losses and negatively impacting electricity generation.

Business Objective: Minimize unplanned failures.

Business Constraint: Maximize power generation.

Success Criteria:

- **Business Success Criteria:** Reduce the unplanned failure of wind turbine engines by at least 30%.
- **Economic Success Criteria:** Achieve a cost saving of at least $2M per year due to the reduction of unplanned downtime.

Approach: Data Analytics Project Management Methodology.

Metadata for Wind Turbine Dataset:

Variable	Description	Unit
Date	Timestamp of recorded measurement	YYYY-MM-DD
Wind_Speed	Speed of the wind that influences turbine operation	meters per second (m/s)
Power	Power output generated by the wind turbine	kilowatts (kW)
Nacelle_Ambient_Temp	Temperature inside the nacelle	Degrees Celsius (°C)
Generator_Bearing_Temp	Temperature of bearings inside the generator	Degrees Celsius (°C)
Gea_Oil_Temp	Temperature of the gear oil used for lubrication in the gearbox	Degrees Celsius (°C)
Ambient_Temp	External environmental temperature surrounding the wind turbine	Degrees Celsius (°C)
Rotor_Speed	Speed of the rotor blades spinning in response to wind	Revolutions per minute (RPM)
Nacelle_Temp	Overall internal temperature inside the nacelle	Degrees Celsius (°C)
Bearing_Temp	Temperature of the main shaft bearings	Degrees Celsius (°C)
Generator_Speed	Rotational speed of the generator shaft	Revolutions per minute (RPM)
Yaw_Angle	Orientation angle of the wind turbine relative to the wind direction	Degrees (°)
Wind_Direction	The direction from which the wind is blowing	Degrees (°) [0° = North, 90° = East, 180° = South, 270° = West]
Wheel_Hub_Temp	Temperature at the wheel hub which connects the rotor to the main shaft	Degrees Celsius (°C)
Gearbox_Inlet_Temp	Temperature of the gearbox at the oil inlet	Degrees Celsius (°C)
Failure_Status	Indicator of wind turbine failure based on operational conditions	Binary (0 = No Failure, 1 = Failure)

FiMBD: First Moment Business Decision * **SMBD:** Second Moment Business Decision * **TMBD:** Third Moment Business Decision * **FoMBD:** Fourth Moment Business Decision

Q1: First Quartile * **Q3:** Third Quartile * **IQR:** Interquartile Range * **LB:** Lower Bound * **UB:** Upper Bound

Process:

1. Database Creation
2. Data Importing
3. Data Type Casting
4. Rename Columns
5. Duplicates Checking
6. Missing Values Checking
7. EDA
    - First Moment Business Decision
    - Second Moment Business Decision
    - Third Moment Business Decision
    - Fourth Moment Business Decision
8. Outlier Detection – IQR Method
9. Feature Engineering
    - Discretization
10. Scaling

EDA_SQL_Report

Total Features: 16

Total Records Measured: 3600

Timeline: 01-01-2022 to 31-12-2023

Timeline_Status: Inconsistence (Only 2 records of sensor data measured in 2022 – Jan-01 and the remaining 3598 records are meandered from 2023-jan-01 to 2023-Dec-31)

Duplicate Records: 0

Missing Values: 0

Overall Wind Turbine Failures = 33.33%

2022 Annual Total Failures: 1

2022 Annual Failures Rate: 50%

2023 Annual Total Failures: 1199

2023 Annual Failures Rate: 33.32%

	FiMBD			SMBD					TMBD	FoMBD	
Variable	**Mean**	**Median**	**Mode**	**Variance**	**Sta Dev**	**Min**	**Max**	**Range**	**Skewness**	**Kurtosis**	
Wind_Speed(m/s)	16.3916	13.873	24.75	174.29	13.20	-5.23	53.878	59.107	0.806	-0.37	
Statistical Insights	1. Mean (16.39) > Median (13.87) indicated data is slightly right-skewed. 2. Wind speed of 24.75 m/s occurs most frequently (98 times). 3. High Variance (174.29) and Standard Deviation (13.20 m/s) shows, wind speeds are widely spread out from the mean. 4. Range = 59.10 m/s (from -5.23 to 53.88) large spread due to the presence of extreme values or possible anomalies. 5. Skewness = 0.806, Positively skewed (long tail on the right). 6. Kurtosis = -0.37< 3, The distribution is flatter than normal. Fewer outliers and data is more evenly spread. 7. 5 Outliers found above 44.731 m/s. But there is no failure status for these outliers									**Q1**	6.37
										Q3	21.71
										IQR	15.34
										LB	-16.63
										UB	44.73
Business Insights	1. Negative wind value: Wind speed should not be negative. **Urgent need to review sensor calibration or data quality procedures otherwise it will cause a problem**. 2. Mean Wind Speed = 16.39 m/s Indicates **sustainable wind availability suitable for energy production**. 3. Mode = 24.75 m/s > Mean **Suggests wind turbines often experience speeds ideal for peak power generation**. 4. Maximum Wind Speed = 53.88 m/s and high wind events may approach turbine cut-out limits. So, **review turbine tolerance and ensure automatic shut-down mechanisms are in place**. 5. Occasional wind bursts can be leveraged for **dynamic load management** or **predictive generation models**. 6. Wind speed is **not highly volatile**, lowering the risk of erratic generation dips. 7. Wind Turbine failed at Min Wind speed of 0 m/s and Max wind speed of 44.51 m /s. **Need to strongly inspect the wind speed sensor because even at the wind speeds > 44.51 m/s the wind turbine didn't fail.** 8. Maximum Wind Speeds are recorded from 24th Dec 2023 – 29th Dec 2023. 9. Wind Turbine failed at minimum wind speed of 0 m/s on 21st Oct 2023. 10. Wind Turbine failed at maximum wind speed of 44.51 m/s on 8th Feb Oct 2023.										

	FiMBD			SMBD					TMBD	FoMBD	
Variable	**Mean**	**Median**	**Mode**	**Variance**	**Sta Dev**	**Min**	**Max**	**Range**	**Skewness**	**Kurtosis**	
Power(kW)	3.313	2.697	1.982	6.816	2.610	0	11.884	11.884	1.602	2.09	
Statistical Insights	1. Mean (3.313 kW) > Median (2.697 kW) indicates positively skewed distribution. 2. Mode (1.982 kW) shows that most common power output (91 times) is on the lower side. 3. Variance (6.816) and Standard Deviation (2.610 kW) indicating moderate spread in the data. 4. Range = 11.884 kW from 0 to peak power output. Indicates significant variability. 5. Skewness = 1.602 Strong right skew most readings are low, but few are very high. 6. Kurtosis = 2.09 High peak and heavy tails and expect more extreme outliers 7. 1037 Outliers found.									**Q1**	2.21
										Q3	3.24
										IQR	1.02
										LB	0.67
										UB	4.78
Business Insights	1. Mean = 3.313 kW, Mode = 1.982 kW indicating, **Turbines frequently operate in low-power zones, likely due to moderate wind conditions or operational constraints.** 2.Maximum Power = 11.884 kW, Turbines are capable of high power, but such events are rare. **Analyze conditions during peak performance to optimize future yield.** 3. No negative values, Min = 0 Suggests **valid readings and proper logging by sensors.** 4. Power output is fairly stable across time, with **less chance of unpredictable spikes or crashes.** 5. Power generation doesn't keep pace with available wind during some periods. **Investigate turbine calibration or yaw misalignment**. 6. Wind Turbine failed at maximum Power of 11.88 kW on 5th Feb Aug 2023. 7. Wind Turbine not failed at Power generation of 6.96 kW, which recorded on 29th Dec 2023. So, **the limit of power generation is 6.96 kW, beyond that turbine will fail.** 8. Wind Turbine failed at maximum wind speed of 44.51 m/s on 8th Feb Oct 2023 and generated power of 0.59kW. But at the wind speed of 4.22 m/s, the power generated is 6.96 Kw, which is threshold but the turbine is not failed at those readings. **Need to verify the seasonality trends and sensor calibration.**											

	FiMBD			SMBD					TMBD	FoMBD	
Variable	**Mean**	**Median**	**Mode**	**Variance**	**Sta Dev**	**Min**	**Max**	**Range**	**Skewness**	**Kurtosis**	
Nacelle_Ambient_Temp (°C)	11.441	9.768	39.68	1897	43.554	-260.91	290.66	551.57	0.931	4.68	
Statistical Insights	1. Mean (11.441) > Median (9.768) Mild positive skew. The distribution leans slightly to the right, indicating some higher-than-average values. 2. Mode (39.68) A value that appears frequently (281 times) but quite far from both mean & median. Likely indicates localized operational hot spots. 3. Variance (1897) & Std Dev (43.554) Extremely high variability in temperature readings, suggests inconsistent or noisy data. 4. Extremely Wide Range (551.57°C) Data includes outliers or corrupted readings. 5. These are unrealistic for nacelle temperatures, possibly sensor errors, unit mismatch, or corrupt data entries. 6. Very High Kurtosis (4.68) Heavy tails, indicating a large number of outliers or extreme values. 7. Skewness (0.931) Right skewed, suggesting long tail of high-temperature anomalies. 8. 722 Outliers found.									**Q1**	1.21
										Q3	28.02
										IQR	26.89
										LB	-39.22
										UB	68.37
Business Insights	1. Abnormal Temperature Readings Detected Recorded values range from -260.91°C to 290.66°C, which are outside physical limits. These anomalies could be due to: • Faulty or uncalibrated sensors • Data corruption or wrong unit conversion 2. The very high standard deviation and range mean internal temperatures vary significantly, which could indicate: • Operational inconsistencies • HVAC system malfunction • Thermal insulation issues 3. Wind Turbine failed at maximum Nacelle_Ambient_Temp of 290.66 °C on 18th Nov 2023. 4. Wind Turbine not failed at Nacelle_Ambient_Temp of 106.16 °C, which recorded on 28th Dec 2023. So, **the limit of Nacelle_Ambient_Temp of 106.16 °C, beyond that turbine will fail.**										

	FiMBD			SMBD					TMBD	FoMBD	
Variable	**Mean**	**Median**	**Mode**	**Variance**	**Sta Dev**	**Min**	**Max**	**Range**	**Skewness**	**Kurtosis**	
Generator_Bearing_Temp(°C)	84.07	83.123	85.596	800.2	28.287	9.91	143.56	133.64	-0.127	0.39	
Statistical Insights	1. Mean ≈ Median ≈ Mode Distribution appears to be approximately symmetric, with no extreme skew. 2. Standard Deviation (28.28) and Range (133.64°C) There's a wide temperature spread - needs domain validation to check acceptable thermal boundaries. 3. Low Skewness (-0.127) Slight left skew, but nearly symmetrical distribution -good for statistical modeling. 4. Kurtosis 0.39 Indicates Slightly more peaked than normal, but not alarming. Mild outliers might be present. 5. Min (9.91°C) seems too low Generator bearings should rarely operate below ambient – this could be a sensor fault or downtime reading. 6. 637 Outliers found.									**Q1**	72.58
										Q3	94.96
										IQR	22.375
										LB	39.023
										UB	128.52
Business Insights	1. Max temp recorded is 143.56°C, which might exceed the safe operating limits of generator bearings. Consistently high temperatures reduce bearing lifespan and can trigger turbine shutdowns. 2. Minimum of 9.91°C is abnormally low - likely from: • Sensor misreading • Periods of inactivity (e.g., shutdown or maintenance) 3. High Kurtosis (123.7) means sharp peaks in data, suggests transient overheating events that need real-time alerts. 4. Wind turbine failed at a minimum Generator_Bearing_Temp of 9.91°C on 10th Mar 2023 and failed at a maximum Generator_Bearing_Temp of 143.56°C on 13th Sep 2023. 5. Wind Turbine not failed at Generator_Bearing_Temp of 98.98°C, which recorded on 16th Jun 2023. **So, the limit of Generator_Bearing_Temp of 98.98°C, beyond that turbine will fail.**										

	FiMBD			SMBD					TMBD	FoMBD	
Variable	**Mean**	**Median**	**Mode**	**Variance**	**Sta Dev**	**Min**	**Max**	**Range**	**Skewness**	**Kurtosis**	
Gear_Oil_Temp(°C)	84.278	76.972	89.127	529.410	23	49.515	128.723	79.208	0.431	-1.13	
Statistical Insights	1. Mean > Median Indicates right-skewed distribution, though Skewness (0.431) is mild — most values slightly lean toward higher temps. 2. Significant spread in gear oil temps, suggesting variability in operating loads or environmental conditions. 3. Wide Range (≈79°C) A large operating window, indicating potential load changes, turbine idling, or operational stress. 4. Kurtosis is -1.13, Very flat distribution. Data is more uniformly distributed with very few extreme values. 5. No outliers found.									**Q1**	65.96
										Q3	106.37
										IQR	40.40
										LB	5.34
										UB	166.98
Business Insights	1. Max gear oil temperature recorded: 128.72 °C Compare with OEM-specified maximum (typically 110–120 °C). If exceeded, initiate: • Gearbox inspection • Lubricant condition assessment • Cooling system validation 2. Higher average and peak temperatures can accelerate oil degradation. • Implement a predictive maintenance schedule based on gear oil thermal exposure • Perform oil viscosity, TAN (Total Acid Number) tests periodically										

	FiMBD			SMBD					TMBD	FoMBD
Variable	**Mean**	**Median**	**Mode**	**Variance**	**Sta Dev**	**Min**	**Max**	**Range**	**Skewness**	**Kurtosis**
Ambient_Temp(°C)	17.776	10.254	-20.6	895.114	29.918	-20.6	87.541	108.14	0.898	-0.21

Statistical Insights	1. The average ambient temperature is 17.776°C, indicating a generally moderate temperature range. The median temperature is 10.254°C, which is slightly lower than the mean. This suggests a right-skewed distribution, indicating some higher temperature outliers. 2. The most frequent temperature recorded (101 Times) is -20.6°C, which is unusual. It could be a data anomaly or a specific operational condition causing this frequent low temperature. 3. High variance (895.114) and standard deviation (29.918) indicate a wide spread of temperatures. This suggests that ambient temperatures fluctuate greatly, potentially causing stress on the turbine system. 4. The positive skewness (0.898) indicates a right-skewed distribution. This suggests that the data has a longer tail on the positive (higher temperature) side, meaning there are occasional temperature spikes. 5. The kurtosis -0.21 indicating tails are close to normal. No major concerns. Outlier impact is low 6. 123 outliers found.	**Q1**	-3.93
		Q3	30.50
		IQR	34.43
		LB	-55.59
		UB	82.16

Business Insights

1. Max: 87.54 °C is unusually high for ambient — may be a sensor issue or direct sunlight exposure.
    - Investigate sensor placement and calibration.
    - Add shielding or insulation to avoid false ambient readings.

2. The system is experiencing very low temperatures (as low as -20.6 °C) frequently. **Cold weather may cause startup issues, affect lubricant viscosity, or slow rotation of key components.**

3. High temperature variability (±30°C) may stress key turbine parts like gearboxes, bearings, and sensors. **Frequent thermal expansion and contraction may lead to material fatigue or sudden breakdowns.**

4. Wind Turbine not failed at Ambient_Temp of 77.29°C, which recorded on 31st Dec 2023. **So, the limit of Ambient_Temp of 77 °C, beyond that turbine will fail.**

	FiMBD			SMBD					TMBD	FoMBD	
Variable	**Mean**	**Median**	**Mode**	**Variance**	**Sta Dev**	**Min**	**Max**	**Range**	**Skewness**	**Kurtosis**	
Rotor_Speed (RPM)	193.357	184.222	309	16026.805	126.597	0.049	463.104	463.054	0.378	-0.70	
Statistical Insights	1. No outliers found. 2. Mean > Median Indicates right-skewed distribution and that the most frequently occurring RPM is substantially higher than both the mean and median. 3. the variance is quite high (16026.81), confirming that rotor speeds fluctuate widely over the recorded period. 4. The minimum recorded speed is 0.049 RPM, which might represent startup or idle states, while the maximum reaches 463.104 RPM, likely near the upper limit of the system's capability and rotor has the ability to operate under vastly different load or process conditions. 5. The kurtosis is -0.7, suggesting a platykurtic distribution, which implies fewer outliers and a relatively flat distribution curve.									**Q1**	98.53
										Q3	262.79
										IQR	164.25
										LB	-147.856
										UB	509.17
Business Insights	1. The wide range indicates **flexible usage**, but high variance could point to **inconsistent workloads** or **inefficiencies** in usage patterns. **And limit the rotor speed to 309 RPM.**										

	FiMBD			SMBD					TMBD	FoMBD	
Variable	**Mean**	**Median**	**Mode**	**Variance**	**Sta Dev**	**Min**	**Max**	**Range**	**Skewness**	**Kurtosis**	
Nacelle_Temp(°C)	46.459	46.640	61.8	708.41	26.615	-20.526	121.61	142.144	-0.170	0.25	
Statistical Insights	1. The median is 46.64°C, very close to the mean, suggesting a symmetrical distribution of temperature values. 2. With a value of 708.41, the data shows significant spread in temperature values across observations. 3. The range is 142.14°C, highlighting the nacelle's exposure to a wide spectrum of thermal conditions. 4. A skewness of -0.170 indicates a slightly left-skewed distribution, meaning there are more high-temperature values with a few lower outliers. 5. The kurtosis is 0.25, suggesting a leptokurtic distribution, which implies normal, but mild evidence of heavier tails. 6. 613 outliers found.									**Q1**	36.21
										Q3	57.42
										IQR	21.21
										LB	4.39
										UB	89.24
Business Insights	1. The presence of **negative temperatures (as low as -20.5°C)** indicates **exposure to freezing climates**, requiring **robust insulation or heating mechanisms** to protect critical components.										

	FiMBD			SMBD					TMBD	FoMBD	
Variable	**Mean**	**Median**	**Mode**	**Variance**	**Sta Dev**	**Min**	**Max**	**Range**	**Skewness**	**Kurtosis**	
Bearing_Temp(°C)	83.03	71.4	71.4	977.77	31.269	10.22	152.948	142.72	0.077	-0.12	
Statistical Insights	1. The average bearing temperature is 83.03°C, indicating moderately high operating conditions for bearings. 2. The most frequent temperature value is also 71.4°C, reinforcing that many observations are centred around the median. 3. A variance of 977.77 shows a substantial spread in the data, indicating temperature fluctuations. 4. A slightly positive skewness of 0.077 implies a nearly symmetric distribution, but with slightly higher-end values. 5. With a kurtosis of -0.12 the distribution is platykurtic, meaning it has fewer and less extreme outliers, and is flatter than a normal distribution. 6. 261 outliers found.									**Q1**	71.4
										Q3	102
										IQR	30.59
										LB	25.50
										UB	147.89
Business Insights	1. Wind Turbine failed beyond the bearing temperature of 122 °C. So, **consider ~120 °C as threshold for the bearing temperature.**										

	FiMBD			SMBD					TMBD	FoMBD	
Variable	**Mean**	**Median**	**Mode**	**Variance**	**Sta Dev**	**Min**	**Max**	**Range**	**Skewness**	**Kurtosis**	
Generator_Speed (RPM)	1394.99	1388.93	1782	302615.30	550.10	0	3963.61	3963.61	0.091	0	
Statistical Insights	1. The median speed is 1388.93 RPM, slightly lower than the mean, indicating a nearly symmetric distribution. 2. The mode is 1782 RPM, which is significantly higher than both mean and median. This shows a frequent occurrence of high-speed readings, possibly during peak operation. 3. At 550.10 RPM, the generator speed data is highly variable, indicating frequent speed fluctuations. 4. A slight positive skew (0.091) implies that the distribution is nearly symmetric, with a mild tail on the higher side. 5. A kurtosis of 0 suggests a Perfectly normal-tailed distribution 6. 67 outliers found.									**Q1**	1123.92
										Q3	1662.43
										IQR	538.50
										LB	316.16
										UB	2470.20
Business Insights	1. Wind Turbine failed at maximum generator speed of 2474.5 RPM on 4th Feb DEC 2023 and generated power of 8.46 kW. But at the generator speed of 3963.61 RPM, the power generated is 5.56 Kw, which is threshold but the turbine is not failed at those readings. **Need to verify the seasonality trends and sensor calibration.**										

	FiMBD			SMBD					TMBD	FoMBD
Variable	**Mean**	**Median**	**Mode**	**Variance**	**Sta Dev**	**Min**	**Max**	**Range**	**Skewness**	**Kurtosis**
Yaw_Angle (°)	49.23	17.90	0	3121.66	55.87	0	178.519	178.519	0.97	-0.56

Statistical Insights	1. No outliers found. 2. The median is 17.90°, which is significantly lower than the mean, suggesting a right-skewed distribution. 3. The mode is 0°, showing that the wind turbine most frequently faces the reference direction (e.g., true north or default yaw position). 4. A high variance of 3121.66 indicates a broad spread of yaw angle values, and an angle ranges from 0° to 178.519°, confirming the turbine can rotate across a wide directional arc. 5. The positive skew of 0.97 implies the presence of more values clustered around the lower angles, with a long tail extending to higher yaw angles.	**Q1**	6.40
		Q3	93.03
		IQR	86.63
		LB	-123.54
		UB	222.98
Business Insights	1. **Broad yaw movement range (0° to 178.5°)** indicates the turbine system is **fully functional in adjusting to wind shifts** and can **maximize efficiency** by turning toward the wind source.		

	FiMBD			SMBD					TMBD	FoMBD
Variable	**Mean**	**Median**	**Mode**	**Variance**	**Sta Dev**	**Min**	**Max**	**Range**	**Skewness**	**Kurtosis**
Wind_Direction (°)	61.24	37.308	7.22	11979.7	109.45	-413.41	631.96	1045.38	0.94	3.96

Statistical Insights	1. The average wind direction is 61.24°, suggesting a general east - northeast wind flow. 2. The median is 37.31°, significantly lower than the mean, indicating positive skewness. 3. The most frequent wind direction is 7.22°, showing predominant wind from the north-northeast. 4. A large standard deviation of 109.45° further supports the observation of high variability in wind direction. 5. Very High Kurtosis (3.96) Heavy tails, indicating a large number of outliers or extreme values. 6. 444 outliers found.	**Q1**	10.53
		Q3	91.82
		IQR	81.276
		LB	-111.37
		UB	213.72
Business Insights	1. Wind predominantly comes from **northerly directions**, as suggested by the **mode of 7.22°** and **median of 37.31°**. 2. Business teams should **flag and address data anomalies**, as **inaccurate wind direction** may lead to **suboptimal yaw alignment**, reducing efficiency and increasing wear.		

	FiMBD			SMBD					TMBD	FoMBD	
Variable	**Mean**	**Median**	**Mode**	**Variance**	**Sta Dev**	**Min**	**Max**	**Range**	**Skewness**	**Kurtosis**	
Wheel_Hub_Temp (°C)	19.973	20.279	79.44	3291.29	57.36	-89.25	119.09	208.35	-0.05	-0.88	
Statistical Insights	1. No outliers found. 2. The most frequent value is 79.44°C, significantly higher than both mean and median — suggesting recurring peaks or clusters at high temperatures. 3. A slight negative skewness (-0.05) suggests the data is approximately symmetric, but with a tiny shift toward the left. 4. The kurtosis is -0.88, suggesting a platykurtic distribution, which implies fewer outliers and a relatively flat distribution curve									**Q1**	-19.40
										Q3	60.28
										IQR	79.68
										LB	-138.92
										UB	179.8
Business Insights	1. The **minimum value is abnormally low** for real-world wheel hub operations and likely indicates **sensor faults or data recording errors**. 2. From a performance standpoint, **prolonged high temperatures** in the wheel hub area can cause **lubrication breakdown**, **bearing wear**, or **component failure.**										

	FiMBD			SMBD					TMBD	FoMBD	
Variable	**Mean**	**Median**	**Mode**	**Variance**	**Sta Dev**	**Min**	**Max**	**Range**	**Skewness**	**Kurtosis**	
Gearbox_Inlet_Temp (°C)	29.804	16.79	9.903	894.80	29.91	0	118.80	118.80	1.85	1.83	
Statistical Insights	1. The average temperature at the gearbox inlet is 29.80°C, indicating the general thermal behaviour under standard operating conditions. 2. The median is 16.79°C, which is much lower than the mean, showing a right-skewed distribution where more readings are concentrated on the lower side. 3. A positive skewness of 1.85 indicates a long right tail, meaning a few high-temperature values are pulling the distribution to the right. 4. The observed values range from 0°C to 118.80°C, a significant spread that highlights extreme operational conditions or anomalies. 5. The kurtosis is 1.83, suggesting moderate to high outliers present 6. 600 outliers found.									**Q1**	13.96
										Q3	24.72
										IQR	10.76
										LB	-2.17
										UB	40.86
Business Insights	1. **Sensor checks and data validation** are recommended for high values, especially close to **100°C+, which could be critical for lubrication and mechanical integrity**.										