

- **Design parameters** → define geometry, material, and stiffness of axle and gears.
 - **Operational parameters** → depend on how the vehicle is driven and maintained.
 - **Environmental parameters** → depend on external operating conditions.
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1 Design Parameters

Feature	Meaning	If Value Increases	Effect on Failure	Reasoning
Module_mm	Tooth size of gear	↑	▼ Decrease	Larger teeth distribute load better → lower stress
Pinion_Teeth	No. of teeth on pinion	↑	▼ Decrease	Higher tooth count → smoother torque transfer
Face_Width_mm	Width of gear tooth contact	↑	▼ Decrease	Wider face spreads load → reduces surface pressure
Pressure_Angle_deg	Angle between teeth line of action	↑	▲ Increase	Higher angle → higher radial forces, more stress
Profile_Shift	Tooth shape offset	↑	▼ Decrease	Positive shift improves contact & strength
Contact_Ratio	No. of teeth in contact	↑	▼ Decrease	More teeth in contact → smoother, less stress
Backlash_mm	Clearance between mating teeth	↑	▲ Increase	Too much gap → impact load, wear
Case_Depth_mm	Depth of hardened layer	↑	▼ Decrease	Deeper case → better fatigue & wear resistance

Surface_Hardness_HRC	Hardness of tooth surface	↑	☒ Decrease	Harder surface resists pitting/scuffing
Runout_mm	Eccentricity of gear	↑	☒ Increase	Misalignment → uneven stress → early failure
Housing_Stiffness_index	Stiffness of housing	↑	☒ Decrease	Rigid housing maintains alignment
Torque_Speed_Ratio	Torque/speed ratio	↑	☒ Increase	Indicates high load operation → more risk
Aging_Factor	Material fatigue age	↑	☒ Increase	Older components → more likely to fail
Thermal_Stress_Index	Heat-induced stress	↑	☒ Increase	Excessive temperature → material softening/fatigue

📊 Summary:

✓ Safe operation → higher values of **Module_mm**, **Face_Width_mm**, **Contact_Ratio**, **Case_Depth_mm**, **Surface_Hardness_HRC**, and **Housing_Stiffness_index**.

⚠ Failure risk rises with high **Pressure_Angle_deg**, **Backlash_mm**, **Runout_mm**, **Torque_Speed_Ratio**, **Aging_Factor**, **Thermal_Stress_Index**.

⚙️ 2 Operational Parameters

Feature	Meaning	If Value Increases	Effect on Failure	Reasoning
Load_Torque(Nm)	Torque transmitted	↑	⚠ Increase	High torque → high bending stress
Speed(RPM)	Rotational speed	↑	⚠ Increase	More cycles → fatigue accumulation
Vehicle_Load(kg)	Total load on axle	↑	⚠ Increase	Heavier load → more torque demand

Lubricant_Temp(°C)	Oil temperature	↑	 Increase	Oil thins → poor lubrication
Oil_Viscosity(cSt)	Oil thickness	↑	 Decrease	Better film strength (too high also bad)
Oil_Contamination_Index	Dirt level in oil	↑	 Increase	Abrasive wear increases
Lubrication_Efficiency	Oil film quality	↑	 Decrease	Better lubrication reduces wear
Maintenance_Gap(km)	Distance between maintenance	↑	 Increase	Longer gaps → poor upkeep
Brake_Usage_Freq(/100k m)	Brake frequency	↑	 Increase	Frequent braking → high thermal stress
Noise_Level(dB)	Noise in operation	↑	 Increase	Indicates misalignment/wear
Vibration(mm/s)	Dynamic vibration	↑	 Increase	High vibration → bearing/gear damage
Shock_Severity_Index	Severity of sudden loads	↑	 Increase	Impact loads damage teeth
Axle_Age(km)	Total usage	↑	 Increase	Wear accumulates with time
Cumulative_Damage_Index	Lifetime stress accumulation	↑	 Increase	Fatigue damage over time
Temperature_Rise(°C)	Temp increase during operation	↑	 Increase	High temp = more stress, less oil strength

Summary:

- ✓ Safe → moderate torque, temp, vibration, regular maintenance, good lubrication.
- ⚠ Failure risk increases with excessive torque, high load, contamination, long maintenance gap, and high vibration/noise.



3 Environmental Parameters

Feature	Meaning	If Value Increases	Effect on Failure	Reasoning
Ambient_Temp(°C)	Surrounding temp	↑	▲ Increase	Adds to thermal stress
Humidity(%)	Moisture level	↑	▲ Increase	Corrosion risk rises
Altitude(m)	Operating elevation	↑	▼ Slight Decrease	Less air density → lower drag/cooling effect (minor)
Road_Roughness(m/s ²)	Surface unevenness	↑	▲ Increase	Causes shocks, vibration, stress

Summary:

- ✓ Safe → moderate ambient temp and humidity, smoother roads.
⚠ Rough roads and humid/hot climates → higher axle failure risk.
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4 Correlation Direction Overview

Category	Positive Correlation (↑ Value → ↑ Failure)	Negative Correlation (↑ Value → ↓ Failure)
Design	Pressure_Angle, Backlash, Runout, Torque_Speed_Ratio, Aging_Factor, Thermal_Stress_Index	Module_mm, Face_Width, Contact_Ratio, Case_Depth, Surface_Hardness, Housing_Stiffness
Operational	Load_Torque, Speed, Vehicle_Load, Lubricant_Temp, Oil_Contamination, Maintenance_Gap, Brake_Usage, Noise_Level, Vibration, Shock_Severity, Axle_Age, Cumulative_Damage, Temperature_Rise	Oil_Viscosity, Lubrication_Efficiency
Environmental	Ambient_Temp, Humidity, Road_Roughness	Altitude (minor effect)