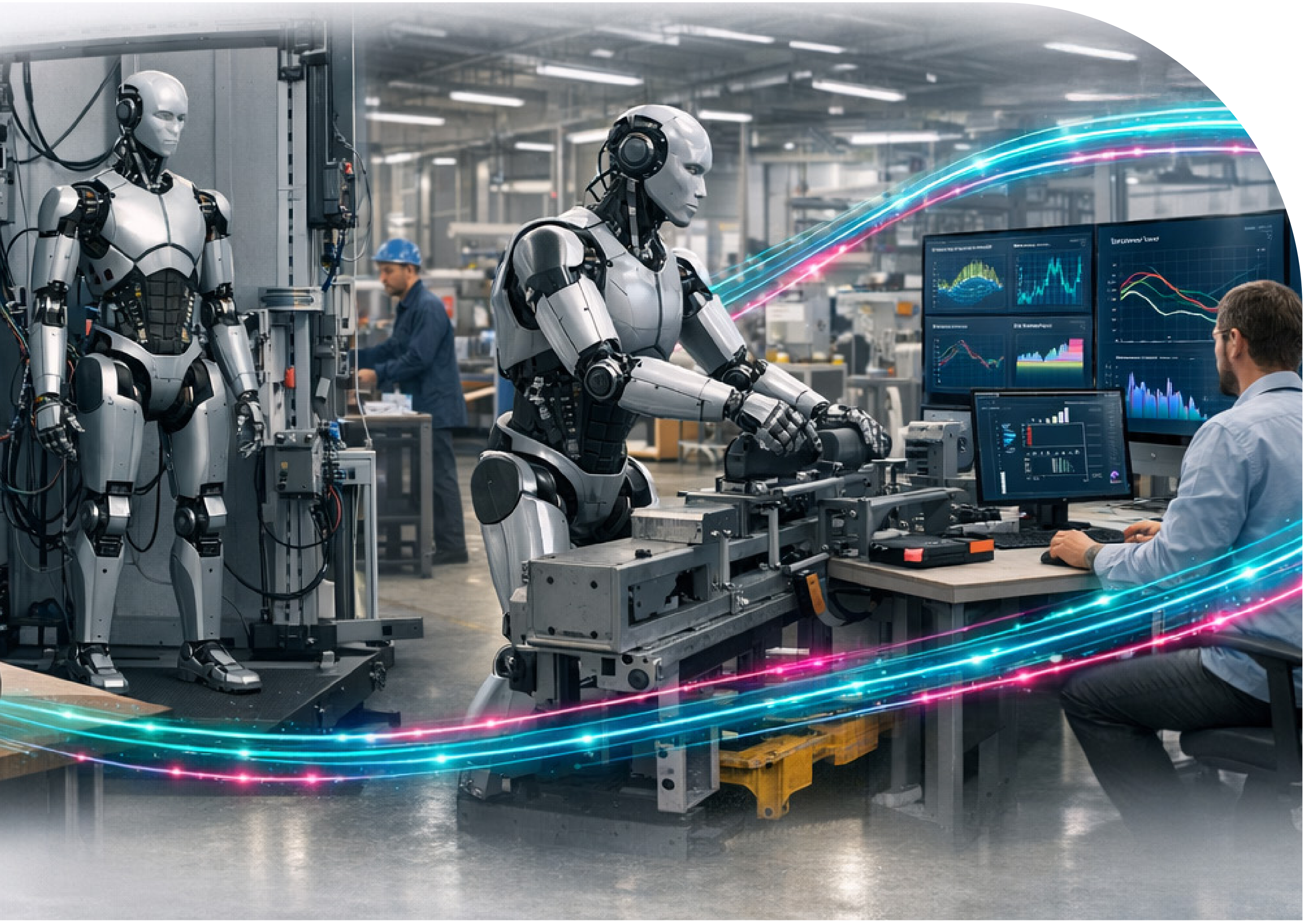

WHITE PAPER

# Building Durable and Reliable Robotics in a Changing World

Robotics adoption is accelerating across manufacturing, logistics, healthcare, and service industries. What was once confined to controlled, predictable environments is now being deployed into dynamic, real-world conditions. Robots are no longer experimental technologies - they are operational assets expected to deliver consistent performance, safely, and with maximum uptime.

At the same time, robot capabilities have expanded rapidly. Advances in artificial intelligence, sensing, and control systems allow robots to perceive, reason, and act with unprecedented sophistication. Yet as these systems become more capable, complexity means increased risk of failure. Downtime disrupts supply chains. Unexpected failures increase operational costs. In safety-critical environments, reliability directly affects risk.

As a result, durability and reliability have emerged as defining factors in whether robotics programs scale successfully or stall in early deployment. The next phase of robotics innovation will not be defined by what robots can do – but how they can do it consistently, safely, and predictably over time.

## The Challenge: Why Robotics Reliability Remains Difficult

Despite significant technological progress, developing and deploying reliable robotic systems remains a persistent challenge. This is not due to a lack of engineering capability, but because robotics is a new technology that operates under conditions that challenge traditional durability and reliability approaches.

### Real-World Operating Conditions Are Highly Variable

Modern robots are exposed to complex, varying loads driven by changing tasks, environments, and user interactions. Unlike traditional machinery, robotic systems rarely experience uniform or predictable duty cycles, making it difficult to rely on simplified assumptions during design.

### Failure Modes Are Increasingly Interconnected

Robots combine mechanical structures, electronics, software, sensors, and power systems into tightly coupled architectures. Failures are often systemic rather than localized because mechanical degradation, electronic stress, and control behaviour interact in unexpected ways.

### Reliability is Often Addressed too Late

In many programs, durability and reliability analysis is introduced after physical prototypes exist or, even worse, after issues appear in the field. By this stage, design changes are costly, schedules are impacted, and confidence in the platform is compromised.

### Operational Data is Under Used

Robots generate vast quantities of operational field data: forces, torques, vibration, temperatures, and usage patterns. Yet many organisations lack practical ways to translate this data into actionable durability and reliability insight across the product lifecycle.

These challenges mean that traditional, siloed approaches to engineering product validation are no longer sufficient. Robotics demands a more integrated, lifecycle-oriented view of durability and reliability.

## Our Perspective: A New Approach to Durability and Reliability in Robotics

As robotics systems evolve, so too must the way durability and reliability are engineered. The industry is entering an era where reliability must be designed in from the very beginning - continuously informed by real operating conditions and system level understanding.

From our experience working across complex engineering domains, we see several principles shaping successful robotics programs.

### 1. Reliability Must Be Treated as a Lifecycle Discipline

Durability and reliability are not onetime verification activities. They must span early concept design, detailed engineering, testing, field deployment, and operational support. Early insight prevents late-stage surprises and enables confident scaling.

### 2. Risk of failure must be identified with FMEA (failure mode and effects analysis)

FMEA identifies design risks early, allowing the team to analyze and improve high-risk elements. This is particularly important for robotics, with complex designs and a limited historical knowledge base.

### 3. Real Operating Loads Matter More Than Assumptions

Reliable robots are built on an understanding of how they are truly used. Incorporating measured loads, usage profiles, and environmental conditions into engineering analysis allows teams to predict structural life, wear out behaviour, and failure risk with far greater confidence.

### 4. Data Must Be Transformed Into Engineering Insight

High volumes of data from sensors and operational logs are only valuable if it can be efficiently processed, contextualised, and turned into decisions.  To simply measure is not enough: automated, repeatable analysis workflows are essential for making data driven durability and reliability practical at scale.

### 5. System Level Thinking Is Essential

Reliability cannot be optimised at the component level alone. Robots operate as integrated systems made of hundreds of components - and the robot’s reliability is defined by the combined interaction of those components’ reliability.  Further, robots are often deployed in fleets where availability, maintainability, and repair strategies directly impact operational performance, uptime, and cost. Thinking at the system level is key.

### 6. Reliability Engineering Enables Better Business Outcomes

When durability and reliability are addressed proactively, organisations unlock faster development cycles, reduced redesign risk, improved uptime, safer operation, and lower total cost of ownership. Reliability becomes a strategic enabler, not a constraint.

## Enabling Reliable Robotics in Practice

Applying these principles requires engineering environments that bridge design and operation - combining durability analysis, reliability modelling, and real-world data insight. When these capabilities are connected, robotics teams can validate designs earlier, respond faster to field behaviour, and make informed decisions across the lifecycle of a robot or fleet.

This integrated approach supports:

- Early identification of structural and component failure risks
- Practical use of operational load and usage data
- Quantitative reliability and maintenance decision making
- Confident scaling from prototype to deployment

By grounding reliability engineering in real operating behavior and system level insight, producers and users of robots are better equipped to meet the demands of increasingly autonomous, mission critical applications.

## Reliability as the Foundation for the Next Phase of Robotics

The future of robotics depends less on intelligence alone and more on durability, predictability, and trust, as reliability ultimately determines success in complex fielded environments. Organizations that prioritize durability and reliability from early design through fleet deployment will be best equipped to scale, adapt, and lead the next generation of robotics.

### How HBK Supports Robotics Engineering from Design to Deployment

As robotics systems become more autonomous, complex, and operationally critical, engineering teams need practical ways to predict structural durability, manage reliability risk, and learn from real-world usage. HBK supports robotics organisations with an integrated portfolio of durability and reliability engineering tools that connect design, testing, and operation across the full product lifecycle.

Rather than responding to failures after deployment, HBK enables a proactive, data driven approach to designing and fielding robots that perform reliably in unpredictable, real-world conditions.

### Durability Engineering for Robotics Structures

Robotic structures are subject to complex, variable loading driven by motion profiles, task diversity, and environmental conditions. Predicting fatigue life early in development is essential to prevent premature structural failures and costly redesigns.

HBK supports durability engineering through **nCode DesignLife**, enabling robotics teams to:

- Predict fatigue life of structural parts like robot frames, joints, actuator housings, and end effectors
- Identify durability hotspots using realistic load inputs
- Analyse fatigue cracking behaviour for metals, composites, and mixed materials
- Validate designs virtually using finite element (FE) modeling, before physical prototypes are built

This allows durability to be proactively designed in from the start, rather than addressed late through reactive testing.

### Turning Robotics Test and Field Data into Actionable Insight

Modern robots are connected equipment with dozens of on board sensors. They generate large volumes of time series data from force sensors, accelerometers, torque sensors, IMUs, and operational logs. Measuring this data is easy: the challenge is transforming this data into usable engineering insight.

**nCode GlyphWorks** is used by robotics teams to:

- Process high volumes of test and field data efficiently
- Extract representative events and load cases from real robot usage
- Apply digital signal processing and automate analysis workflows
- Support durability assessment and predictive maintenance initiatives

This enables consistent learning from both laboratory testing and deployed robots, closing the loop between design assumptions and actual operating behaviour.

### System Level Reliability and Fleet Performance

Robots are complex assemblies of mechanical, electronic, and software elements. And that's just for a single robot: for many organisations, robots are deployed as fleets where availability, maintainability, and uptime are critical.

ReliaSoft provides a comprehensive reliability engineering environment for robotics applications:

- **ReliaSoft Weibull++**
  Need to predict reliability of a robotic component? Weibull++ is a comprehensive reliability analysis tool that performs life data analysis utilizing multiple lifetime distributions, and warranty and degradation data analysis with an intuitive interface geared toward reliability engineering.

- **ReliaSoft Cloud**
  Need to identify risk of failure in a critical new design? Easily deployable and scalable, ReliaSoft Cloud empowers teams of all sizes with AI-driven insights and powerful dashboards for effective risk visualization and design improvement tracking in the FMEA process.

- **ReliaSoft Lambda Predict**
  Want to get an early start in reliability without any failure data? Lambda Predict facilitates reliability prediction analysis based on the major published standards, including MIL-HDBK-217F (MIL-217), Bellcore/Telcordia, FIDES, NSWC Mechanical and Siemens SN 29500, incorporating environmental stress factors.

- **ReliaSoft BlockSim**
  Let's move from component reliability analysis to model a robot's complex systems. ReliaSoft BlockSim provides a comprehensive platform for system reliability, availability, maintainability and related analyses that allows you to model the most complex systems and processes using reliability block diagrams (RBDs), fault tree analysis (FTA), or Markov diagrams.

- **ReliaSoft RCM++**
  How do we improve the robot's uptime and minimize maintenance cost? ReliaSoft RCM++ enhances asset reliability and streamlines maintenance planning with advanced reliability-centered maintenance (RCM) analysis for robot fleets.

Together, these tools allow teams designing and deploying robots to move from reactive failure response to proactive reliability decision making.

## A Proven Foundation for Scalable Robotics

HBK supports robotics innovators across manufacturing, logistics, and industrial automation by helping them:

- Reduce development time and redesign risk
- Improve confidence in real world deployment
- Increase uptime, safety, and lifecycle performance
- Scale robotics programs with reliability engineered in from the outset

By combining durability analysis, high volume data processing, and system level reliability modelling, HBK provides a robust foundation for dependable, scalable robotics.

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