WHITE PAPER

The Specification Gap

How Downtime Is Being Wired Into Your Machines, and the specification changes that stop it

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WHAT YOU WILL FIND INSIDE

- The three gaps in machine specifications that quietly create the biggest downtime risks
- Why the real cost of built-in machine problems rarely shows up in the warranty
- How outdated design assumptions continue to appear in new machines without being challenged
- What better design decisions mean for uptime, maintenance effort, and long-term operating cost
- The key questions to ask machine builders and the specification updates to make before your next purchase

WRITTEN FOR

Engineering Managers
Plant Managers
Operations Leaders
Maintenance Teams
CPG Manufacturering Teams

EXECUTIVE SUMMARY

The Downtime Was Designed In. It Does Not Have to Stay.

Every time a packaging line stops unexpectedly, the response is immediate. Operators check the HMI. Maintenance is called in. Production waits. What is rarely asked is the more important question: **why was that failure point designed into the machine in the first place?**

In many cases, the root cause is not a major component failure or a software issue. It is something far more ordinary and far more costly over time: an avoidable weakness in the machine's electrical design. These weaknesses appear at connection points, interfaces, and installation-dependent details that are vulnerable to vibration, contamination, thermal cycling, service disturbance, and normal human variability during assembly.

This white paper examines why these built-in failure points continue to appear in new packaging equipment, even though more robust design approaches have been available for years. The issue is not simply outdated supplier habits or lack of available technology. It is, more fundamentally, **a specification problem.**

Most machine specifications are written to define performance, safety, footprint, standards compliance, and approved component preferences. Far fewer clearly define the electrical design practices that have the greatest long-term impact on reliability, maintainability, and unplanned downtime. That gap matters. When critical details are left unspecified, machine builders are free to rely on familiar design methods that may meet the purchase requirement on paper while still embedding avoidable operational risk into the finished machine.

The purpose of this paper is to help engineering managers, plant leaders, and operations teams look at packaging machine specifications through a different lens — not just as a tool for buying machine performance, but as a tool for **preventing downtime before the machine is even built.**

~80%

of Automation Faults Originate in Field Wiring

Not in the PLC, not in the software, not in major mechanical systems. The vulnerability sits in the physical layer — connections, sensors, and power distribution points.

Industry practitioner consensus

30%+

of Electrical Failures Caused by Loose Connections

Thermographic survey data consistently shows loose connections as the leading single cause of electrical failure in industrial plants — ahead of component failure.

Grace Technologies thermographic survey data

$260K

Average Unplanned Downtime Cost Per Hour

Across industrial sectors. Your number may be lower — but for any line with meaningful throughput, the cost of recurring electrical faults is a number worth calculating.

Siemens True Cost of Downtime Report, 2024

THE CORE FINDING

Warranty may cover the cost of the component. What it does not reimburse is the far larger operational cost: **lost production, maintenance time, delayed schedules, and the business impact of missed commitments.** When downtime is caused by built-in electrical failure points, the true cost is borne overwhelmingly by the end user — whether the machine is under warranty or not.

WRITTEN FOR
Engineering Managers, Plant Managers, Operations Leaders at CPG Manufacturers

PRIMARY ARGUMENT
Reliability is not designed into most CPG machine specifications — so downtime gets designed into the machine instead

KEY ACTION
Update procurement specifications before the next capital purchase to require IP67 decentralized architecture

SECTION 01

The Wiring Architecture in Your Machines: A Brief Explanation

You do not need to be an electrical engineer to understand this issue. But it does help to know what is happening behind the control cabinet door, because **the architecture used there has a direct effect on uptime, troubleshooting time, maintenance effort, and long-term operating cost.** Most packaging machines are still built around a centralized control architecture — not because it is ideal, but because it is familiar.

TWO ARCHITECTURES — ONE STILL DOMINANT, ONE NOW PROVEN

TRADITIONAL APPROACH

Centralized Architecture

The PLC, I/O, power supplies, relays, terminal blocks, and control components are mounted inside a central steel cabinet. Every sensor, valve, pilot light, and safety device on the machine is wired back to that enclosure. Once cables enter the cabinet, each conductor must be stripped, ferruled, identified, landed, and secured by hand.

On even a moderately complex machine, that quickly turns into **hundreds of individual terminations** — each one representing another place where workmanship, vibration, contamination, or time can eventually create a fault. The cabinet is not simply a neat place to organize hardware. It is a protective shell around components that are not designed to survive direct exposure to the plant floor.

CHARACTERISTICS

- Hundreds of hand-made terminations per machine
- Every device runs a home-run cable back to the cabinet
- Fault diagnosis requires cabinet access and schematics
- Skilled electrician required for build, service, and repair
- Components rated IP20 — require cabinet protection
- Reliability depends on workmanship quality and long-term stability

MODERN APPROACH

Decentralized Architecture

Machine-mounted modules are placed directly where the devices are located on the machine. Sensors and actuators connect locally using sealed, factory-made cables with locking M12 circular connectors. Rather than running hundreds of individual conductors back to the cabinet, the machine communicates through a much smaller number of network and power connections.

The result is a simpler physical architecture with **fewer manual terminations, fewer opportunities for assembly variation, and fewer failure points hidden inside the machine.** IP67-rated hardware is designed for the plant environment — not protected from it. It does not need a cabinet to survive.

CHARACTERISTICS

- Standardized, sealed M12 connections — factory pre-tested
- Devices connect locally with short cordsets
- Per-channel LED fault indication at point of failure
- Assembly technician can build and service — no electrician required
- IP67 rated — designed for washdown, dust, vibration
- Consistent output regardless of who built the machine

WHY THE ARCHITECTURE CHOICE IS A BUSINESS DECISION

The architecture is not just an engineering preference. It determines how long the machine takes to build, how easy it is to commission, how difficult it is to troubleshoot, how vulnerable it is to nuisance faults, and how much maintenance effort is required to keep it running. **In other words, the architecture choice shapes the day-to-day cost of living with the machine for its entire working life.**

SECTION 02

What Actually Causes Unplanned Downtime in Packaging Machines

The most frustrating downtime events are rarely the ones where something fails cleanly and obviously. The more disruptive faults are the ones that appear, disappear, and then return without warning. In packaging environments, those events often do not begin in the PLC logic or the software. **More often, they begin in the physical layer of the machine — the connections, interfaces, sensors, and power distribution points that link the control system to the real world.**

THE THREE PRIMARY FAILURE MECHANISMS

01

Vibration-Induced Connection Degradation

Packaging machines vibrate by nature. Fillers, cappers, cartoners, labellers, and conveyors all create constant motion and mechanical disturbance. Over time, that vibration works against any design that depends on large numbers of manually made electrical terminations remaining stable year after year.

At first, the effect may be subtle. A connection that was acceptable during assembly begins to degrade in service. Under motion, it opens briefly or loses contact quality just long enough to trigger a fault. When the machine stops, the connection settles again. Maintenance arrives, sees nothing obvious, restarts the machine, and production resumes — at least for a while.

These faults are not random. They are built into the architecture.

02

Moisture, Contamination, and Plant Reality

Packaging equipment does not operate in ideal conditions. It lives in the real world of washdown, condensation, cleaning chemicals, airborne particulates, product residue, and daily temperature swings. Even where the primary control hardware is enclosed, the broader electrical system is still exposed to the consequences of that environment over time.

Cable entries, disturbed service points, internal terminations, and other installation-dependent areas all become potential sources of degradation. A connection does not have to fail dramatically to create trouble. It can oxidize, weaken, or become unstable under load long before it shows visible signs of damage.

Electrically compromised well before it appears obviously broken.

03

The Intermittent Fault Problem

The most expensive characteristic of these failures is their intermittent nature. The machine stops, the fault is logged, a technician responds, and by the time the cabinet is open, the problem has disappeared. The wire is still in place. The terminal looks fine. The sensor responds during a quick test. Nothing appears definitively wrong.

So the machine is restarted, the issue is noted, and the line returns to production. Then the same fault returns four hours later, or the next shift, or during a production run when downtime is least acceptable.

The real burden is the repeated investigation, the uncertainty, and the troubleshooting time chasing a fault that refuses to present itself on demand.

30%+

of All Electrical Failures in Industrial Plants Are Caused by Loose Connections

Thermographic survey data consistently identifies loose connections as the leading single cause of electrical failure — ahead of component failure, software issues, or mechanical problems.

Grace Technologies thermographic survey data

~80%

of Automation Faults Originate in Field Wiring, Sensors, and Power Supplies

Not in the PLC or control logic. The vulnerability sits in the physical layer — the path between the device and the control system. This is where the architecture decision has its greatest impact.

Industry practitioner consensus

When a machine depends on hundreds of workmanship-sensitive electrical terminations, **each one becomes a potential source of intermittent faults, longer troubleshooting, repeated stops, and hidden lifecycle cost.** The issue is not just failure. It is how difficult those failures are to isolate once production is on the line — and how much of that difficulty is a direct consequence of how the machine was designed and built.

SECTION 03

The Knowledge Your Maintenance Team Is Carrying

There is another cost built into traditional machine design that rarely appears on a maintenance budget: **the knowledge your most experienced technicians carry in their heads** — and the operational risk created when that knowledge walks out the door.

In most CPG plants, the person who truly understands how a packaging line behaves electrically is not reading from a manual. They know which machine faults after washdown, which cabinet section is always suspect, and which "random" stop is never really random. That knowledge is valuable — but it is also a warning sign. **When a machine depends on one experienced technician's memory and instincts to remain reliable, it is being held together operationally by tribal knowledge.**

And tribal knowledge is not a strategy.

When that technician retires, leaves, or moves on, the plant loses more than labour hours. It loses the internal map of the machine's hidden behaviour. The next technician, however capable, has to start over. During that relearning period, fault-finding takes longer, downtime lasts longer, and the risk of misdiagnosis goes up. Production does not care that the learning curve is understandable. The line is still down.

This Is a Design Issue, Not a Training Issue

Traditional centralized control systems create faults that are often buried, intermittent, and difficult to isolate without machine-specific experience. The more a machine depends on that kind of architecture, the more it rewards memory over visibility and **punishes anyone who does not already know its habits.**

When field connections are standardized, sealed, and easier to diagnose at the point where the fault occurs, troubleshooting becomes faster and less dependent on accumulated experience. The machine becomes easier to read, easier to service, and easier to support with a newer maintenance workforce.

TIME TO FIRST PRODUCTIVE FAULT RESOLUTION

1 hr

DECENTRALIZED IP67

A new technician can identify and resolve most routine field-level faults on a decentralized machine within an hour of starting. Per-channel LED indicators make the fault location visible without schematics or cabinet access.

Months

TRADITIONAL IP20 PANEL

On traditional panel-based systems, reaching the same level of fault-finding confidence can take months of accumulated machine-specific experience. The knowledge is in the person, not the machine.

WHAT LEAVES WHEN AN EXPERIENCED TECHNICIAN GOES

- ! **The fault map** — which machines have known weak points, which faults are intermittent, and where to look first
- ! **The workarounds** — the informal fixes and compensating actions that keep the line running between proper repairs
- ! **The history** — which faults have recurred, what was tried, and what actually worked versus what just cleared the fault temporarily
- ! **The instinct** — the ability to hear, feel, or read a machine's behaviour and know something is about to fail before it does

THE WORKFORCE CONTINUITY QUESTION

When your most experienced maintenance technician retires, how much of your machine's fault-finding knowledge leaves with them? If the answer is **"more than it should,"** *the issue is architectural. Better machine design reduces that dependency by making faults easier to see, isolate, and resolve without years of accumulated experience.*

THE RESILIENCE ARGUMENT

If your machines still require years of undocumented experience to troubleshoot efficiently, then part of your uptime is walking out the door every time a senior technician leaves. **That is not just a maintenance problem. It is a resilience problem built into the machine itself.**

SECTION 04

The Warranty Gap

Warranty is a common answer to the question of machine reliability risk. "If it fails in the first year, the OEM fixes it." That answer is true in a narrow sense and **misleading in every sense that matters financially.**

A standard packaging machine warranty typically covers replacement parts and, in many cases, OEM labour to diagnose and repair the covered failure. What it does not cover is the production you did not make while the line was stopped. It does not cover delayed orders, overtime to recover lost output, internal maintenance time spent investigating the problem before the OEM was called, or the second and third shifts lost while waiting for a technician to arrive.

That gap between what warranty covers and what downtime actually costs is where the real financial exposure sits. Depending on the product, line speed, and plant configuration, unplanned downtime on a packaging line can cost anywhere from several thousand dollars per hour on a lower-throughput line to tens of thousands per hour on a high-speed primary packaging operation. Siemens' True Cost of Downtime report benchmarks average unplanned downtime across industrial sectors at $260,000 per hour. **The exact number is not the point. Your number is.**

There is a second dimension to the warranty argument that also deserves to be named directly. Many electrical failures do not present as obvious wiring or connection failures. They appear as machine faults, sensor issues, communication interruptions, or intermittent stops with no clear root cause. Maintenance investigates, finds nothing conclusive, and restarts the machine. When the problem repeats often enough to justify a warranty claim, the diagnosis process begins again — this time with OEM involvement. That investigation may take days. **During those days, the operational cost still belongs to you.**

$0

of Your Production Downtime Is Covered by Your Machine Warranty

Regardless of whether the failure itself is technically covered. The warranty covers the repair. It does not cover the production you did not make while the line was stopped.

CALCULATE YOUR OWN EXPOSURE

Step 1: Take your line's hourly production value (units per hour × product margin, or simply revenue per hour).

Step 2: Multiply by the average hours of unplanned downtime per machine per year attributable to electrical faults.

Step 3: That is your annual wiring-related downtime cost per machine.

Step 4: Multiply by your machine count.

For most CPG plants with more than five or six packaging lines, the result is a number worth acting on — before the next capital purchase.

TABLE 1 — THE GAP BETWEEN WHAT WARRANTY COVERS AND WHAT A DOWNTIME EVENT ACTUALLY COSTS

WHAT WARRANTY TYPICALLY COVERS	WHAT WARRANTY DOES NOT COVER
✓ Replacement parts for covered failures	✗ Production lost while the line is stopped
✓ OEM technician labour for covered repairs	✗ Your maintenance team's investigation time before the OEM was called
✓ Return visits for repeat failures (sometimes)	✗ Overtime required to recover lost production output
✓ Software updates related to covered defects	✗ Schedule disruption, late orders, and customer commitments missed
	✗ Travel wait time before OEM technician arrives on site
	✗ Management time coordinating the response and communicating with customers

THE POST-WARRANTY PICTURE

After the warranty period, the full cost of every service event falls on the end user: diagnosis, labour, parts, travel, and recovery time. **Machines built around large numbers of installation-dependent electrical connections do not become less maintenance-intensive over time. They become more so.** Vibration continues. Thermal cycling continues. Oxidation progresses.

SECTION 05

A 40-Year-Old Method That Nobody Has Questioned

Hand-terminated centralized wiring did not become standard because engineers made poor decisions. It became standard because, for a long time, it was the only practical way to build industrial machines. **And it has persisted ever since because few customers have given suppliers a reason to do it differently.**

HOW THE DEFAULT WAS SET — AND WHY IT STUCK

1970s – 1980s

The Only Option Available

Fieldbus networks capable of carrying I/O over a single cable were not yet commercially established. Machine-mounted sealed electronics suitable for the factory floor were not widely available at practical cost. **The traditional control cabinet was not chosen for its reliability — it was chosen because it was what the technology of the time allowed.**

1990s – 2000s

Alternatives Emerge — Adoption Begins Elsewhere

Machine-mounted, sealed I/O becomes commercially available and technically mature. Automotive and pharmaceutical manufacturers begin specifying decentralized architectures where uptime, modularity, and maintainability matter. **CPG packaging specifications largely do not follow.**

2010s – Present

Technology Mature — CPG Specification Still Lagging

Every major automation supplier now offers robust IP67 field-mountable architectures as mainstream catalogue items. The technology is proven. **The issue is not technical readiness. The issue is that CPG machine specifications have not caught up with the technology.**

So why does traditional architecture still dominate so many packaging machines? Because machine builders usually build to the specification they are given, and most CPG machine specifications still focus on what the machine must do rather than how it should be electrically designed.

Speeds, formats, throughput, safety, and integration requirements are typically well defined. Electrical architecture often is not. And when that detail is left open, most OEMs will default to the design approach their engineers know, their panel shops are set up to build, and their service teams are accustomed to supporting.

This is not an indictment of packaging OEMs. It is a recognition of how industrial defaults work. **Suppliers tend to stay with established methods until a customer, a market shift, or an internal design push creates a compelling reason to change.** Some machine builders are already using more modern architectures where customers have asked for them or where their own engineering teams have driven the shift.

But across much of CPG packaging, the default has remained in place because the people who absorb the operational cost of that default have rarely been the ones writing the electrical requirements in the first place. The technology changed years ago. The specification often did not.

THE SPECIFICATION GAP — DEFINED

The Purchase Order Is One of the Most Powerful Design Documents You Control

When CPG manufacturers include clear electrical architecture requirements in their procurement documents — alongside the performance, format, integration, and safety requirements they already define — machine builders respond.

Suppliers who already use more modern architectures can confirm compliance. Suppliers who do not are forced to address the requirement directly. Either way, **the buyer gains clarity before the machine is built.**

"Your machine builder will usually continue building the way they always have until the specification tells them otherwise. ***Its value lies in how you use it before the machine is built.****"*

THE REAL ISSUE

The technology changed years ago. The specification often did not. **That gap — between what is technically available and what CPG buyers have historically required — is where avoidable downtime continues to be designed into new machines.** Closing it does not require new technology. It requires a different procurement conversation.

SECTION 06

What a Connectorized Architecture Means for Your Plant

FOR MAINTENANCE

Visibility at the Point of Failure

Faults are indicated where they occur — on the local module, at the channel level. The technician does not start by opening a cabinet and tracing through layers of internal wiring. In many cases, the affected channel is visible immediately and the corrective action is straightforward. **What might take hours can often be reduced to minutes.**

FOR PRODUCTION

Mean Time to Repair — Reduced

In a traditional centralized system, an intermittent electrical fault can require detailed testing through a cabinet containing hundreds of connections, often with reference to schematics. In a decentralized system, fault isolation is faster, more local, and **less dependent on specialist knowledge.** Recovery may be as simple as replacing a cable at the machine level.

FOR THE MACHINE ENVIRONMENT

Built for the Plant Floor

Machine-mounted IP67 components are designed to operate in the same real-world conditions the machine itself must survive: washdown, dust, temperature swings, vibration, and exposure to normal plant contamination. Traditional panel components depend on the cabinet for protection. **IP67 hardware does not need that protection.**

TABLE 2 — DOWNTIME COST COMPARISON BY ARCHITECTURE TYPE

COST CATEGORY	TRADITIONALLY WIRED (IP20)	MODERN CONNECTORIZED (IP67)
Production downtime (diagnosis)	Hours: fault buried in panel wiring, schematic tracing required, licensed electrician needed	Minutes: per-channel LED indicator at point of failure, no cabinet access required
Production downtime (repair)	Specialist electrician required — re-terminate, re-torque, verify continuity, update documentation	Swap cable or module — any technician, no tools, no schematic, minutes to restore
Warranty response wait time	OEM mobilization: days to weeks — travel, scheduling, diagnosis time before repair begins	Faster resolution: module swap by own maintenance staff, no OEM visit required in most cases
Covered vs. actual cost	Part may be covered. Production downtime: your cost — regardless of warranty status	Lower downtime regardless of coverage — faster recovery reduces total exposure
Post-warranty service cost	High: licensed electrician at \$81–\$136/hr including travel, schematic access, cabinet work	Low: assembly technician, minutes per event, no specialist required
Intermittent fault diagnosis	Days of investigation possible — fault disappears when machine stops, no visible root cause at rest	Per-channel, per-LED isolation — fault location visible immediately when it occurs
Repeat failures (same root cause)	Common: vibration re-loosens terminals, same fault recurs weeks or months later	Eliminated: M12 locking collar maintains contact integrity under vibration by design
Scheduled maintenance burden	Annual re-torque, thermographic survey required — ongoing cost to maintain connection integrity	Not required for IP67 connectors — standardized sealed connections do not degrade under normal service

THE BROADER POINT

A more modern connectorized architecture does not just change where the I/O is mounted. It changes the maintenance model, the speed of recovery, and the degree to which uptime depends on specialist troubleshooting inside a centralized cabinet. **That is why the architectural choice matters — it does not just shape the machine's design. It shapes the day-to-day cost of living with it.**

SECTION 07

The Reliability Evidence

The argument for changing how packaging machines are specified does not rest on theory. It rests on published data from independent sources, thermographic survey programmes, military reliability studies, and the practical experience of maintenance teams who have worked with both approaches. **The evidence consistently points in the same direction: the physical layer of the machine is where the majority of electrical failures originate, and connection integrity is the single most important factor in that layer.**

FOUR INDEPENDENT EVIDENCE SOURCES

GRACE TECHNOLOGIES — THERMOGRAPHIC SURVEY DATA

30%+

of All Electrical Failures in Industrial Plants Caused by Loose Connections

Grace Technologies' thermographic survey programme — conducted across a broad range of industrial facilities — consistently identifies loose connections as the single leading cause of electrical failure, ahead of component failure, software issues, or mechanical problems.

The significance of this finding is not just the percentage. It is that **loose connections are a predictable, architecture-dependent failure mode** — not a random event. They are a consequence of how the machine was built and what it is asked to survive in service.

> Loose connections are not random. They are built into designs that depend on large numbers of hand-made terminations.

INDEPENDENT RESEARCH

FLUKE CORPORATION — THERMOGRAPHY IN ELECTRICAL MAINTENANCE

Thermal Imaging Reveals What Visual Inspection Cannot

Fluke's published guidance on electrical maintenance thermography documents how connection degradation — oxidation, micro-arcing, and resistance increase — is frequently invisible to visual inspection and only detectable through thermal imaging under load.

This matters because it means that **a connection can be electrically compromised well before it presents any visible sign of failure** — and well before it triggers a fault that production records. The degradation is progressive and silent until it is not.

> A connection can be compromised for months before it causes a fault visible to production.

INDEPENDENT RESEARCH

ANSI/NETA MTS — MAINTENANCE TESTING SPECIFICATIONS

Industry Standard Requires Periodic Re-Torque of All Electrical Connections

The ANSI/NETA Maintenance Testing Specifications — the authoritative North American standard for electrical maintenance — explicitly requires periodic re-torquing of all bolted and screw-type electrical connections as part of a standard maintenance programme.

This requirement exists because the standard recognizes that **screw-type terminations do not maintain their original torque indefinitely** in service. Vibration, thermal cycling, and material creep all contribute to connection loosening over time. The standard does not suggest this might happen. It assumes it will.

> The industry standard assumes screw connections will loosen in service. The maintenance programme is designed around that assumption.

INDUSTRY STANDARD

NSWC CRANE — FAILURE MODE ANALYSIS

Connector and Wiring Failures Are the Leading Source of Electronic System Failures

Analysis published by the Naval Surface Warfare Center Crane Division — one of the most rigorous sources of electronic reliability data available — identifies wiring failures as the leading cause of electronic system failures across a wide range of applications.

The breakdown is instructive: **connection point failures account for approximately 20% of all electronic system failures**, wiring failures account for a further significant proportion, and component failures — the category most people assume is dominant — account for a smaller share than the physical layer.

> The physical connection layer — not the component — is where electronic systems most commonly fail.

INDEPENDENT RESEARCH

PRACTICAL TEST

The 2am Test

Consider how your maintenance team currently responds to an electrical fault at 2am on a Saturday. On a traditionally wired machine, the response begins with opening a cabinet, pulling out schematics, and starting to trace through dozens or hundreds of terminations looking for something that may not be visible at rest. On a decentralized machine, the response begins with looking at the module on the machine — where the fault indicator is already lit. **The difference in mean time to repair is not marginal. It is the difference between a 20-minute recovery and a two-hour investigation.** Multiply that across a year of unplanned events on multiple lines, and the architecture choice has a measurable financial consequence.

SOURCE CLASSIFICATION

- INDEPENDENT RESEARCH
- INDUSTRY STANDARD / CONSENSUS
- SUPPLIER / MANUFACTURER DATA

Full source list and classifications on the final page of this document.

SECTION 08

What to Ask Your Machine Builders

The following questions are designed to surface how a machine builder approaches electrical architecture before the purchase order is placed. **The goal is not to catch suppliers out — it is to understand their design defaults and create the opportunity to specify something better.** A supplier who cannot answer these questions clearly is telling you something important about what you are about to buy.

SIX SUPPLIER QUALIFICATION QUESTIONS

01 What is the approximate number of individual hand-made electrical terminations in this machine?

This question establishes the scale of the manual workmanship dependency. A machine with 400 or more hand-made terminations has 400 or more potential failure points whose reliability depends on individual assembly quality. **There is no right answer — but the number should prompt a conversation about whether it can be reduced.**

Good signal: supplier can answer precisely and has considered reducing it.

02 What IP rating are the I/O and control components mounted on the machine — outside the main cabinet?

IP20-rated components outside a protective enclosure are exposed to the plant environment without adequate protection. IP67 components are designed to survive it. **This question identifies whether the machine's electrical components are suited to the environment they will actually operate in.**

Good signal: IP67 field-mounted modules with sealed M12 connections.

03 How does a maintenance technician identify the location of a sensor or actuator fault during a production stop?

The answer reveals how visible and accessible fault information is during a real downtime event. **If the answer involves opening a cabinet, consulting schematics, or using a multimeter to trace through wiring, the machine's fault visibility is low.** If the answer involves a per-channel LED at the point of failure, fault visibility is high.

Good signal: per-channel LED indication at the local I/O module, no cabinet access required.

04 What connector standard is used for field device connections, and are they factory pre-tested?

Standardized, pre-tested connectors eliminate the workmanship variability that comes with hand-made terminations. **M12 circular connectors with locking collars are the industrial standard for IP67 field connections.** Factory pre-testing means the connection was verified before the machine was assembled — not after it was installed.

Good signal: M12 A/B/D-coded connectors, factory pre-tested cables with continuity verification.

05 Can a non-electrician perform routine sensor and cable replacements during a production stop?

This question tests the practical maintainability of the machine. In a decentralized connectorized architecture, most field-level repairs require no tools, no schematic, and no licensed electrician. **If the answer is no, the machine's maintenance model depends on specialist availability at the moment of failure** — which is rarely guaranteed during a production stop.

Good signal: yes, swap cable or module, no tools, no electrician, under 10 minutes.

06 What is your standard approach to cable routing and protection for field-level connections?

Cable routing and protection quality has a direct effect on long-term reliability. **Cables that are correctly rated for the application, properly supported, and protected at entry points are far less likely to develop intermittent faults from vibration, abrasion, or contamination ingress.** This question reveals whether the OEM treats cabling as a design detail or an afterthought.

Good signal: application-matched cable type, proper strain relief, documented routing standards.

SAMPLE SPECIFICATION LANGUAGE — READY TO ADAPT

The following clauses can be added to your standard machine procurement specification. Adapt as needed for your environment and standards requirements.

CLAUSE 1 — ARCHITECTURE

All field I/O and control modules mounted external to the main control enclosure shall be rated to a **minimum of IP67** and shall use standardized sealed circular connectors for all field device connections.

CLAUSE 2 — CONNECTORS

All field-level connections shall use **M8 or M12 circular connectors** with locking collars. Field-wireable connectors shall not be used for permanent machine wiring. All cables shall be factory pre-assembled and tested prior to installation.

CLAUSE 3 — FAULT VISIBILITY

All I/O modules shall provide **per-channel LED fault indication** visible at the module location without requiring access to the main control enclosure. Fault status shall be accessible via the machine HMI with channel-level resolution.

CLAUSE 4 — MAINTAINABILITY

Routine sensor and cable replacement shall be achievable by a **general maintenance technician** without specialist electrical qualifications, without access to the main control enclosure, and without reference to machine schematics.

CLAUSE 5 — CABLE SELECTION

All cables shall be selected to match the specific application environment: PUR jacket for general industrial use, PVC for food and beverage washdown, TPE for UV exposure. Cable gauge shall be appropriate for the connected load with a minimum 20% current margin.

CLAUSE 6 — DOCUMENTATION

The supplier shall provide a **complete connection schedule** identifying all field device connections, connector types, cable specifications, and module channel assignments. Documentation shall be sufficient to support fault diagnosis without OEM assistance.

SECTION 09

The Industry Has Already Made This Move

The technology required to move away from traditional centralized wiring is not experimental or emerging. It is mainstream, well-supported, and available from every major automation supplier. **The question is not whether the technology is ready. The question is whether the specification asks for it.** Automotive and pharmaceutical manufacturers have been specifying decentralized IP67 architectures for years. CPG packaging is the sector where the gap between available technology and standard practice remains widest.

MAJOR AUTOMATION SUPPLIERS WITH ESTABLISHED IP67 FIELD-MOUNTABLE PRODUCT LINES

Rockwell Automation
ArmorBlock 5000 / POINT I/O

Machine-mounted IP67 I/O modules for EtherNet/IP networks. Designed for direct machine mounting without enclosure. **Widely specified in automotive and food and beverage sectors.**

Siemens
ET 200pro / ET 200eco PN

IP65/67/69K rated distributed I/O for PROFINET. Designed for direct machine mounting in harsh environments. **Standard in automotive body shop and assembly applications.**

Beckhoff
EP Series EtherCAT Box

IP67 EtherCAT I/O modules for direct machine mounting. M8/M12 connectivity throughout. **Supports decentralized I/O strategies for modern industrial machine design.**

Murrelektronik
Impact67 / MVK Fusion CIP

IP67 modular I/O, safety, and power distribution for PROFINET, EtherNet/IP, and EtherCAT. **Designed specifically for decentralized machine architectures with integrated diagnostics.**

Pilz
PSSuniversal / PSS 4000

IP67 safety I/O and decentralized safety architecture for machine-level deployment. **Widely used where safety and connectivity are integrated at the machine level.**

SECTOR ADOPTION COMPARISON — DECENTRALIZED IP67 ARCHITECTURE

ADOPTION INDICATOR	AUTOMOTIVE MANUFACTURING	PHARMACEUTICAL / FOOD	CPG PACKAGING
Overall adoption level	HIGH Standard specification in most new builds; IP67 field I/O is the default, not the exception	HIGH IP69K washdown-rated architecture standard; driven by hygiene and uptime requirements	LOW – GROWING Traditional panel-based architecture still dominates most new packaging machine builds
Primary driver for adoption	Uptime, modularity, rapid changeover, and reduced commissioning time in high-volume assembly	Hygiene compliance, washdown requirements, and strict uptime demands in regulated environments	Beginning to be driven by labour shortages, maintenance workforce challenges, and OEM early adopters
Specification maturity	Well-established; IP67 field I/O requirements appear in standard machine procurement documents	Well-established; IP69K and decentralized I/O requirements standard in equipment specifications	Emerging; most CPG machine specifications still do not explicitly require decentralized IP67 architecture
OEM familiarity	High; automotive OEMs have built IP67 decentralized designs as standard for 15+ years	High; pharma/food OEMs routinely design to IP69K as a baseline requirement	Mixed; some packaging OEMs offer IP67 options or use it by default, many still default to IP20 panel
Maintenance workforce impact	Reduced dependency on specialist electricians; technician-level service standard on most field I/O	Faster fault resolution; per-channel diagnostics reduce mean time to repair significantly	Significant opportunity; most CPG plants still require specialist electrical knowledge for routine fault-finding

THE CPG OPPORTUNITY

Automotive and pharmaceutical manufacturers did not adopt decentralized IP67 architectures because they had access to better technology. They adopted it because their procurement specifications required it. **CPG packaging has the same technology available. The missing piece is the specification.**

CONCLUSION

The Downtime Was Built In. It Does Not Have to Stay.

Every packaging machine that ships with hundreds of hand-made electrical terminations, IP20-rated components, and no clear electrical architecture requirement in the procurement specification carries avoidable operational risk. **That risk is not inevitable. It is a consequence of a specification gap that can be closed.**

THREE THINGS WORTH TAKING AWAY FROM THIS PAPER

01

The Failure Points Are Structural, Not Random

The faults that create the most disruptive downtime on packaging lines — intermittent stops, repeated electrical failures, difficult-to-diagnose events — are not bad luck. They are a predictable consequence of building machines around large numbers of installation-dependent connections in environments where **vibration, contamination, and thermal cycling are constant.**

02

Warranty Does Not Cover What Downtime Actually Costs

The real cost of a built-in electrical failure is not the replacement part. It is the production you did not make, the maintenance time spent investigating, the overtime required to recover, and the business impact of missed commitments. **That cost is borne by the end user regardless of whether the machine is under warranty.**

03

The Specification Is the Most Powerful Tool You Have

Machine builders tend to build the way they always have until the specification tells them otherwise. Adding clear electrical architecture requirements to procurement documents — alongside the performance, safety, and integration requirements already defined — is how CPG manufacturers close the gap **before the machine is built, not after.**

STEP 01

Review Your Current Specifications

Check whether your current machine procurement documents include any electrical architecture requirements. Most do not. That gap is where the conversation starts.

STEP 02

Calculate Your Downtime Exposure

Use the framework in Section 4 to put a number on your annual wiring-related downtime cost per machine. For most CPG plants with multiple lines, the result justifies a specification update.

STEP 03

Update Before the Next Capital Purchase

The best time to require a better electrical architecture is before the machine is built. Use the sample specification language in Section 7 as a starting point and adapt it to your procurement process.

CONNECTIVITY CHAT — FREE 30-MINUTE CONSULTATION

Talk Through Your Specific Situation

If you are evaluating a capital purchase, reviewing your current machine specifications, or trying to understand how these design principles apply to your specific packaging environment, a 30-minute Connectivity Chat is a good place to start. **No agenda, no pitch deck, no obligation.**

- **Who it is for:** Engineering managers, plant managers, and operations leaders at CPG manufacturers
- **What happens:** You describe your situation, I share what I have seen work in similar environments, and you decide what to do with that
- **Book at:** ConnectivityColin.com/chat

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SOURCES AND REFERENCES

Research and Data Sources

Independent Research | Industry Consensus / Practitioner Data | Supplier / Manufacturer Data

01 INDEPENDENT RESEARCH

True Cost of Downtime 2024

Siemens AG — $260,000/hr average unplanned downtime benchmark across industrial sectors. Used for downtime cost modelling throughout this paper.

02 INDEPENDENT RESEARCH

Thermographic Survey Data — Loose Connection Failure Rates

Grace Technologies — Thermographic inspection data showing loose connections as the leading single cause of electrical failure in industrial plants, cited at 30%+ of all electrical faults.

03 INDUSTRY CONSENSUS

Field Wiring as Primary Source of Automation Faults (~80%)

Widely cited practitioner consensus across industrial automation literature. Reflects accumulated field experience rather than a single published study. Used as directional benchmark only.

04 INDEPENDENT RESEARCH

Electrical Maintenance Testing Standard ANSI/NETA MTS

InterNational Electrical Testing Association — Maintenance testing standard referenced for connection torque verification, thermographic survey requirements, and scheduled inspection intervals.

05 INDEPENDENT RESEARCH

Electrical Safety and Maintenance — Thermography in Predictive Maintenance

Fluke Corporation — Application data on thermal imaging for electrical fault detection. Referenced for loose connection identification methodology and maintenance interval guidance.

06 INDEPENDENT RESEARCH

IEC 60529 — Degrees of Protection Provided by Enclosures (IP Code)

International Electrotechnical Commission — Formal standard defining IP20 and IP67 protection ratings referenced throughout this paper for architecture classification.

07 INDEPENDENT RESEARCH

Workforce and Skills Gap in U.S. Manufacturing

Deloitte / Manufacturing Institute — Analysis of skilled trades shortage in U.S. manufacturing. Referenced for electrician availability and wage data used in labour cost modelling.

08 INDEPENDENT RESEARCH

U.S. Bureau of Labor Statistics — Electrician Wage Data

BLS Occupational Employment and Wage Statistics — Industrial electrician hourly wage data ($40.50 median, $68/hr 90th percentile) used in labour cost comparisons.

09 INDEPENDENT RESEARCH

NSWC Crane — Failure Mode and Effects Analysis Data

Naval Surface Warfare Center Crane Division — Failure mode distribution data for electronic components and interconnects. Referenced for connector vs. component failure rate comparisons.

10 INDUSTRY CONSENSUS

Machine Wiring Time Study — Centralized vs. Decentralized Architecture

Rockwell Automation / Volga-Dnepr Engineering Study — Time comparison of traditional panel wiring (20h 5min) vs. IP67 decentralized wiring (6h 39min) for equivalent machine complexity. Third-party verified.

11 SUPPLIER / MANUFACTURER DATA

IP67 Field I/O Product Documentation and Application Data

Murrelektronik, Rockwell Automation, Siemens, Beckhoff, Pilz — Product specifications, application notes, and installation data for IP67 machine-mounted I/O systems referenced for architecture descriptions.

12 INDEPENDENT RESEARCH

IPC-A-610 — Acceptability of Electronic Assemblies

IPC International — Industry standard for electronic assembly quality. Referenced for workmanship variability discussion and the basis for human error rates in manual termination processes.

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