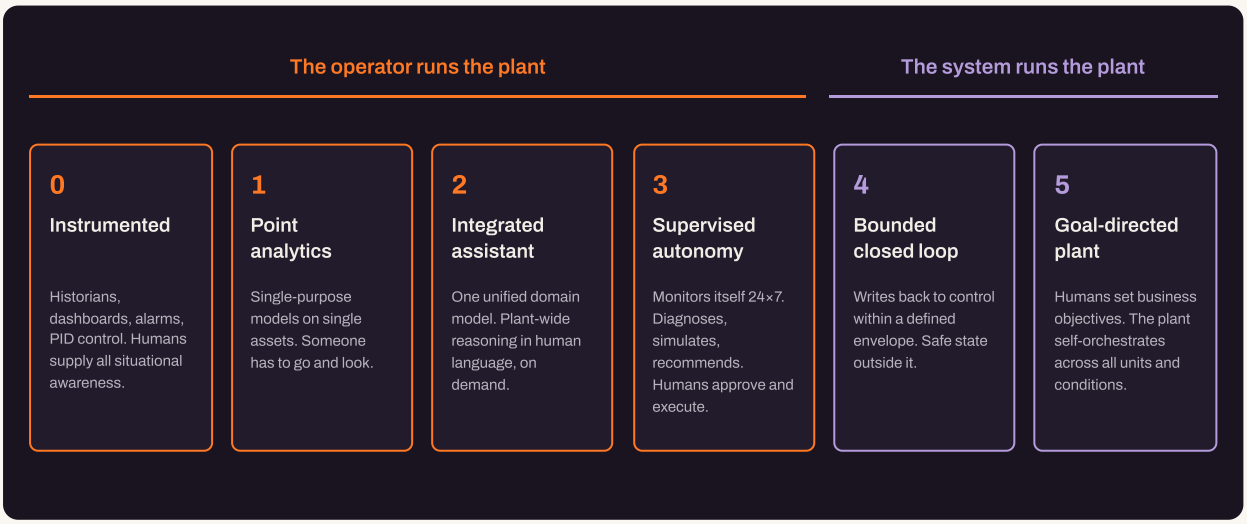
AN OPEN INDUSTRY SCALE · ARUNDO 2026

The Six Levels of Autonomous Plant Operations

Version 1.0 · September 2026

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A common language for plant autonomy: six levels from the instrumented plant to the goal-directed plant, with definitions, entry criteria and level boundaries — modeled on the precedent of SAE J3016's levels of driving automation.



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Foreword

In 2014, "self-driving" meant everything and nothing — until SAE International published J3016 and its six levels of driving automation gave the industry a shared, precise vocabulary. Suppliers, regulators and manufacturers could finally say exactly what a system did, and did not do.

Plant autonomy is at that moment now. "Autonomous operations," "self-optimizing plant" and "industrial AI" are used interchangeably for capabilities that differ by a decade of engineering. This scale exists to end that ambiguity: six levels, defined by what the system does and who holds authority, from the instrumented plant in which humans supply all understanding, to the goal-directed plant that orchestrates itself against business objectives.

The scale is deliberately honest. Most plants today operate at Levels 0–1. Level 2 runs in production. Level 3 is the current engineering frontier. Levels 4 and 5 are the destination that architecture decisions made today either enable or preclude. A scale that flattered its readers — or its author — would be useless to both.

1 Scope

This document defines a six-level classification of autonomy for industrial plant operations in asset-heavy industries — energy, oil & gas, chemicals, mining, manufacturing, maritime and utilities. It classifies **operations**, not products: a level describes what an operation's systems do in production, under real conditions, with authority defined. It is technology-agnostic and vendor-neutral in its definitions.

The scale classifies the operational scope to which it is applied. A plant may legitimately operate at different levels for different parts of the operation; the classification should state its scope (a unit, a site, a fleet).

2 Normative reference and precedent

This scale is modeled on the structure of **SAE J3016** (Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles, SAE International, most recently revised April 2021), which defines six levels of driving automation (0–5) with a characteristic transfer of authority from human to system. The parallel is structural, not technical: like J3016, this scale is anchored in **who holds authority** and **what the system does unprompted**, and like J3016 it places the decisive handoff between its third and fourth levels. Section 7 provides the level-by-level correspondence.

3 Use of this document

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Revision. The scale carries the year of its edition ("Arundo 2026") and is reviewed annually. Proposed revisions may be submitted to contact@arundo.com.

4 Terms and definitions

Autonomy level

A classification (0–5) of an operation's systems by what they do unprompted and who holds authority over actions affecting the process.

Domain model

A single connected representation of an operation's physical and digital elements — assets, hierarchies, sensors, analytical models, computations and documents — and their relationships. The prerequisite of Level 2.

Point analytics

An analytical or machine-learning model attached to a single asset or narrow function, with its own data path and asset definition.

Unprompted operation

System activity — monitoring, diagnosis, recommendation — initiated by the system on its own schedule or triggers, rather than in response to a human query.

Recommendation

A proposed action emitted by the system, carrying its diagnosis, the alternatives considered and a confidence score, for human approval.

Operating envelope

The explicitly declared set of conditions, thresholds and hard limits within which a Level 4 system is permitted to act on the control layer.

Degrade to safe state

The mandatory Level 4 behavior of relinquishing closed-loop action and settling the process to a defined safe condition when the operating envelope is exited.

Goal-directed operation

Level 5 operation in which human input consists of business objectives and their governance, and the system plans and acts across all units and conditions to meet them.

Authority

The right to cause an action that affects the process. The scale's central variable: human at Levels 0–3, shared within an envelope at Level 4, systemic under human objectives at Level 5.

Confidence score

A quantified statement of the system's certainty attached to a recommendation, enabling proportionate human review.

5 The scale at a glance

LEVEL	NAME	AUTHORITY	DEFINING CAPABILITY
0	Instrumented	Human	Measurement, visualization and fixed-rule automation; humans supply all situational awareness.
1	Point analytics	Human	Isolated models on single assets; a human must seek out and contextualize every result.
2	Integrated assistant	Human	One domain model; plant-wide reasoning in human language, on demand.
3	Supervised autonomy	Human approves	Unprompted monitoring, diagnosis, simulation and confidence-scored recommendation.
4	Bounded closed loop	Shared, in envelope	Write-back to the control layer within a declared envelope; safe-state degradation outside it.
5	Goal-directed plant	System, under objectives	Self-orchestration across all units and conditions against business objectives.

The decisive handoff — from "the operator runs the plant" to "the system runs the plant" — occurs between Levels 3 and 4, where authority over process-affecting action first transfers, in bounded form, to the system.

6 Level definitions

Level 0 — Instrumented

Definition. The plant is measured but not understood by its systems. Data acquisition, visualization and fixed-rule automation exist; all interpretation is human.

CHARACTERISTICS

- Historians, dashboards, threshold alarms, trips and regulatory PID control.
- Automations are fixed-rule and context-free: they act on values, never on meaning.
- Situational awareness resides entirely with operators and engineers.

IN PRACTICE

The control room sees thousands of numbers; people supply all the meaning. Alarm floods, tribal knowledge, and shift-dependent understanding are characteristic. Level 0 plants are typically data-rich and understanding-poor.

ENTRY CRITERIA

- Sensor coverage of the process with historized storage.
- Basic alarming and regulatory control in service.

> **Boundary.** Level 1 is entered when the first analytical model interprets data about a specific asset without human prompting of each analysis.

Level 1 — Point analytics

Definition. Single-purpose analytical or machine-learning models operate on single assets. Intelligence exists in isolated islands; no model can see beyond its own asset.

CHARACTERISTICS

- Condition monitoring, anomaly detection or performance models attached to individual equipment.
- Each model carries its own data pipeline, asset definition and user surface.
- Results require a human to seek them out and place them in plant context.

IN PRACTICE

Islands of intelligence in an ocean of dashboards. Value is real but capped: a pump model cannot report that the problem started upstream, and each additional use case costs approximately as much as the previous one. Most of the industry operates at this level.

ENTRY CRITERIA

- At least one production analytical model attached to a specific asset.
- A maintained data path from source systems to that model.

> **Boundary.** Level 2 is entered when analyses execute against one shared model of the operation rather than per-tool copies of it.

Level 2 — Integrated assistant

Definition. A unified asset and domain model of the operation exists, with orchestration to run analysis across it on demand. Plant-wide, cross-domain reasoning is available in human language. The system remains reactive: humans must know what to ask.

CHARACTERISTICS

- One connected representation of assets, hierarchies, sensors, models, computations and documents.
- Orchestrated execution of analyses spanning units, systems and disciplines.
- Natural-language interrogation of the operation, with evidence attached to answers.

IN PRACTICE

Every sensor, asset, model and manual in one connected model; engineers converse with the whole plant. Questions that formerly required cross-team data assembly are answered in minutes. This is the first level at which the operation, rather than its parts, can be reasoned about.

ENTRY CRITERIA

- A single domain model spanning the operation's assets, data and documentation.
- Query and analysis execution across that model without per-question engineering.
- Provenance: answers traceable to their sources.

> **Boundary.** Level 3 is entered when the system initiates: monitoring, diagnosis and recommendation occur without a human prompt.

Level 3 — Supervised autonomy

Definition. The plant monitors itself continuously and unprompted. It detects deviations, diagnoses causes, simulates options and emits recommended actions with confidence scores. Humans approve and execute every action.

CHARACTERISTICS

- 24×7 unprompted surveillance across the modeled operation.
- Automated diagnosis and simulation of alternatives for detected deviations.
- Recommendations carry rationale, alternatives considered and a confidence score.
- No action reaches the process without human approval and execution.

IN PRACTICE

The plant becomes the most attentive engineer on shift — one that never sleeps, never rotates out, and watches every unit at once. Deviations are caught at the drift stage rather than the alarm stage. Because every recommendation is inspectable, operator trust is built into the mechanism.

ENTRY CRITERIA

- Always-on evaluation of the domain model against live data.
- Diagnostic and simulation capability sufficient to rank actions.
- A human approval workflow for every recommended action.

> **Boundary.** Level 4 is entered when the system is permitted to act on the control layer itself, within an explicitly defined envelope.

Level 4 — Bounded closed loop

Definition. The system writes back to the control system within a defined operating envelope: named conditions, confidence thresholds and hard limits. Outside the envelope it degrades to a safe state. Humans set objectives and handle exceptions.

CHARACTERISTICS

- Closed-loop action on the control layer, restricted to a declared envelope.
- Every permitted action is named in advance; every action taken is logged and reversible.
- Automatic degradation to a defined safe state when conditions exit the envelope.

IN PRACTICE

The delay between insight and action disappears for the routine corrections that constitute most of operations: setpoints trimmed toward the optimum around the clock, with a consistency no shift schedule can match. People supervise exceptions rather than execute adjustments.

ENTRY CRITERIA

- Demonstrated Level 3 operation with sustained recommendation quality.
- A formally defined envelope agreed with operations and safety functions.
- Write-back integration with the control system, with logging and reversal.

> **Boundary.** Level 5 is entered when envelope restrictions are removed and the plant orchestrates itself against business objectives alone.

Level 5 — Goal-directed plant

Definition. Humans supply business objectives — margin, throughput, yield, an emissions cap. The plant self-orchestrates across all units and conditions, with no operating-envelope restriction.

CHARACTERISTICS

- Objective-driven orchestration across every unit and condition.
- Continuous re-planning at machine speed as markets, feedstocks and equipment states change.
- Human roles concentrate on objectives, exceptions and improvement.

IN PRACTICE

The operation holds its economic optimum continuously rather than at the cadence of planning meetings. No plant operates at Level 5 today; the level defines the destination against which architectures at Levels 2–4 should be evaluated.

ENTRY CRITERIA

- Demonstrated Level 4 operation across the scope of the objectives.
- Objective functions agreed at business level, with governance for their revision.

> **Boundary.** Level 5 is the terminal level of this scale.

7 Correspondence to SAE J3016

The correspondence below is structural: each row pairs levels at the same position in their respective authority transfers. It does not imply technical equivalence between driving automation and plant operations.

	THIS SCALE (PLANT OPERATIONS)	SAE J3016 (DRIVING AUTOMATION)	SHARED STRUCTURAL PROPERTY
0	Instrumented	No Automation	Warnings and momentary or fixed-rule interventions only; the human sustains all control and understanding.
1	Point analytics	Driver Assistance	Automation of a single, narrow function; everything else remains human.
2	Integrated assistant	Partial Automation	Multiple functions integrated into one system; continuous human supervision and initiative required.
3	Supervised autonomy	Conditional Automation	The system handles the task and requests the human, who must respond; authority remains human.
4	Bounded closed loop	High Automation	Autonomous action within a defined domain or envelope; safe behavior on its boundary without human takeover.
5	Goal-directed plant	Full Automation	No domain restriction; the system operates wherever the task exists.

8 Level determination

An operation's level is determined by the highest level whose entry criteria (Section 6) are met **in production** for the stated scope. Six determining questions, answered honestly, locate most operations; "not sure" is answered as "no".

1. Do any models watch individual assets today? (No → Level 0)
2. Can one system answer a question that spans two different units? (Boundary 1→2)
3. Do your models and tools share a single asset model? (Boundary 1→2)
4. Can engineers query live plant data in plain language, with evidence attached? (Level 2)
5. Does anything monitor the plant unprompted — and explain why it flagged what it flagged? (Boundary 2→3)
6. When something drifts, does the system propose an action, with alternatives and a confidence score, for approval? (Level 3)

A guided self-assessment implementing these questions is maintained at **arundo.com/find-your-level**.

9 Revision history

VERSION	DATE	CHANGES
1.0	September 2026	First published edition of the Arundo 2026 scale.

About the author

Arundo Analytics AS has built and operated industrial AI, machine-learning and data systems for asset-heavy operators since 2015 — more than a hundred solutions in production across energy, chemicals, maritime and manufacturing. Arundo authored this scale, places its own customers on it honestly, and builds Arundo Foundation, the platform engineered to climb it. · arundo.com · Oslo · Stockholm · Houston