Bridging mechanical design and industrial AI

How valve manufacturers can prepare ball valves for evidence-based maintenance, digital twins and future industrial-AI workflows.

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Figure 1. Ball-valve assemblies manufactured by Batu Valve Türkiye and fitted with electric actuators. Such configurations illustrate the mechanical foundation through which available actuator and plant data may support future condition assessment.

The industrial opportunity is not to put artificial intelligence (AI) inside every valve. It is to preserve the mechanical evidence, operating context and lifecycle baselines that allow selected critical ball valves to participate credibly in modern maintenance workflows.

Plants lack valve evidence

Plants already record pressure, flow, temperature, commands and valve position. Yet these signals do not automatically identify internal leakage, distinguish valve friction from actuator or coupling problems, or prove that an infrequently operated isolation valve will move on demand. Maintenance requires a decision on a named asset, not a generic prediction. The economic use case is therefore a selected population of critical actuated valves, for which design data, actuator history, process context and verified baselines remain connected[17, 23].

What owners are adopting now

Asset Performance Management is already being deployed across operating assets, including an Aker BP programme covering five North Sea assets[41]. Digital twins support monitoring, scenarios and maintenance, although data integration, validation, scale and workforce readiness remain major barriers[42-44]. Selective autonomous control has reached full-scale refinery and gas-treatment applications[45, 46], but this does not justify autonomy for isolation or safety functions. For valves, the nearer-term opportunity is time-series detection, digital-twin context and retrieval-grounded maintenance assistance with human approval.

Link each failure mode to defensible evidence

A credible use case begins with a failure mode and a decision. An indicator may justify investigation without proving root cause: increasing torque can reflect seat friction, packing load, corrosion, misalignment, differential pressure or actuator condition; partial stroke can demonstrate movement but not seat tightness. The engineering task is to state the evidence, its confounders and the confirmation required before action.

Make actuator data mechanically trustworthy

Torque, position, and stroke time are only valuable if the mechanical load path is repeatable. ISO 5211:2026 standardises part-turn actuator attachments, while ISO 5640:2024 addresses mounting kits[3, 4]. The valve manufacturer should additionally control bracket stiffness, alignment, coupling fit, backlash, fasteners and shaft datum. Otherwise, a change in the recorded signature may originate in the adapter rather than the valve. ISA75.26

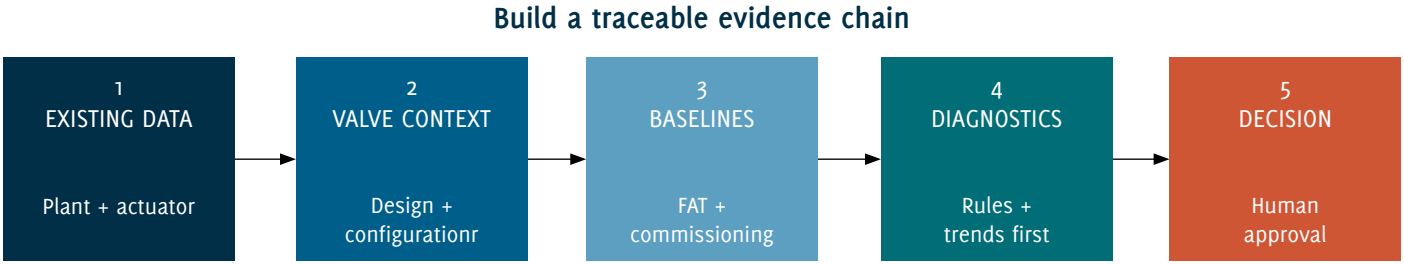


Figure 2. A traceable evidence chain connects mechanical configuration and lifecycle baselines to diagnostics and an accountable human decision.

also recognises the need for consistent acquisition and reporting of diagnostic signals for actuated valves, while leaving interpretation to the user[16].

Pressure-boundary integrity remains primary. Any cavity, bleed or drain connection used for pressure response must be part of the qualified valve configuration under the applicable API 6D and ISO 14313 design basis[1,2]. Acoustic, ultrasonic or temperature measurements should be optional project provisions, not generic ports drilled into an existing body. Research supports their potential but also shows sensitivity to pressure, operating conditions, mounting, and test arrangement[18, 19].

Three industrial patterns already in service

On China's West-East Pipeline, intelligent electric actuators retained commissioning footprints, bidirectional torque profiles and position history[11]. An Izmit refinery retrofit compared opening and closing torque with commissioning signatures to identify wear and tight spots[12]. For ESD valves, commercial packages combine partial-stroke results, position feedback and load trends[13-15]. These cases show an economical pattern: preserve data already produced by actuation. They also show its limit - movement diagnostics do not prove seat tightness.

Turn factory testing into a digital baseline

For selected actuated packages, FAT should export break-to-open and running torque versus angle, seating torque, stroke time, test conditions, actuator supply and configuration identity[8].

A factory curve is not a universal alarm limit because service pressure, fluid, temperature and installation stress differ. The lifecycle record should therefore retain factory, site-commissioning and post-maintenance baselines, compared under matching operating states.

Table 1. A failure-mode-to-evidence matrix separates an indicator from proof and makes diagnostic claims testable.

Failure mode	Candidate evidence	Key confounders	Confirmation
Rising resistance	Torque-angle and stroke-time trend	Pressure, temperature, supply and alignment	Controlled functional test / inspection
Incomplete stroke	Command, position and travel time	Air or power supply, switch and gearbox	Functional test and actuator checks
Internal leakage	Upstream, downstream or cavity response	Thermal effects, trapped pressure and seat direction	Qualified leakage verification
Packing degradation	Load trend and external inspection	Temperature and prior maintenance	Emission or visual examination
Post-maintenance change	New signature versus accepted baseline	Changed seat, packing, coupling or actuator	Baseline-reset acceptance test

Table 2. Proposed minimum content of a Valve Diagnostic Readiness Package. VDRP is a framework proposed in this article, not an existing industry standard.

VDRP element	Supplier deliverable	Why it matters
Valve passport	Serial-linked as-built configuration, units, interfaces and revision history	Prevents an orphaned signal
Healthy-signature envelope	Factory and commissioning ranges for torque, angle, stroke time and test context	Avoids treating one curve as a universal limit
Failure-to-evidence matrix	Candidate indicator, confounders, coverage and required confirmation for each selected failure mode	Separates indication from proof
Sensor-escalation gate	Add sensing only when consequence, access and an unresolved evidence gap justify lifecycle cost	Keeps the business case selective
Evidence-retrieval map	Tagged links to drawings, FAT records, manuals, accepted baselines and maintenance history	Grounds future RAG or copilot answers
Baseline-reset record	New accepted reference after packing, seat, actuator, gearbox or coupling work	Prevents false trend continuity

Valve Diagnostic Readiness Package

The proposed Valve Diagnostic Readiness Package (VDRP) is a procurement deliverable, not an electronic product or a claim that the valve diagnoses itself. It connects the mechanical configuration to whatever actuator, historian or analytics platform the owner selects. Its technology-neutral content includes a valve passport; a healthy-signature envelope; a failure-mode-to-evidence matrix; data-quality and operating-context fields; a sensor-escalation gate; an evidence-retrieval map; and a baseline-reset record after maintenance. The approach extends established diagnostic-data and lifecycle-information principles into a ball-valve-specific supplier package[5, 16, 20-23, 36].

The matrix is the economic control point. Torque or stroke time may justify inspection but cannot prove seat leakage. Acoustic-emission and cavity-pressure studies can classify leakage under controlled conditions[18, 24-29], yet performance depends on pressure, geometry, mounting, noise and training data. Permanent sensing is justified only where a named failure mode remains unresolved and the resulting decision has measurable value.

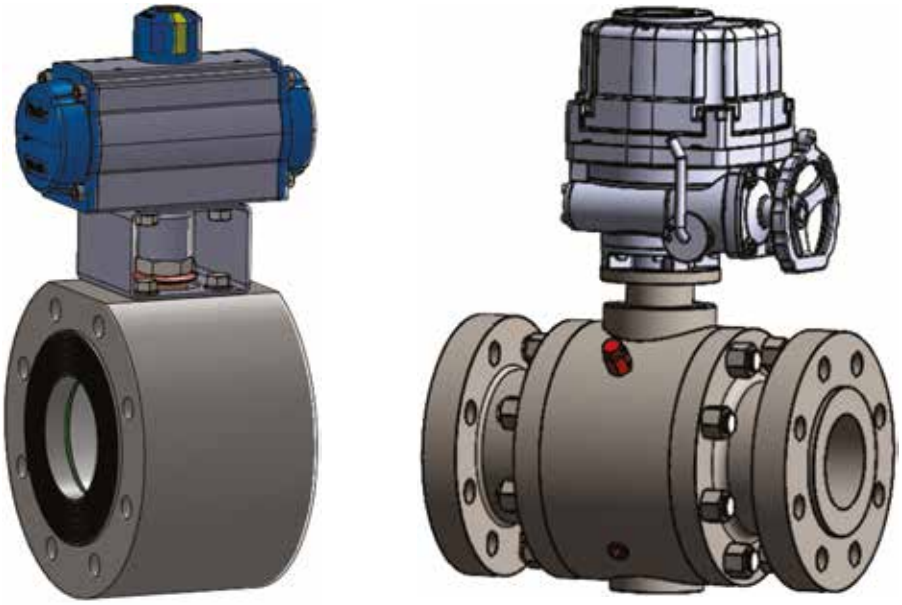


Figure 3. Actuated ball-valve configurations: a pneumatically actuated wafer ball valve (left) and an electrically actuated flanged ball valve (right). Diagnostic reliability begins with a controlled and repeatable valve–actuator interface. 3D engineering views: Batu Valve.

Give existing systems valve context

A torque curve without configuration is an orphaned signal. The supplier should provide a machine-readable, serial-linked record of valve identity, design, materials, seat and cavity behaviour, torque basis, actuator and mounting-kit identifiers, tests, maintenance instructions and revision history. ISO 14224, PA-DIM and the Asset Administration Shell provide relevant lifecycle and semantic structures[5, 21, 22], while machine-interpretable valve specifications are now being demonstrated[20]. The supplier need not build every architecture; clean source data, explicit units and a mapping guide are the practical starting point.

Use an evidence ladder, add an AI copilot

Implementation should begin with identity, configuration, FAT results and transparent trends[6, 7]; established stiction methods remain useful for modulating duties[30, 31]. Few-shot and time-series foundation models may help where failure labels are sparse, but larger models do not automatically beat simpler methods[34-36]. Valve-specific deep learning still depends on representative operating states[32, 33], so fleet learning must compare like-for-like assets and report uncertainty, false alarms and drift.

The near-term architecture separates detection from language assistance: a rules or time-series engine flags deviation, while a retrieval-grounded copilot links it to the VDRP, drawings, baselines, manuals and work orders and drafts a source-cited action[37-40]. It must expose uncertainty and never directly change a valve command, proof-test interval or safety function; deployment remains governed by OT-security requirements[9, 10].

Put readiness into the EPC workflow

During FEED, the owner should classify valves by consequence, accessibility, duty and maintenance decision. Datasheets or

Table 3. A procurement-ready responsibility boundary: every claim is paired with an owner and acceptance evidence.

Lifecycle actor	Owns	Acceptance evidence	Does not imply
Valve manufacturer	Pressure integrity, load path, observable interfaces, as-built record, FAT baseline	Qualified drawings; interface tolerances; serial-linked baseline files	Warranty of an owner-selected sensor or algorithm
Actuator / instrument supplier	Measurement performance, calibration, enclosure and hazardous-area compliance	Calibration and device certificates; diagnostic parameter list	Knowledge of the valve's internal failure physics
System integrator	Signal conditioning, time alignment, tag mapping, historian and data-quality rules	Loop / integration tests; timestamp and tag verification	Authority to alter valve qualification or safety requirements
Analytics provider	Feature logic, model validation, uncertainty, drift and version control	Validation set; false-alarm / missed-detection report; model record	Autonomous maintenance or safety decisions
Asset owner / operator	Use case, OT security, process context, labels, inspections and maintenance decisions	Commissioning baseline; work-order feedback; governance approvals	Delegation of operational accountability to AI



Figure 4. Ball valves installed within a packaged gas pressure-reduction and regulation skid. Such installations illustrate how the proposed VDRP could relate valve identity and available actuator data to pressure, operating duty and maintenance context, supporting more traceable condition assessment. Photo courtesy of Batu Valve.

material requisitions can specify baseline content, event resolution, context fields, optional provisions, data format and VDRP deliverables. Bid evaluation should ask which failure modes are observable, what can confound an indicator and what confirmation is required. Lifecycle-linked product-information research supports this approach[47]. FAT preserves the healthy signature; commissioning adds the installed reference; maintenance archives and resets the baseline; inspection and work-order outcomes close the feedback loop.

Clear division of responsibility

AI readiness is credible only when each deliverable has an owner and an acceptance record. The mechanical supplier should enable trustworthy observation, but should not inherit unbounded responsibility for third-party sensing, communications or analytics. If the manufacturer supplies a complete actuated package, its interface testing and baseline documentation expand accordingly. For a bare valve, diagnostics readiness should mean controlled interfaces, as-built metadata and optional purchaser-specified provisions - not a promise to diagnose the asset or supply an autonomous system.

Conclusion

The industrial gap lies between valve failure physics, signals, configuration, context and maintenance outcome. A traceable VDRP can close part of it through controlled interfaces, machine-readable identity, accepted baselines and a failure-mode-to-evidence matrix. Owners and EPC contractors can then connect selected critical ball valves to APM, digital twins, time-series models or maintenance copilots without turning the valve into an autonomous electronic product. The future-ready valve is observable, identifiable, comparable and evidentially traceable.

References available on request. ■

About Batu Valve Türkiye

Batu Valve Türkiye designs and manufactures industrial and pipeline ball valves. The company evaluates emerging technologies for valve monitoring and lifecycle maintenance. Where specified, its valves can be engineered with project-specific interfaces, monitoring provisions, documentation and digital baselines to support integration with third-party IIoT and predictive-maintenance systems.