

Data-Driven Intelligent Monitoring and Evaluation: A Multi-Industry Application Study

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Abstract: The growing complexity of modern engineering and management systems has made traditional monitoring and evaluation approaches increasingly inadequate. This chapter establishes a theoretical framework for data-driven intelligent monitoring and evaluation by examining how online monitoring, degradation assessment, and efficiency evaluation have evolved across industrial, transportation, healthcare, and management contexts. Rather than assuming a linear progression from diagnosis to prediction, the discussion acknowledges that methodological transfer across domains remains uneven and context-dependent. Existing studies often emphasize algorithmic performance while paying limited attention to data quality, sensor reliability, and institutional constraints. Considering these limitations, the chapter proposes a four-layer framework, monitoring, evaluation, prediction, and optimization, as a tentative organizing logic rather than a fixed prescription. Further research is needed to test whether such a framework can be generalized without losing sensitivity to domain-specific conditions.

Keywords: Data-Driven Monitoring; Performance Degradation; Intelligent Evaluation; Multi-Industry Comparison; Theoretical Framework;

1. Introduction

The growing complexity of modern engineering and management systems has made traditional monitoring and evaluation approaches increasingly inadequate. This chapter establishes a theoretical framework for data-driven intelligent monitoring and evaluation by examining how online monitoring, degradation assessment, and efficiency evaluation have evolved across industrial, transportation, healthcare, and management contexts. Rather than assuming a linear progression from diagnosis to prediction, the discussion acknowledges that methodological transfer across domains remains uneven and context-dependent. Existing studies often emphasize algorithmic performance while paying limited attention to data quality, sensor reliability, and institutional constraints. Considering these limitations, the chapter proposes a four-layer framework, monitoring, evaluation, prediction, and optimization, as a tentative organizing logic rather than a fixed prescription. Further research is needed to test whether such a framework can be generalized without losing sensitivity to domain-specific conditions.

The emergence of data-driven monitoring as a distinct research area can be traced to several converging developments. On the engineering side, the increasing availability of low-cost sensors and embedded computing has made continuous state observation feasible in settings where periodic inspection was once the norm. In automotive-grade radio frequency power amplifiers, endurance aging introduces gradual performance degradation that may not be captured by conventional end-of-line testing, and online monitoring has been proposed as a possible remedy ^[1]. Similar concerns appear in V2X on-board terminals, where

receiving sensitivity must be validated under multiple working conditions rather than a single nominal configuration [2]. These engineering efforts share a common assumption: that continuous data streams contain information about system health that discrete testing cannot provide. Whether this assumption holds across all operating regimes is, however, an open question.

On the management side, the rise of digital platforms has generated new forms of operational data that can be used for efficiency evaluation. Industry-university-research collaborative innovation platforms, for example, produce data on achievement transformation that may be used to assess platform performance [3], while enterprise service platforms generate operational data that can support efficiency evaluation [4]. The methodological challenge here is different from that in engineering: data are often self-reported, definitions of efficiency vary across stakeholders, and causal inference is difficult because platforms evolve alongside the environments they operate in. These differences suggest that a single monitoring framework, however elegant, may not travel well across domains without substantial adaptation.

The framework proposed in this chapter is therefore deliberately modest. It does not claim that monitoring, evaluation, prediction, and optimization form a universal sequence; rather, it suggests that these four layers represent recurring concerns that appear, in different forms, across the domains reviewed in this paper. The monitoring layer concerns the acquisition and validation of state information. The evaluation layer concerns the translation of state information into judgments about performance or health. The prediction layer concerns the extrapolation of current trends into future states, often with explicit uncertainty. The optimization layer concerns the use of these judgments and predictions to inform decisions. In practice, these layers overlap, and their boundaries are not always clear.

One difficulty encountered in constructing this framework was the temptation to treat it as a taxonomy into which every study could be neatly placed. Several studies resisted such placement. Research on multi-sensor fusion in intelligent pet collars, for example, combines monitoring, recognition, and control in a single embedded system [5], while work on dog bark recognition based on Mel-frequency cepstral coefficients and lightweight neural networks blurs the line between monitoring and prediction [6]. Rather than forcing these studies into separate layers, the framework treats them as instances where multiple layers are active simultaneously. This adjustment was not anticipated at the outset and reflects a broader lesson: theoretical frameworks in data-driven research are often more useful as diagnostic tools than as classification schemes.

Another difficulty concerned the treatment of uncertainty. Engineering studies often report performance metrics with confidence intervals, while management studies frequently rely on qualitative evidence and case-based reasoning. Comparing these evidence types directly is problematic, and the chapter does not attempt to do so. Instead, it treats uncertainty as a cross-cutting concern that manifests differently in different domains. In engineering, uncertainty may be aleatoric, arising from sensor noise or environmental variation; in management, it may be epistemic, arising from incomplete understanding of organizational behavior. Recognizing this distinction may help future research avoid the error of applying engineering-style uncertainty quantification to problems where it is not appropriate.

The chapter also reflects on the limitations of the multi-industry comparative approach adopted in this paper. Comparing monitoring practices across engineering, management, and healthcare risks superficiality, as the institutional, regulatory, and cultural contexts differ substantially. To some extent, this risk is unavoidable. The justification for comparison is not that the domains are identical but that they face structurally similar problems: how to acquire reliable data, how to evaluate performance under uncertainty, how to predict future states, and how to use predictions to inform decisions. Whether these structural similarities are deep enough to support meaningful cross-domain learning remains to be seen, and further research is needed to test this possibility.

2. Online Monitoring and Performance Degradation Evaluation Methods

This chapter examines online monitoring and performance degradation evaluation across several technically demanding domains, including automotive-grade RF power amplifiers, polymer lithium-ion batteries in wearable devices, semiconductor manufacturing systems, and laminated automotive windshield glass. The central concern is not merely whether degradation can be detected, but how detection methods behave under endurance aging, thermal stress, multi-physics coupling, and real-time

computational constraints. Research on RF power amplifier aging suggests that online monitoring can capture early-stage degradation, yet the sensitivity of such methods may vary with operating conditions and measurement noise ^[1]. Similarly, battery thermal runaway warning systems and semiconductor remaining useful life prediction models demonstrate the value of multi-task learning and cloud-native architectures, although their reliance on historical data raises questions about transferability ^{[8][9]}. In the case of automotive glass, geometric curvature inspection and thermo-mechano-electromagnetic coupling analysis reveal that manufacturing tolerance coordination remains a persistent challenge ^[10]. These findings are interpreted with caution, as different data sources and experimental setups may introduce biases that are not always fully acknowledged.

The methodological landscape of online monitoring is more fragmented than it first appears. In the case of automotive-grade RF power amplifiers, the challenge is not simply to detect degradation but to distinguish it from normal parameter drift caused by temperature, supply voltage variation, and load mismatch. The online monitoring method proposed in recent work addresses this by tracking multiple performance indicators over time and applying degradation evaluation criteria that are calibrated to endurance aging ^[1]. One limitation of this approach is that calibration requires prior knowledge of aging behavior, which may not be available for new device generations. This limitation is not unique to RF amplifiers; similar issues arise in battery health monitoring, where degradation trajectories depend on usage patterns that are difficult to anticipate.

Polymer lithium-ion batteries in wearable pet devices present a different set of challenges. Thermal runaway is a rare but potentially catastrophic event, and early warning systems must balance sensitivity against false alarm rates. A safety management system that integrates thermal monitoring with warning logic has been proposed ^[8], but the study does not fully specify how warning thresholds were determined or how they might transfer to other battery chemistries. This is a common limitation in safety-critical monitoring research: the consequences of false negatives are severe, yet the evidence base for threshold selection is often thin. Further research is needed to establish whether data-driven threshold adaptation can improve warning reliability without introducing unacceptable complexity.

Semiconductor manufacturing systems offer a contrasting case, where the monitoring problem is complicated by high-dimensional data, rapid process changes, and the need for real-time decisions. A cloud-native lakehouse architecture for real-time semiconductor analytics has been proposed, emphasizing the balance among performance, cost, and energy efficiency ^[9]. This work is notable for treating architectural concerns as first-class research questions rather than implementation details. However, the evaluation is based on a specific deployment context, and it is unclear how well the architecture would generalize to fabs with different data volumes or latency requirements. The risk here is negative transfer: if the tasks are not sufficiently related, joint training may degrade performance rather than improve it.

Automotive laminated windshield glass introduces yet another dimension, namely the coupling of geometric, thermal, mechanical, and electromagnetic properties. A multi-point geometric curvature inspection framework with unified-datum decoupling, region-aware adaptive NSGA-II layout, and closed-loop mold compensation has been proposed ^[10]. The complexity of this framework reflects the difficulty of achieving dimensional consistency in large-size laminated glass, where small deviations can accumulate during lamination. These studies are methodologically ambitious, but the reliance on simulation and controlled experiments raises questions about performance in mass production environments, where variability is higher and feedback loops are longer. Accelerated tests are useful but may not perfectly reproduce field conditions, and the extrapolation from laboratory to service life involves assumptions that are not always made explicit.

Comparing these domains, several common threads emerge. First, degradation is rarely a single-variable phenomenon; it typically involves interactions among multiple physical or operational factors. Second, monitoring methods are only as good as the data they rely on, and data quality issues, missing values, sensor drift, labeling errors—are pervasive. Third, the choice of evaluation metrics shapes what is detected and what is missed, and metric selection is often driven by practical considerations rather than theoretical ones. These threads suggest that degradation evaluation is not a purely technical problem but a socio-technical one, in which measurement infrastructure, maintenance practices, and organizational priorities all play a role.

One methodological difficulty encountered in reviewing these studies was the inconsistency of reporting practices. Some studies report extensive validation results, while others provide only illustrative examples. Some discuss limitations candidly, while others

do not. This inconsistency makes it difficult to compare methods on a common basis and may lead to overconfidence in methods that have been tested in narrow conditions. A possible remedy is the development of reporting standards for degradation evaluation studies, analogous to those in clinical research. Whether such standards would be adopted, and whether they would improve practice, is an open question. Further research is needed to explore this possibility.

3. Multi-Sensor Fusion and Intelligent Recognition Methods

Multi-sensor fusion and intelligent recognition have become increasingly important in edge scenarios where computational resources are limited and environmental conditions are unpredictable. This chapter explores several representative applications, including dog bark recognition based on Mel-frequency cepstral coefficients and lightweight neural networks, multi-sensor fusion in intelligent pet anti-barking collars, multi-agent deep reinforcement learning for shared e-mobility fleet rebalancing, and real-time collaborative programming environments. One observation that emerges is that lightweight models can achieve acceptable recognition accuracy, but their performance may degrade when sensor placement, background noise, or device heterogeneity changes ^[6]. In shared mobility, multi-agent reinforcement learning offers a promising approach to fleet rebalancing, yet the gap between simulated environments and real-world traffic dynamics remains a concern ^{[12][13]}. Collaborative programming environments, meanwhile, illustrate how real-time interaction data can support monitoring, although the relationship between monitoring granularity and user privacy is not straightforward ^[14]. These cases suggest that multi-sensor fusion is not simply a technical aggregation problem; it also involves trade-offs among accuracy, latency, energy consumption, and user acceptance.

The case of dog bark recognition illustrates both the promise and the fragility of lightweight approaches. An algorithm based on Mel-frequency cepstral coefficients and a lightweight neural network has been proposed, motivated by the need to run recognition on embedded devices with limited memory and power ^[6]. The method achieves reasonable accuracy on the reported dataset, but the dataset composition is not fully described, and it is unclear how the method would perform on breeds or acoustic environments not represented in training. This is a familiar problem in applied machine learning: performance on benchmark data may not predict performance in deployment. The study acknowledges this limitation, though the discussion of mitigation strategies is brief.

Intelligent pet anti-barking collars provide a concrete setting in which recognition and control are tightly coupled. A control system based on multi-sensor fusion has been described, integrating acoustic, motion, and possibly physiological signals to distinguish barking from other vocalizations and to trigger a corrective response ^[5]. The system-level perspective is valuable, but the study does not fully address the ethical dimensions of automated corrective devices, including the potential for stress or discomfort. These concerns are not merely externalities; they may affect user acceptance and, consequently, the practical viability of the technology. A more explicit treatment of ethical and welfare considerations would strengthen future work in this area.

Shared e-mobility fleet rebalancing presents a different kind of recognition problem, namely the recognition of demand patterns and the coordination of multiple agents. A multi-agent deep reinforcement learning approach to fleet rebalancing has been proposed, building on earlier work that applied deep reinforcement learning to expanding EV sharing systems ^{[12][13]}. The methodological progression is notable, moving from single-agent to multi-agent formulations. However, the evaluation is primarily simulation-based, and the transferability of learned policies to real systems is uncertain. Simulation environments inevitably simplify reality, and the simplifications may be consequential: for example, if demand is modeled as a stationary process but actual demand is non-stationary, learned policies may perform poorly. The studies acknowledge some of these issues, but a systematic treatment of sim-to-real transfer remains a topic for further research.

Real-time collaborative programming environments offer a contrasting application in which monitoring is directed at human activity rather than physical systems. A collaborative programming environment for lightweight IDEs has been described, emphasizing real-time interaction and shared editing ^[14]. Monitoring in this context might involve tracking edit patterns, detecting conflicts, or assessing team productivity. Each of these monitoring tasks raises privacy and surveillance concerns, particularly in workplace settings. The study does not focus on these concerns, but they are relevant to any attempt to deploy monitoring in collaborative environments. This leads us to further thinking about the relationship between monitoring and autonomy: the more granular the monitoring, the greater the potential for insight, but also the greater the potential for intrusion.

Across these applications, a recurring tension appears between model complexity and deployment constraints. Lightweight models are attractive for edge deployment, but they may sacrifice accuracy. Complex models may achieve higher accuracy, but they may be impractical for real-time use. The choice is not purely technical; it depends on the relative costs of different error types, which vary by application. In dog bark recognition, a false negative may be tolerable, while in anti-barking control, a false positive may cause unnecessary correction. In fleet rebalancing, a suboptimal policy may increase operating costs, while in collaborative programming, excessive monitoring may reduce user trust. These considerations suggest that evaluation should be application-specific rather than based on generic accuracy metrics.

Another observation is that multi-sensor fusion is often presented as a solution to robustness problems, but fusion can also introduce new failure modes. If one sensor is biased, the fused estimate may be biased in ways that are difficult to detect. If sensors are correlated, fusion may provide less benefit than expected. If fusion logic is complex, it may be difficult to diagnose when something goes wrong. These issues are not always addressed in the literature, and further research is needed to develop fusion methods that are not only accurate but also transparent and diagnosable. Whether such methods are feasible in resource-constrained edge settings is an open question.

4. Digital Platforms, Standard Systems, and Efficiency Evaluation

This chapter shifts attention to digital platforms, standard systems, and efficiency evaluation in enterprise and service contexts. It considers online-offline integrated operation models, private domain traffic management for physical stores, ERP and WMS integration for inventory turnover efficiency, cross-industry data integration standards, enterprise management informatization architectures, and the construction of smart wellness models integrating traditional Chinese medicine standards with digital systems. A recurring theme is that digitalization does not automatically produce efficiency gains; rather, outcomes depend on how standards are designed, how data flows across organizational boundaries, and how platform governance is structured ^{[16][17]}. Studies on industry-university-research collaborative innovation platforms suggest that achievement transformation efficiency is influenced by factors beyond technology, including incentive mechanisms and institutional trust ^[3]. The chapter also notes that efficiency evaluation itself is not neutral, as indicator selection can shape organizational behavior in unintended ways ^[18]. Considering these complexities, the discussion avoids treating digital platforms as uniform solutions and instead highlights the need for context-sensitive evaluation frameworks.

The literature on online-offline integrated operation models in the comprehensive service industry provides a useful starting point. An analysis of how digital integration reshapes service delivery has emphasized the coordination of online and offline channels ^[16]. The analysis is primarily qualitative, drawing on case evidence rather than large-scale quantitative data. This methodological choice is understandable given the heterogeneity of service industries, but it limits the generalizability of the findings. A complementary study examines digital operation and management models for private domain traffic in physical stores, highlighting the importance of customer relationship management and data analytics ^[17]. The concept of private domain traffic is relatively new, and its long-term sustainability is uncertain; platform policies, consumer behavior, and regulatory frameworks may all change in ways that affect its viability. Further research is needed to assess whether private domain strategies offer durable advantages or temporary arbitrage.

The case of ERP and WMS integration is more established. A study has examined how seamless integration of ERP and WMS can enhance corporate inventory turnover efficiency, arguing that data consistency across systems reduces delays and errors ^[18]. The argument is plausible, but the evidence is based on a limited number of cases, and the causal direction is not fully established: firms that integrate ERP and WMS may differ systematically from firms that do not, and these differences may confound the relationship between integration and efficiency. A related study addresses technical standard development for cross-industry data integration in enterprise-level ERP systems ^[19]. Standard development is a slow, consensus-based process, and the study provides useful insights into the challenges involved. However, standards are not self-enforcing, and adoption depends on incentives that vary across firms and industries. A third study examines compliance and cross-border transfer technology for customer data in

financial CRM systems, highlighting the tension between data utility and regulatory constraints ^[20]. This tension is likely to persist, and technical solutions alone may not resolve it.

Enterprise management informatization provides a broader framing. A full-domain architecture system for enterprise management informatization under the digital economy has been proposed, emphasizing integration across functional domains ^[21]. The architecture is ambitious, but its implementation requires substantial organizational change, and the study does not fully address the change management challenges involved. A companion study analyzes the “standard plus system” dual-drive model, arguing that standards and systems reinforce each other ^[22]. The model is appealing, but it may work better in some organizational cultures than others, and the conditions for success are not fully specified. A third study examines the transformation mechanism of enterprise informatization technical achievements from the perspective of industry-university-research-user integration ^[23]. The multi-stakeholder perspective is valuable, but the study relies on a limited number of cases, and the findings may not generalize.

The integration of traditional Chinese medicine standards with digital systems offers a distinctive case. A multicenter observational study examines standardized traditional Chinese medicine external therapy for chronic soft tissue pain ^[24], while a related study addresses the construction and application of a standard system for traditional external therapy in health preservation ^[25]. A smart wellness model integrating traditional Chinese medicine health preservation industry standards and digital systems has also been proposed ^[26]. These studies are notable for attempting to bridge traditional medical practice and modern digital infrastructure. The challenge is that traditional Chinese medicine concepts do not always map cleanly onto digital data models, and standardization may inadvertently reduce the flexibility that characterizes traditional practice. Whether digital systems can support rather than constrain traditional medicine is an open question, and further research is needed to explore this tension.

Comparing these cases, several themes emerge. First, digital platforms are not neutral infrastructure; they embody assumptions about how work should be organized and how value should be measured. Second, standards are essential for interoperability but may also entrench particular interests and exclude alternatives. Third, efficiency evaluation is performative: what is measured tends to be what is managed, and what is managed tends to become what matters. These themes suggest that the study of digital platforms and standard systems requires not only technical expertise but also institutional and ethical analysis. A purely technical approach may miss important aspects of how platforms function in practice.

One difficulty encountered in reviewing this literature was the variability in evidence quality. Some studies provide detailed case evidence, while others rely on conceptual arguments. Some discuss limitations, while others do not. This variability makes it difficult to draw firm conclusions about what works and what does not. A possible response is to treat the literature as a source of hypotheses rather than conclusions, and to design future research that tests these hypotheses more rigorously. Whether such research is feasible, given the complexity of the phenomena involved, is uncertain. Further research is needed to develop methods that are both rigorous and context-sensitive.

5. Safety Warning, Compliance Management, and Comprehensive Evaluation

The final chapter turns toward safety warning, compliance management, and comprehensive evaluation, not as a separate domain but as a lens through which the monitoring, evaluation, prediction, and optimization concerns developed in earlier chapters may be reconsidered in light of regulatory, ethical, and clinical realities; it asks how the data-driven methods discussed for engineering systems, digital platforms, and healthcare interventions might be governed when the consequences of error are unevenly distributed and when the criteria for success are contested rather than agreed upon, and it reflects on the difficulty of comparing safety across domains where one system's failure may be measured in equipment downtime while another's may be measured in patient harm, a disparity that makes any unified evaluation framework attractive in theory yet problematic in practice; rather than proposing such a framework, the chapter suggests that cross-domain learning may be possible only if concepts are translated with care and if the limitations of current evidence, including small sample sizes, short follow-up periods, and the difficulty of isolating intervention effects from contextual factors, are acknowledged rather than smoothed over, and it looks toward future research that might combine longitudinal designs, broader and more heterogeneous datasets, and greater attention to implementation contexts, so that the question of how data-driven systems can be governed responsibly across heterogeneous domains becomes not a concluding remark but an opening for further inquiry.

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Conflicts of Interest

The author(s) declare no conflicts of interest.

Ethical Approval and Consent to Participate

Not applicable.

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