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First Pass Yield and Defect-Driver Analysis in Distributed Operations; A Conceptual Framework for Controllable-Variable Isolation

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Abstract

First Pass Yield (FPY) is among the most widely reported operational quality metrics, yet its interpretation degrades once delivery is distributed across sites, shifts, contractors, or jurisdictions. Observed dispersion then reflects structural endowments, contextual exposures, measurement artifacts, and managerial practice at once, and conventional benchmarking treats the mixture as a single signal, producing misattributed accountability and improvement programmes aimed at variables no local manager can move.

The paper develops the Controllable-Variable Isolation (CVI) framework, separating the portion of FPY variation actionable at a defined organizational level from the portion that is not. It proceeds through four stages: normalization across heterogeneous sites, variance decomposition and driver attribution, controllability gating through a three-test screen, and prioritization by expected yield elasticity per unit of implementation cost. Two constructs anchor it: a five-dimension controllability score built from authority, latency, cost, reversibility, and observability; and a level-shifting rule reassigning high-leverage but locally uncontrollable drivers to the level where authority resides.

The framework is synthesized from conceptual and review scholarship across ten streams, spanning lean process improvement, multi-site performance management, procurement and supplier governance, reliability engineering, safety analytics, audit and measurement integrity, predictive decision support, service and IT operations, regulated health and aviation delivery, and asset-intensive infrastructure. Eight propositions are stated and an illustrative multi-site application is worked through. CVI is a discipline for establishing whether a defect driver can be acted upon before it is assigned to someone to act upon.

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Introduction

First Pass Yield measures the proportion of units clearing a process step correctly on the first attempt, without rework, retest, or reprocessing. It is a single intuitive number, sensitive to problems that cost and throughput metrics conceal, and mapped directly onto the rework loops that consume capacity while producing nothing new. That sensitivity is why it anchors much of the lean and Six Sigma literature, where defect reduction is a primary lever of operational performance (Ambali *et al*., 2021; Ezeugwa *et al*., 2023a; Ike *et al*., 2022).

It works well in a single facility with one product family, one measurement standard, and one management chain, and less well where delivery is distributed across sites differing in equipment vintage, labour market, supplier base, mix, and local interpretation of what counts as a first pass failure. Multi-site research establishes that indicators are comparable only once heterogeneity is accounted for (Akin-Oluyomi & Akhigbe, 2022, 2023a), and that capability is unevenly distributed in ways conditioning what any site can achieve (Falemi *et al*., 2020, 2023b).

The resulting pattern is familiar. A review displays FPY by site; one sits at 96 percent and another at 88; the low performer is asked for a plan populated with whatever the leader does. Some actions are irrelevant, the leader's advantage having come from newer equipment or tighter incoming material (Akinleye & Adeyoyin, 2022a; Okonkwo *et al*., 2023). Some are relevant but sit outside local authority, with central sourcing, corporate engineering, or capital allocation (Akinleye & Adeyoyin, 2022b; Okonkwo *et al*., 2021). Some are relevant and controllable, but are buried in the same list and weighted no differently.

The failure is not analytical sophistication; networks increasingly deploy statistical process control, root-cause protocols, and predictive models ranking defect precursors (Adelanwa *et al*., 2023a; Mayo *et al*., 2021). The failure is the missing step between attribution and action. Attribution answers what is associated with defects; action requires knowing what someone can change, at which level, at what cost, and how soon. Most analyses stop there and let the action question resolve informally, which means it resolves according to whoever is in the room. Safety scholarship makes the parallel argument, showing interventions fail when aimed at a level not holding the relevant control (Arumosoye & Obriki, 2020; Obogo *et al*., 2022; Obriki & Arumosoye, 2020).

This paper proposes Controllable-Variable Isolation to close that gap. Defect-driver analysis in distributed operations should be organized around a controllability partition rather than a defect taxonomy: defects are traced to drivers, drivers classified as structural, contextual, or controllable, and controllable drivers screened for whether authority sits at the level being asked to act. Only what survives belongs in an improvement portfolio; what fails on authority grounds is escalated with its evidence rather than discarded.

The paper makes four contributions: it formalizes the decomposition of FPY variation and defines the isolated controllable share as the quantity improvement should target; it develops a controllability construct with five measurable dimensions; it introduces the level-shifting rule for high-leverage drivers no local unit can move; and it integrates literatures that rarely meet.

Methodology

Approach and Corpus

This study is conceptual and theory-building rather than empirical: its object is to construct an analytical framework, not to test one, and its method is integrative literature synthesis followed by deductive derivation. That design suits a phenomenon documented in fragments across literatures but never assembled into a coherent construct. It permits integration of evidence from domains that do not cite one another, and it cannot establish causal claims; the propositions set out below are therefore testable conjectures rather than findings. The study proceeds through corpus construction, thematic coding, cross-stream synthesis, and framework derivation, with two further subsections specifying the separate empirical methodology for operating the framework.

The evidence base was assembled from a consolidated multi-portfolio reference corpus spanning procurement and supply chain management, occupational safety and health, reliability and maintenance engineering, semiconductor and advanced manufacturing, healthcare infrastructure and clinical operations, pharmaceutical and regulated manufacturing, aviation safety oversight, energy and utility infrastructure, enterprise IT service delivery and security, workforce development, financial and predictive analytics, and project governance. Four inclusion criteria applied. The work had to address a driver of operational outcome variation; concern settings with more than one operating unit, contractor, or jurisdiction, since single-site work cannot speak to the comparability problem; be conceptual, review-based, or framework-oriented, consistent with the theory-building aim; and permit an inference about who controls the driver it describes, since that inference is the raw material of the controllability partition.

Works were excluded where the driver was purely technical with no organizational locus of control, where the setting was a single undifferentiated unit, or where the contribution was descriptive without an articulated mechanism. The resulting corpus comprises 185 sources across forty-one subject clusters, published between 2019 and 2023, deliberately uneven in distribution: procurement, safety, workforce, reliability, and asset-intensive infrastructure are weighted heavily as the dominant driver classes, while technology law, model governance, and skills development are drawn on narrowly, for the specific constraint and measurement-integrity arguments they contribute.

Coding and Synthesis

Each source was coded on three dimensions: driver class, recording whether the work addresses a structural, contextual, or controllable determinant; locus of control, recording the level at which the work locates authority, from supervisor through site, network function, and enterprise governance to external regulator; and evidentiary form, distinguishing conceptual models, reviews, and framework proposals. The second dimension proved the most consequential and most difficult, since many sources describe a driver without stating who can change it, and the locus had to be inferred from the intervention proposed. Where inference was not defensible, the source was retained for its driver contribution but not used to support any controllability claim, a limitation acknowledged below.

Coded sources were grouped into the ten thematic streams presented below. Synthesis proceeded by identifying, for each stream, the treatment of controllability it implies but does not state, then testing whether those implicit treatments are mutually consistent. They are not, and the inconsistency is the paper's point of departure: lean scholarship presumes an actor with authority to intervene, procurement research documents drivers the affected unit cannot set, and safety research alone treats locus of control as an explicit variable.

Derivation followed a deductive sequence. The variance decomposition was specified first, since it defines the quantity to be partitioned; the four-stage procedure was constructed as the path from observation to that partition; the controllability construct was derived by asking what properties determine whether a lever can be pulled; and the level-shifting rule followed as the consequence of admitting that some high-leverage drivers fail the actionability test. Internal validity was assessed by checking each element against at least two independent streams and confirming that the framework generates falsifiable propositions.

Data and Measurement Requirements

The framework requires unit- or lot-level records linking each first pass outcome to site, work centre, product family, period, crew, equipment, and the state of candidate controllable drivers at the moment of processing. The last is the binding constraint: yield data is generally well captured, while the contemporaneous state of maintenance cadence, certification coverage, procedure version, and staffing typically is not (Aneke & Adesemoye, 2019; Nnabueze *et al*., 2021).

Cross-site measurement system analysis is a prerequisite, not a refinement. Where inspection is human-mediated, repeatability studies should precede comparison, since P5 implies undetected definitional drift corrupts the whole decomposition. Detection capability is itself variable and must be characterized before its outputs are compared (Aneke *et al*., 2023; Atta *et al*., 2021, 2022).

Estimation and Identification

Hierarchical generalized linear models with a binomial response and logit link are the natural specification, estimated with crossed random effects for site, work centre, and product family. Components should be reported with uncertainty rather than as point estimates, since estimates on modest panels are frequently imprecise.

Where driver counts are large and interactions suspected, ensemble models with feature attribution surface candidates efficiently (Adelanwa *et al*., 2023b; Mayo *et al*., 2021), but their output feeds Gate 1 as hypothesis generation, since such methods distribute predictive credit without identifying causal effect. Identification should then be strengthened where feasible, through staggered rollout supporting difference-in-differences, single-site interventions among comparable non-adopters supporting synthetic control, or designed experimentation on a subset of lines, which is usually cheaper than the programme it would validate (Tonoyan *et al*., 2022b).

Literature Synthesis

First Pass Yield and Process Improvement

FPY sits within the process quality metrics of lean and Six Sigma practice, whose core is the structured improvement cycle, adapted for organizations lacking the analytical infrastructure it assumed (Ambali *et al*., 2021; Ezeugwa *et al*., 2023a). For multi-stage processes the aggregate is rolled throughput yield:

$$RTY = \mathrm{FPY}_1 \times \mathrm{FPY}_2 \times \ldots \times \mathrm{FPY}_W$$

The multiplicative form matters. Twelve stages at 99 percent give roughly 88.6 percent rolled yield; drifting to 97 percent on three drops it to about 81 percent. Differences immaterial in isolation become large at the level executives observe, so aggregate site gaps can arise from driver differences invisible in any single stage report (Oyeleye *et al*., 2022).

Improvement durability depends on codification. Standard operating procedures have been treated as strategic assets rather than administrative overhead (Eyetsemitan *et al*., 2022); a technically sound change fails without structured validation and user acceptance (Eyetsemitan *et al*., 2023b); and change management determines whether an improvement is absorbed at all (Eyetsemitan *et al*., 2023a). Related work situates improvement within its compliance environment (Eyetsemitan *et al*., 2021), aligns stakeholders across joint ventures (Eyetsemitan *et al*., 2020), applies lean redesign to service cycle time (Oyeleye *et al*., 2022), and extends data-driven optimization across supply chains and retail (Efobi *et al*., 2022b; Ike *et al*., 2022).

Distributed Operations and Comparability

Research on distributed operations converges on one finding: sites within a network are not interchangeable and their indicators are not directly comparable. Indicator design must account for heterogeneity if comparisons are to support decisions rather than distort them (Akin-Oluyomi & Akhigbe, 2023a), and a common standard applied to dissimilar units produces uneven compliance (Akin-Oluyomi & Akhigbe, 2022).

Capability is likewise unevenly distributed. Capability building is a network-level design problem (Falemi *et al*., 2020); staffing volatility degrades the practice consistency yield depends on (Falemi *et al*., 2023b); retention is linked to operational productivity (Falemi *et al*., 2023a); and workforce behaviour combined with real-time operational data is an input to quality outcomes (Akhigbe *et al*., 2023). Supply chain leadership and analytics add the coordination layer (Akin-Oluyomi & Akhigbe, 2023b, 2023c).

Project governance research reaches the same conclusion from another direction: identical methodologies produce divergent outcomes across national and organizational contexts (Amayo *et al*., 2023a), risk and compliance frameworks must be adapted rather than transplanted (Amayo *et al*., 2023b), and team composition conditions delivery performance independently of method (Amayo *et al*., 2023c). Indicator-based accountability frameworks (Sakyi *et al*., 2022b) supply the measurement counterpart. The stream justifies scepticism toward raw cross-site comparison without supplying a procedure for adjusting it.

Supply and Supplier Variation

Much first pass failure originates upstream. Supplier variability is a primary transmission channel for downstream disruption (Agbabiaka *et al*., 2019), an argument made at network scale by resilience frameworks (Ogunwole *et al*., 2021), while materials readiness and inventory availability are linked explicitly to plant uptime (Okonkwo *et al*., 2023), the clearest statement of how a sourcing decision becomes an operational defect.

Governance of procurement conditions how much of that variation reaches the floor. Regulatory-compliant procurement in high-risk environments (Okonkwo *et al*., 2021), data-driven vendor evaluation and bid selection (Patrick *et al*., 2021), asset lifecycle management and inventory visibility (Okonkwo *et al*., 2023), contract negotiation and vendor governance as cost levers (Okonkwo *et al*., 2019), and logistics inefficiency traced to port and demurrage dynamics beyond any plant's authority (Okonkwo *et al*., 2020) establish that controllability of supplier-side drivers depends on the surrounding governance architecture.

The strategic procurement literature extends this: supplier relationship management positions the interface as a managed capability (Akinleye & Adeyoyin, 2022b; Ike *et al*., 2021); negotiation optimization treats cost and specification jointly (Akinleye & Adeyoyin, 2022a); process automation is an efficiency and transparency intervention (Akinleye & Adeyoyin, 2021); business intelligence supports manufacturing procurement optimization (Akinleye *et al*., 2023); and supplier risk assessment addresses the multi-jurisdiction case (Akin-Oluyomi *et al*., 2023b). Sustainability and resilience enter through green procurement strategy (Akin-Oluyomi *et al*., 2023a), ESG adoption evaluation (Akinleye, 2023), sustainable procurement in local manufacturing (Efobi *et al*., 2022a), and post-pandemic resilience indices (Efobi *et al*., 2023), while comparative procurement cost analyses (Akokodaripon *et al*., 2023) and procurement data visualization (Babatope *et al*., 2023) complete the picture.

Analytics-oriented work supplies driver-detection methods: predictive models for demand forecasting accuracy and inventory reduction (Aifuwa *et al*., 2020), real-time risk dashboards for hospital supply chains (Filani *et al*., 2022), end-to-end visibility for traceability (Nnabueze *et al*., 2021), ESG-integrated supplier selection (Okojie *et al*., 2020), blockchain-driven compliance reporting (Abioye *et al*., 2023), revenue assurance analytics (Sakyi *et al*., 2023), customer service analytics as an operational driver (Sakyi *et al*., 2022a), and data-driven operations management aimed directly at performance improvement (Efobi *et al*., 2021). Related work extends the same reasoning to large-scale service organizations (Nnabueze *et al*., 2023) and to emissions and infrastructure monitoring (Okojie *et al*., 2023).

Equipment State and Reliability

Equipment condition is a driver whose controllability varies sharply by horizon. Integrity management and corrosion risk assessment convert degradation from an unobserved cause into a measured one (Atta *et al*., 2020), and the shift from reactive to predictive regimes is organizational as much as technical (Sunday *et al*., 2020). Vibration-based monitoring (Omoegun *et al*., 2023) and sensor-based fault detection (Sunday & Omoegun, 2022) supply the instrumentation layer, while welding inspection (Atta *et al*., 2022) and non-destructive testing (Atta *et al*., 2021) establish that detection of first pass failure is itself a designed capability with its own error characteristics. The semiconductor literature addresses yield most explicitly, where reliability engineering and failure analysis supply the general method for isolating a mechanism before designating it a cause (Gideon *et al*., 2019).

Automation and facility design introduce their own drivers. Machine design and performance evaluation research decomposes measured performance into design and operating factors (Bello *et al*., 2022), while facility research links building information modelling to project performance (Uduokhai *et al*., 2023a), analytical framing to infrastructure delivery efficiency (Nwafor *et al*., 2019b), and site-level environmental exposure to conditions operating units cannot alter (Nwafor *et al*., 2019a).

Human Factors and Safety Analytics

Safety scholarship offers the most developed treatment of causation across organizational levels, and its logic transfers to quality. Error arises from the interaction of task design, supervision, and condition rather than individual carelessness (Obriki & Arumosoye, 2020), and a behaviour returning after correction is usually reproduced by a condition the correction did not address (Obriki & Arumosoye, 2022), an argument applying equally to a defect mode recurring after corrective action.

Leading-indicator research supplies the measurement analogue. Near-miss and hazard observation data are an underused early-warning resource (Arumosoye & Obriki, 2019; Obogo *et al*., 2021), proactive hazard identification from digital data streams is a systematic capability (Obriki & Arumosoye, 2023), and management walkthrough frequency has been linked to culture outcomes (Obriki & Arumosoye, 2019), together establishing the empirical form of the claim that observable process-side variables predict outcome-side failures.

Governance and organizational drivers are treated explicitly here, which is what makes the stream valuable for the controllability question. Contractor safety performance in multi-contract environments addresses the case where the party experiencing the outcome does not control the driver (Arumosoye & Obriki, 2020), while learning-based maturity models (Arumosoye & Obriki, 2021), safety governance models for large facility operations (Obogo *et al*., 2022), and leadership models for culture development (Obogo *et al*., 2023) locate the lever above the working level. Risk pathway models for lifting and rigging (Arumosoye & Obriki, 2022), emergency readiness models (Arumosoye & Obriki, 2023), workforce safety training for operational risk reduction (Obriki *et al*., 2022a), process safety models integrating human factors (Oduro, 2023), institutionalization of durable practice across project-based organizations (Obriki & Arumosoye, 2021), and continuous hazard monitoring (Obriki *et al*., 2023) supply the distributed case.

Human factors research in information security contributes a complementary behavioural literature. Evidence on device adoption and associated risk (Onche *et al*., 2023), authentication behaviour and compliance (Onche & Ogbonna, 2022), and behavioural studies of awareness and confidentiality (Onche *et al*., 2020) show that behavioural drivers are trainable and measurable, and therefore controllable, but only where the conditions supporting the behaviour are addressed too.

Measurement Integrity and Governance

Any framework partitioning variance depends on the integrity of its measurement. Risk-based internal control models (Akomolafe & Agu, 2019a), quantitative compliance risk models (Akomolafe *et al*., 2023b), and risk-based auditing in strategic financial management (Akomolafe *et al*., 2023a) treat the reliability of reported figures as a designed property of the control environment rather than a given, a position extended by IT general controls and audit automation (Mbonu *et al*., 2022), machine learning advances in detection (Atakpa & Abetoh, 2022), privacy-preserving data architectures for regulated analytics (Atakpa & Abolaji, 2022), and integrated governance frameworks spanning security and financial control (Fadayomi *et al*., 2021). Comparative reviews of cross-border auditing (Agu *et al*., 2023a) address the case where one nominal metric is produced under different rules, structurally identical to the multi-site FPY definition problem, while procurement risk frameworks for multinational enterprises (Bello *et al*., 2023), data-driven compliance and reporting systems (Bola-Sadipe *et al*., 2022), and continuous configuration monitoring (Aliliele *et al*., 2023a) extend the logic to operational data.

Regulated life sciences states the problem most sharply. Data integrity reviews catalogue the failure modes through which recorded values diverge from actual events (Aneke *et al*., 2023), and corrective action research finds closure routinely mistaken for cause elimination (Aneke *et al*., 2022a), a distinction mapping onto the difference between attributing a driver and controlling it. Public sector accounting reaches the same conclusion from the audit side, through audit liaison and control compliance in multinational organizations (Ebhojie *et al*., 2023a) and reconciliation control and workflow redesign (Dogbatsey *et al*., 2019). Risk-based internal compliance models (Aneke & Adesemoye, 2021), traceability and chain-of-custody models (Aneke & Adesemoye, 2019), regulatory readiness maturity models (Eze *et al*., 2022b), early warning systems for supply interruption (Eze *et al*., 2022a), quality failure analysis (Aneke *et al*., 2022b), and supply chain governance for essential medicines (Eze *et al*., 2023) describe a quality system in which measurement, control, and authority are aligned, which is what CVI generalizes.

Financial analytics contributes the variance tradition. Predictive budgeting on operational signals (Adesuyi *et al*., 2022), data-led cost governance (Adesuyi *et al*., 2023; Oduleye & Medon, 2021), automated consolidation and transparency (Bola-Sadipe *et al*., 2023; Medon & Oduleye, 2022), behavioural financial analytics (Lawal & Oduleye, 2023b), alignment of planning analytics with strategy (Lawal & Oduleye, 2021b; Medon & Oduleye, 2023), capital allocation decision models (Lawal & Oduleye, 2021a), decision analytics for sustained profitability (Lawal & Oduleye, 2023a), measurement of the strategic impact of financial analysis (Oduleye & Medon, 2023b), tiered treasury consolidation across jurisdictions (Dada *et al*., 2021a), cross-border strategic finance structures (Isiekwu *et al*., 2021), portfolio risk optimization (Eboh & Aliliele, 2023), and anomaly detection in operational time series (Atakpa & Fobellah, 2023; Elebe *et al*., 2023) together supply the apparatus through which decomposed variance becomes managerial decision. Model governance addresses the newest layer, through physics-informed detection in operational technology (Ojukwu *et al*., 2023), model risk management (Ominyi & Anichukwueze, 2023), and cross-regime compliance harmonization (Ominyi & Anichukwueze, 2022a), while operational technology security research bounds what a site may change (Adebayo *et al*., 2022, 2023; Adegbite *et al*., 2020, 2022, 2023; Ahmed *et al*., 2021; Shittu *et al*., 2022) and integrated performance monitoring measures control effectiveness once bounded (Ogbole *et al*., 2021).

Attribution methods have expanded considerably: transformation models for lifecycle performance (Adelanwa *et al*., 2023a), predictive analytics for risk detection (Adelanwa *et al*., 2023b), maintenance modelling on machine learning and cloud infrastructure (Mayo *et al*., 2021), and resilient logistics frameworks integrating analytics with sensing (Anene & Clement, 2022), alongside demand forecasting under mixed drivers (Tonoyan *et al*., 2021a), predictive cash flow modelling (Tonoyan *et al*., 2021b), geospatial methods for siting decisions (Tonoyan *et al*., 2022a), algorithmic optimization combining simulation with financial impact assessment (Tonoyan *et al*., 2022b), and predictive cost optimization (Tonoyan *et al*., 2022c). These answer the attribution question with increasing power; none answers the controllability question, which is organizational rather than statistical.

Evidence From Adjacent Operating Domains

First pass yield has a direct analogue wherever work is transacted rather than fabricated, since first-contact resolution measures the same property. IT service management research establishes the operating environment (Ladapo *et al*., 2023a, 2023b), and KPI-driven optimization of service delivery portfolios (Edivri & Oteri, 2022) supplies the measurement layer. Capacity and scaling enter as controllable drivers through predictive resource scaling (Ahmed *et al*., 2020) and migration practice (Ladapo *et al*., 2022), while work on offline assessment of security-critical systems illustrates the limits on verifying first-pass outcomes (Oshoba *et al*., 2020).

Platform engineering contributes the procedural analogue of standard work: comparative evaluation of release tooling (Badmus *et al*., 2020), version control and review governance (Badmus *et al*., 2022a), and platform governance in regulated environments (Badmus *et al*., 2019b) determine whether a change reaches production correctly the first time, while audit-trail models for configuration management establish how a first-pass outcome is verified after the fact (Oshoba *et al*., 2020). Financial transaction operations supply the highest-volume case, where platforms are engineered for first-pass settlement (Osuji *et al*., 2021).

Multi-site delivery in regulated health systems reproduces the comparability problem acutely. Programme management for coordinated multi-site expansion (Aminu-Ibrahim *et al*., 2021) and lifecycle performance evaluation of purpose-built facilities (Ogbete *et al*., 2023) address network heterogeneity directly, while facility design has been linked to diagnostic performance (Aminu-Ibrahim *et al*., 2022), risk-managed construction to delivery in highly regulated settings (Ogbete *et al*., 2021), and standardised design to scaling across collection networks (Ogbete *et al*., 2022). Governance architecture for system data supplies the measurement layer (Ilodigwe & Adesemoye, 2021).

Clinical operations research addresses the driver classes directly: analytics-driven identification of workflow inefficiency (Nnaji & Akinlolu, 2023) is a process-side driver; staffing ratio optimization (Omaghomi *et al*., 2023) is a staffing driver; safety systems in high-acuity units (Fapohunda *et al*., 2023b) and infection prevention compliance (Omaghomi *et al*., 2022) are adherence drivers; multidisciplinary coordination (Ohunyon *et al*., 2023) and service-model adoption (Fapohunda *et al*., 2023a) are organizational drivers; and real-time informatics reducing decision delay (Nnaji & Akinlolu, 2022) is an instrumentation driver. Aviation safety oversight contributes the regulatory counterpart through comparative benchmarking of certification compliance (Adeyelu & Dagodzo, 2022), risk-tiered oversight models (Adeyelu, 2023), and adaptive safety management implementation (Adeyelu, 2019), while detection capability in food safety (Olorunkosebi *et al*., 2023) and population-level surveillance systems (Anioke & Atima, 2023a; Oparah *et al*., 2023) complete the stream.

Asset-intensive operations supply the clearest separation of structural constraint from controllable practice. Real-time monitoring and fault detection in substations (Shittu *et al*., 2023) is controllable at the asset owner's level, whereas device-level efficiency limits in power electronics (Adenuga, 2023) and network architecture (Adenuga, 2022) are structural on any short horizon. Energy transition research develops the distinction through interpretable failure prediction in distributed assets (Komi & Adamolekun, 2021), comparative control architectures (Komi & Adamolekun, 2022), tiered digital twins for resource-constrained settings (Komi & Adeniji, 2023), storage degradation under weak-grid conditions (Komi & Ganiu, 2022), edge intelligence for resilient control (Komi & Ganiu, 2023), and yield and load forecasting (Ezeugwa *et al*., 2023b; Komi, 2021, 2023).

Inspection and sensing determine what is observable and therefore what can be scored on the observability dimension. Integrated aerial, LiDAR, and geospatial inspection of infrastructure corridors (Dagodzo & Patrick, 2021b), pipeline corridor monitoring (Dagodzo & Patrick, 2020), geospatial asset management (Dagodzo & Patrick, 2021a), and automated vegetation classification (Dagodzo *et al*., 2022) extend detection across dispersed assets, while research on maintenance-free wireless infrastructure establishes the reliability limits of the instrumentation itself (Asiedu & Quainoo, 2023b). A driver that cannot be measured cannot be scored, and an instrument failing intermittently manufactures apparent variation in the outcome it was installed to explain.

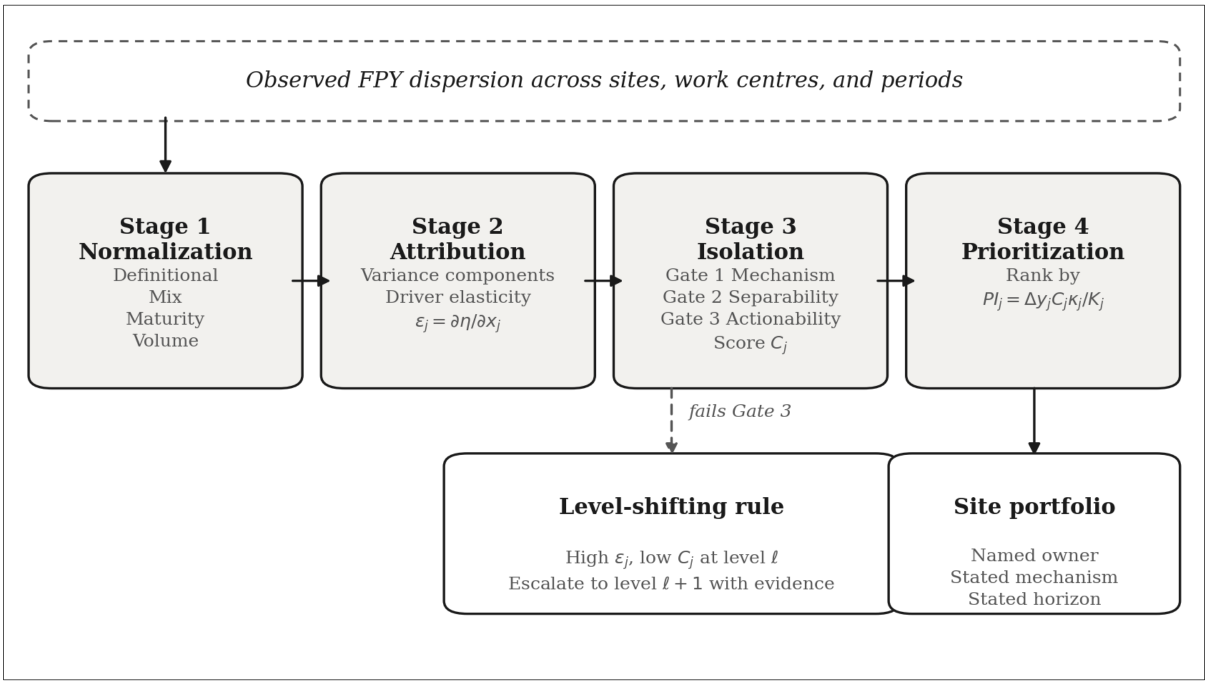
Synthesis

Ten streams converge without meeting. Lean scholarship supplies a repertoire of intervention but assumes an actor with authority to intervene; multi-site research establishes heterogeneity without a procedure for adjusting comparisons; procurement and reliability research identify the dominant driver classes but treat controllability as background; safety analytics develops multi-level causation for injury rather than yield; audit research develops measurement integrity but not variance partition; financial analytics decomposes variance for cost rather than defects; predictive modelling supplies attribution without an action filter; service and IT operations develop the first-contact analogue without a controllability partition; regulated health and aviation delivery stop at compliance; and asset-intensive infrastructure separates structural from controllable determinants cleanly, but within single asset classes rather than across a managed network.

What is missing is a framework that takes an observed FPY gap in a distributed network and returns a defensible statement of the form: this share is structural, this share contextual, this share measurement artifact, and this share controllable at a stated level, by a stated owner, within a stated horizon.

Conceptual Framework

The framework is presented in full in Figure 1. It takes observed yield dispersion as its input and returns two outputs rather than one: an improvement portfolio for the level under review, and an escalation set for the level above it. The subsections that follow specify the notation, the decomposition, and each stage in turn.



Note: Drivers move left to right through the four stages. A driver that clears Gates 1 and 2 but fails Gate 3, the actionability test, is not discarded but escalated under the level-shifting rule with the originating site's evidence attached.

Fig 1: The Controllable-Variable Isolation Framework

Notation and Definitions

Let sites be indexed by *s*, work centres by *w*, product families by *p*, and periods by *t*. With n_{swpt} units started and q_{swpt} passing on first attempt, observed yield is $y_{swpt} = q_{swpt} / n_{swpt}$, and analysis proceeds on the logit scale:

$$\eta_{swpt} = \ln [\, y_{swpt} / (1 - y_{swpt}) \,]$$

Drivers are partitioned into three vectors. Structural drivers are fixed or near-fixed properties of a site: equipment vintage and class, layout, installed automation, environmental control, and constraints imposed by regulated control systems. Contextual drivers vary but are exogenous to the operating unit: incoming material quality, mix complexity, demand volatility, labour market conditions, and the regulatory environment. Controllable drivers are levers a defined owner can set within a defined horizon: procedure currency, certification depth, maintenance cadence, calibration interval, staffing configuration, work-in-process caps, and inspection placement.

Table 1 summarises the three classes and where authority typically sits. The partition is a property of the organization at a stated level and horizon, not of nature: a supplier specification is contextual to a plant manager on a quarterly horizon and controllable to a category director on an annual one (Akin-Oluyomi *et al.*, 2023b; Akinleye & Adeyoyin, 2022b). Failing to declare level and horizon lets any driver be reclassified as whichever category suits the argument.

Table 1: The Three-Way Driver Partition With Typical Locus of Control

Driver class	Definition	Representative drivers	Typical locus of control
Structural	Fixed or near-fixed properties of the site over the improvement horizon	Equipment vintage and class, facility layout, installed automation, environmental control, control-system architecture	Enterprise engineering; capital governance
Contextual	Varies over time but is exogenous to the operating unit	Incoming material quality, product mix complexity, demand volatility, labour market conditions, regulatory regime	Network functions; external regulator
Controllable	Settable by a named owner within a stated horizon	Procedure currency, certification depth, maintenance cadence, calibration interval, staffing configuration, WIP caps, inspection placement	Site and line management

Decomposition and the Isolated Controllable Share

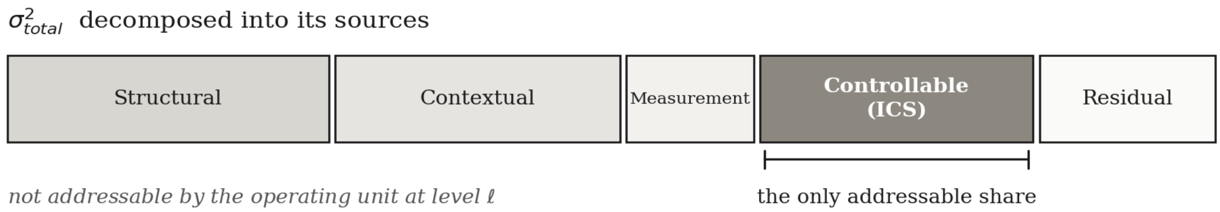
The reference model is a hierarchical specification with crossed random effects:

$$\eta_{swpt} = \mu + \alpha_s + \beta_w + \gamma_p + \delta_t + u'_s\lambda + z'_{swpt}\varphi + x'_{swpt}\theta + \varepsilon_{swpt}$$

where α_s, β_w, γ_p, and δ_t capture site, work centre, product family, and period effects, u, z, and x collect structural, contextual, and controllable drivers, and ε is residual. Total variance decomposes as $\sigma^2_{total} = \sigma^2_{structural} + \sigma^2_{contextual} + \sigma^2_{controllable} + \sigma^2_{measurement} + \sigma^2_{residual}$, giving the isolated controllable share:

$$ICS = \sigma^2_{controllable} / \sigma^2_{total}$$

This is the fraction of observed variation improvement can address, and the denominator correction distributed benchmarking omits. A network reporting an eight point spread with an ICS of 0.2 has at most 1.6 points of addressable gap, so a plan promising eight points promises what the data does not support. The antecedent is variance analytics in cost control, where deviation is decomposed before any of it is assigned to a manager (Adesuyi *et al.*, 2023).



Note: Segment widths are illustrative. The isolated controllable share (ICS) is the only component that improvement effort at level ℓ can address; the remaining components are either fixed, exogenous, or artifactual.

Fig 2: Decomposition of Observed First Pass Yield Variance

Stage One: Normalization

Four normalizations precede comparison. Definitional normalization requires agreement on what constitutes a first pass failure. The commonest source of spurious variation is a divergent boundary: whether an in-line operator adjustment counts as a failure, whether a retest after settling counts as a second pass, whether units scrapped before test enter the denominator. This cannot be solved statistically; it requires a written network definition and an audit of local application (Agu *et al*., 2023a; Aneke *et al*., 2023).

Mix normalization adjusts for differing complexity distributions, by standardization on network-average family yields or by conditioning on the product family term (Tonoyan *et al*., 2021a, 2023). Maturity normalization addresses learning, since a site early in a product ramp is not comparable to one years into it. Volume normalization attaches confidence intervals, since yield on small denominators is noisy and point values without dispersion encourage misreading routine variation as signal.

Stage Two: Attribution

Two questions follow in sequence. The first is where variation lives: extracting variance components shows whether the dominant source is between sites, between work centres, between product families, or across time, which sets the level at which improvement should be organized. A network whose variance is mostly within-site does not have a site performance problem, however the ranked bar chart appears (Akin-Oluyomi & Akhigbe, 2023a).

The second question is which drivers carry the association. For each driver *j* the yield elasticity is the partial effect on the logit scale, $\varepsilon_j = \partial\eta / \partial x_j$, with implied yield change at operating point y_0:

$$\Delta y_j \approx \varepsilon_j \cdot y_0(1 - y_0) \cdot \Delta x_j$$

The factor $y_0(1 - y_0)$ matters managerially: the same improvement yields a larger absolute gain at 85 percent than at 98. High performers face diminishing absolute returns to identical effort, so uniform percentage targets across dispersed starting yields are not uniform in difficulty, a point standardized accountability frameworks obscure (Sakyi *et al*., 2022b).

Stage Three: Isolation

This is the framework's central stage. Each attributed driver must pass three gates before entering an improvement portfolio.

Gate 1: Mechanism. A plausible physical, procedural, or behavioural pathway from driver to defect mode must be articulable. This blocks statistical artifacts, common where correlated operational variables proxy for one another. A driver that cannot be connected to a mechanism in a sentence is a hypothesis requiring designed experimentation, not a finding (Arumosoye & Obriki, 2022; Obriki & Arumosoye, 2020).

Gate 2: Separability. The effect must be distinguishable from site fixed effects, mix, and structural endowment. Where a driver is collinear with a structural feature the attribution is not identified, so it must vary within sites over time or across sites of comparable structure, as reliability engineering insists in requiring a mechanism be isolated before it is designated a cause (Gideon *et al*., 2019).

Gate 3: Actionability. The driver must be settable by an identified owner at the level being asked to act, within a horizon relevant to the improvement cycle, which requires naming the owner. Where none can be named, the driver does not fail the framework; it triggers the level-shifting rule described below. Contractor and subcontractor governance research is the closest existing treatment (Arumosoye & Obriki, 2020).

Drivers passing all three gates are scored for controllability on five dimensions, each rated from one to five, as set out in Table 2.

Table 2: Dimensions of the Controllability Score

Dimension	Diagnostic question	Low score (1)	High score (5)
Authority	Who is able to change it?	Requires board approval or an external party	Site or line supervisor can set it directly
Latency	How long until the effect appears?	More than twelve months	Within one week
Cost	What does the change require?	Major capital expenditure	Procedural change only
Reversibility	Can the change be undone?	Irreversible commitment	Fully reversible at low cost
Observability	Can the change be verified?	Inferred indirectly at best	Directly and continuously measured

The composite score C_j is the mean of the five ratings, normalized to the unit interval. Weights may be adjusted to context but must be declared before scoring, following the discipline risk-based audit frameworks apply to criteria weighting (Akomolafe *et al*., 2023a).

The Level-Shifting Rule

A driver with high leverage and low site-level controllability is the case current practice handles worst. It is either dropped, forfeiting the opportunity, or retained as an action the site cannot execute, which trains the organization to treat all plan items as optional.

The rule specifies the alternative. Where elasticity is high and controllability low at level ℓ, the driver is reassigned to level $\ell + 1$ with the site's evidence as the business case, and the site's obligation becomes escalation rather than execution: supplier drivers to category management (Akin-Oluyomi *et al*., 2023b; Akinleye & Adeyoyin, 2022b), staffing structure to workforce planning (Falemi *et al*., 2023b). Applied consistently, the rule builds a network portfolio from the bottom up, in which a driver appearing in several sites' escalation sets outranks one produced by a single central analysis (Arumosoye & Obriki, 2019; Obriki *et al*., 2023).

Stage Four: Prioritization

Surviving drivers are ranked by an index combining expected effect, controllability, evidential confidence, and cost:

$$PI_j = (\Delta y_j \cdot C_j \cdot \kappa_j) / K_j$$

where Δy_j is expected gain from a feasible change, C_j the controllability score, κ_j confidence in the attribution, and K_j implementation cost inclusive of managerial attention. Including κ_j stops a large but weakly supported estimate outranking a smaller well-identified one (Tonoyan *et al*., 2022c). Including C_j is the departure from Pareto ranking, which orders by effect size alone and so places uncontrollable drivers atop lists meant to drive local action.

Propositions

P1. Cross-site FPY dispersion is dominated by structural, contextual, and measurement heterogeneity rather than controllable practice variation, so unadjusted benchmarking misattributes performance (Akin-Oluyomi & Akhigbe, 2022, 2023a).

P2. Normalization prior to attribution increases the share of variance correctly assigned to controllable drivers and reduces the share assigned to site effects (Agu *et al*., 2023a; Aneke *et al*., 2023).

P3. Marginal return to a controllable driver falls as the site's binding structural constraint approaches its limit; practice cannot substitute for structural capability beyond that point (Atta *et al*., 2020).

P4. Drivers with high leverage and low site-level controllability produce larger network improvement under the level-shifting rule than when assigned locally (Arumosoye & Obriki, 2020).

P5. Heterogeneity in the operational definition of first pass failure inflates apparent controllable variation and biases benchmarking against sites applying stricter definitions (Aneke *et al*., 2022a, 2023).

P6. Programmes targeting isolated controllable drivers produce more durable gains than those targeting composite defect categories, the former specifying a lever and an owner (Aneke *et al*., 2022a; Eyetsemitan *et al*., 2022).

P7. The isolated controllable share is a function of governance maturity: networks with clearer authority allocation exhibit higher ICS at equivalent structural heterogeneity.

P8. Escalated drivers appearing independently in multiple sites' evidence sets have higher realized network return than those identified centrally (Akin-Oluyomi & Akhigbe, 2023c; Arumosoye & Obriki, 2019).

Application and Deployment

Governance and Deployment

Four governance provisions follow. The partition must be documented and versioned with level and horizon stated, since an undeclared partition invites retrospective reclassification. Escalated drivers require a named network owner with a response obligation, or the rule sheds accountability rather than relocating it (Sakyi *et al*., 2022b). Site review should use normalized yield with the controllable share attached rather than raw rankings (Sakyi *et al*., 2022b). And the portfolio should be capacity-constrained, since improvement effort competing with output pressure is abandoned before it returns (Eyetsemitan *et al*., 2023a).

Illustrative Application

Consider six sites running a fourteen-stage electromechanical assembly. Reported FPY ranges from 87.4 to 96.1 percent, a spread of 8.7 points, and the two lowest sites have been asked for recovery plans. The example is hypothetical.

Normalization: A definitional audit finds two sites excluding operator in-line adjustments from the failure count while four include them; restating on the inclusive definition removes 2.1 points. Mix adjustment removes 1.8 points, and restricting to mature products at one site nine months into a ramp removes 0.9. The normalized spread is 3.9 points (Agu *et al*., 2023a; Aneke *et al*., 2023).

Attribution: Decomposition attributes 41 percent of remaining variance to between-work-centre differences within sites, 26 percent between sites, 18 percent to product family, and 15 percent to residual and period effects. The problem is not primarily a site problem: two work centre types underperform everywhere, a pattern a site-ranked presentation would conceal (Akin-Oluyomi & Akhigbe, 2023a).

Isolation: Five candidates surface. Lot variation from a single-source network supplier shows the largest elasticity but scores 0.22 on controllability, neither specification nor source being locally settable (Agbabiaka *et al*., 2019; Akinleye & Adeyoyin, 2022b). Fixture calibration interval scores 0.81, being locally settable, quickly effective, cheap, reversible, and verifiable (Atta *et al*., 2021). Certification depth on the two problem work centres scores 0.74. Ambient humidity in two unconditioned facilities scores 0.18 and fails Gate 3. Procedure currency scores 0.88 but shows small elasticity, compliance already being high (Eyetsemitan *et al*., 2022).

Level shifting and prioritization: Lot variation and environmental control are escalated with site evidence attached, becoming a sourcing qualification item and a capital request (Akin-Oluyomi *et al*., 2023b); neither remains on any site's plan, the supplier escalation drawing on evidence from four of six sites (Akin-Oluyomi & Akhigbe, 2023c). Calibration interval and certification depth carry the portfolio, recovering an estimated 2.4 of the 3.9 points, with predictive maintenance added as a second-wave item (Sunday *et al*., 2020).

Discussion

The framework's most immediate consequence is deflationary: applied to a typical network it will usually show the headline yield gap to be smaller than reported and the addressable portion smaller still. This is uncomfortable for programmes sized against the headline figure, and explains why normalization attracts resistance from the parties who commissioned the analysis. The resistance is instructive rather than obstructive, since a gap that shrinks under definitional audit was never a performance gap, and managing it as one consumes attention the controllable share requires.

A second theme concerns the relationship between the isolated controllable share and governance structure. The decomposition treats the partition as given once level and horizon are declared, but that declaration is itself a governance choice. A network centralizing sourcing, engineering standards, and capital allocation reduces the controllable share available to any site, and should expect flatter dispersion and a smaller local portfolio; a network devolving those decisions raises both the local controllable share and the variance attributable to local practice. Neither configuration is superior in general. What matters is that the improvement architecture matches the authority architecture, and the framework makes that correspondence visible rather than leaving it implicit.

Implications

Theoretical Implications

The framework repositions controllability from an implicit assumption to an explicit analytical object with measurable dimensions, extending the insight that most variation is systemic into a multi-level setting where the question is at which level the system is governed (Arumosoye & Obriki, 2020; Obogo *et al*., 2022; Obriki & Arumosoye, 2020).

The level-shifting rule aggregates local evidence into central action, addressing a coordination problem the multi-site literature identifies but does not resolve procedurally (Akin-Oluyomi & Akhigbe, 2022, 2023a). Improvement capacity therefore depends not only on local capability but on a functioning upward channel for drivers local units cannot move, reframing network improvement as a property of the authority architecture rather than the analytical toolkit. The framework also bridges parallel literatures: procurement established supplier variation as an operational driver (Agbabiaka *et al*., 2019; Akinleye & Adeyoyin, 2022b) without an apparatus for expressing its site-level uncontrollability, and reliability engineering developed equipment-state models (Gideon *et al*., 2019) without an organizational filter.

Managerial Implications

Five implications follow directly.

- Definitional harmonization should precede any cross-site comparison; no amount of modelling recovers what an inconsistent definition destroys (Aneke *et al*., 2023).
- Site rankings on raw FPY should be replaced by normalized yield reported with confidence intervals, since point rankings on noisy denominators invite intervention where none is warranted.
- Improvement portfolios should be screened for controllability before assignment, and the screening documented so it can be audited later.
- Drivers escalated under the level-shifting rule require a named network owner and a response obligation; without both, the rule becomes a disposal channel.
- Improvement capacity should be treated as a constrained resource, with portfolio size set against available management attention (Eyetsemitan *et al*., 2023a).

Sectoral and Policy Implications

The framework applies beyond discrete manufacturing. In regulated life sciences the controllability screen separates actions that close findings from actions that eliminate causes (Aneke & Adesemoye, 2020; Aneke *et al*., 2022a). In healthcare and public service delivery, normalization before ranking carries equity implications (Adelanwa *et al*., 2023a). In infrastructure and energy, explicit partition of the uncontrollable clarifies what a delivery organization is answerable for (Amayo *et al*., 2023b; Okonkwo *et al*., 2021). Across jurisdictions, normalization needs convergence in standards, the level-shifting rule at its outermost boundary.

Limitations

The framework is conceptual and has not been validated empirically. Its propositions are stated so as to be testable, but none has been tested here, and an integrative review of conceptual sources establishes plausibility and coherence, not effect.

Five limitations warrant emphasis. The controllability score's dimension weights are asserted rather than derived, and different schemes reorder priorities. The framework assumes driver separability, whereas interaction is common. It is static, whereas controllability changes as authority is delegated and capability accumulated. It presumes a measurable first pass outcome. And, as noted in the methodology, the locus of control for many sources had to be inferred from the intervention each proposed, introducing coder judgement into the partition at its foundation.

Future Research

The agenda below is ordered by tractability rather than importance. The first priority is a multi-site panel study estimating the isolated controllable share across networks of varying dispersion, integration, and governance maturity, providing initial evidence on Propositions 1, 2, and 7, feasible with data large networks already hold. A second is construct validation of the controllability score, establishing which of its five dimensions predict implementation success. A third tests the level-shifting rule against Proposition 8, comparing realized returns on drivers escalated with distributed site evidence against those identified centrally.

Domain extensions also suggest themselves: service operations, where first pass resolution is a close analogue but the defect mechanism is informational (Sakyi *et al*., 2023); high-automation settings, where autonomous systems shift the driver profile toward configuration; real-time instrumentation, where continuous isolation becomes feasible (Omoegun *et al*., 2023; Sunday & Omoegun, 2022); and digital twins, offering controllability assessment through simulation. Workforce dynamics also matter, since staffing volatility and capability accumulation alter which drivers are controllable (Falemi *et al*., 2020, 2023a, 2023b).

Three longer-horizon directions also appear productive: a dynamic formulation in which the partition evolves as authority is delegated and capability accumulates; an interaction-aware extension for drivers whose leverage depends jointly on structural conditions, separability being the framework's least defensible simplification; and identification strategies suited to networks where staggered adoption is the only available source of variation.

Conclusion

First Pass Yield is a sound metric applied badly in distributed operations. The problem lies not in the metric but in the comparison, which treats structural endowment, contextual exposure, measurement drift, and managerial practice as one undifferentiated signal and assigns the resulting gap to whoever runs the lowest-ranked site.

The framework proposes a discipline: normalize before comparing, decompose before attributing, screen for controllability before assigning, and escalate rather than discard what local units cannot move. Its output is a smaller portfolio, populated by items carrying a named owner, a plausible mechanism, a stated horizon, and an estimated return. That is a less impressive plan and a more likely one. Before asking why a yield gap exists, an organization should establish how much of it anyone can close, and who that someone is.

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