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Management Department of
Project Management**



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Title Page:

**Developing an Organizational Framework for Participatory Inventory
Management in Educational Laboratories: A Feasibility and Risk
Assessment Approach to Operational and Environmental Sustainability**

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مشروع تطوير إطار عمل تنظيمي للإدارة التشاركية للمخزون في المختبرات التعليمية: دراسة جدوى
وتقييم المخاطر كمنهجية لتحقيق الاستدامة التشغيلية والبيئية

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قُدمت هذه الرسالة استكمالاً لمتطلبات الماجستير في إدارة المشاريع في كلية الإدارة بجامعة ميدأوشن

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أقر أنا الطالبة: **منار حمد السهلي**، المقيدة ببرنامج ماجستير إدارة المشاريع في كلية الإدارة بجامعة ميدأوشن بالرقم الجامعي (242000780)، بأن البحث المقدم بعنوان:

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هو من إعدادي الشخصي بالكامل، وأتحمل المسؤولية الكاملة عنه من جميع الجوانب، وذلك بدايةً من اختيار فكرة البحث، وتحديد المشكلة البحثية، وصياغة الأهداف، ووضع الفروض أو التساؤلات، مروراً بجمع البيانات والمراجع، وتحليلها باستخدام الأساليب العلمية المناسبة، وصولاً إلى استخلاص النتائج والتوصيات.

كما أقر بما يلي:

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توثيق جميع المراجع والمصادر المستخدمة توثيقاً علمياً صحيحاً.

أن البحث لم يتم اقتباسه كلياً أو جزئياً من أي مصدر دون الإشارة إليه.

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الملخص العربي

تُعَدُّ المختبرات التعليمية من أكثر بيئات التعليم العالي كثافةً في استهلاك الموارد، إذ تتركز فيها الأجهزة والمواد الكيميائية والمستهلكات التي تتحدّد بإدارتها الكفاءة المالية والأداء البيئي معاً. وتقع هذه الدراسة في إحدى أكبر مؤسسات التعليم العالي الحكومية في المملكة العربية السعودية، وتحديداً في كلية العلوم مع اتخاذ أحد أقسام العلوم الحيوية وحدةً مضمّنةً للتحليل، وتتأطّر بأولويات رؤية المملكة العربية السعودية 2030 في الكفاءة المالية والاستدامة والتحول الرقمي.

وتُشخّص الدراسة النظام السائد لإدارة المخزون بوصفه نظاماً لا مركزياً غير تشاركي؛ إذ يحتفظ كلُّ مختبرٍ بسجلاته وطلباته الخاصة، في غياب أيّ رؤيةٍ مشتركة، أو سياسةٍ مؤسسيةٍ للإعارة بين المختبرات، أو بنية بياناتٍ موحّدة. ويشكّل هذا الوضع "فجوةً النضج في إدارة المخاطر"، التي تتجلّى نوعياً في ازدواجية الشراء، وانخفاض استغلال الأصول، وهدر المواد الكيميائية منتهية الصلاحية، وغياب القاعدة التنظيمية التي لا تنجح مبادرات الرقمنة من دونها.

ومن الناحية المنهجية، تعتمد الدراسة على التحليل النوعي البنوي والسياساتي والحوكمي؛ فهي لا تستخدم استباناتٍ دراسةٍ ميدانية، ولا بياناتٍ مسحية، ولا إحصاءاتٍ تجريبية، بل تتمثّل أدواتٌ تقويمها في مصفوفاتٍ نوعية، وبواباتٍ جاهزيةٍ تحليلية، وضوابطٍ سياساتية، وتُعرّض ادعاءاتها بوصفها ادعاءاتٍ تصميميةٍ لا نتائجٍ تجريبية.

وتصمّم الدراسة إطاراً متكاملًا يقوم على خمس عدسات: مسارٍ متكيفٍ للنضج في إدارة المخاطر ("الإعلام/الامتثال" Inform/Conform ثم "الإدارة/التطبيع" Managed/Normalized ثم "الأداء" Perform)؛ ونموذج تحليل الفراشة (Bow-Tie) الذي تتمثّل حواجزه الوقائية في توحيد الفهرس وبنود الأهلية، وحواجزه التخفيفية في مبدأ "الأولى انتهاءً يُصرّف أولاً" (FEFO) والمشاركة بين المختبرات؛ والمواءمة مع منطق استمرارية الأعمال في المواصفة ISO 22301:2019 (تحليل أثر الأعمال والأنشطة ذات الأولوية)؛ والمطابقة مع المواصفة ISO 14001:2015 في معالجة الجوانب البيئية؛ وتصنيف المخاطر وفق منظومة FIRM بوصفها منظومة تصنيفٍ لا أداة تنقيطٍ كمّي. ويأسس هذا الإطار في بنية حوكمة ثلاثية المستويات تضم مجلس حوكمة المخزون الأكاديمي، ولجنة التوحيد القياسي الفنية، ووحدة سلسلة الإمداد الرقمية، مع بقاء فنيّ المختبرات في المستوى التشغيلي المحض، إلى جانب الإطار السياساتي للإعارة بين المختبرات الذي يحكم الإعارة المؤقتة للأصول ونقل العهدة وتتبع المسؤولية.

وتتوصّل الدراسة، على النحو النوعي، إلى أنّ جدوى الإطار قوية مشروطةً عبر الأبعاد التنظيمية والمالية والتقنية والبيئية، ومحكومةً بأربع بواباتٍ جاهزيةٍ تحليلية (G1-G4). كما تقدّم الدراسة سجلاً مصنّفاً للمخاطر يضمّ خمس عشرة مخاطرةً وفق منظومة **FIRM**، لكلٍ منها مالِكٌ محدّد واستراتيجية تخفيف؛ ولوحة حوكمةٍ لأربعة عشر مؤشر أداءٍ رئيسياً معرفّةً بطرق القياس وأهدافٍ اتجاهية؛ وخارطة طريقٍ تنفيذية من أربع مراحل: التأسيس المؤسسي واعتماد السياسات (الشهران 1-2)، وتوحيد الفهرس وإدخال البيانات (الشهران 3-4)، والتطبيق التجريبي في قسم الأحياء مع اختبار سير العمل (الشهران 5-6)، ثم التوسّع على مستوى الكلية خلف بوابةٍ مستمرةٍ لجاهزية المنصة الرقمية.

وتتمثّل إسهاماتُ الدراسة في تقديم نموذج حوكمةٍ نوعيٍّ متكاملٍ للإدارة التشاركية لمخزون المختبرات، متوائماً مع معايير التميز **ISO** ورؤية المملكة العربية السعودية 2030، وقابلٍ للنقل إلى مؤسسات التعليم العالي السعودية والخليجية، وقائمٍ على تسلسل "التنظيم قبل التقنية".

الكلمات المفتاحية: إدارة المخزون التشاركي؛ المختبرات التعليمية؛ الحوكمة؛ تقييم المخاطر؛ تحليل الفراشة؛ استمرارية الأعمال؛ الاقتصاد الدائري؛ رؤية المملكة العربية السعودية 2030.

Abstract

Educational laboratories are among the most resource-intensive environments in higher education, concentrating on instruments, chemicals, and consumables whose management determines both fiscal efficiency and environmental performance. This study was conducted within a large public higher education institution in Saudi Arabia—a major multi-departmental academic environment—focusing on a large public science faculty, with a life sciences department as the embedded unit of analysis and is framed by Saudi Vision 2030 priorities of fiscal efficiency, sustainability, and digital transformation.

The study diagnoses the prevailing inventory regime as decentralized and non-participatory: laboratories keep separate records and requisitions, without shared visibility, an inter-lab lending policy, or a standardized data structure. This condition constitutes a **“Risk Maturity Gap,”** expressed qualitatively in duplicate purchasing, depressed asset utilization, expired-chemical waste, and the absence of the organizational baseline without which digitalization initiatives fail.

Methodologically, the study is a qualitative structural, policy, and governance analysis. It employs no field-study questionnaires, survey data, or empirical statistics; its evaluation instruments are qualitative matrices, analytical readiness gates, and policy controls, and its claims are design claims, not empirical findings.

The study designs an integrated five-lens framework: an adapted risk-maturity trajectory (Inform/Conform → Managed/Normalized → Perform); a Bow-Tie risk model whose prevention barriers are catalog standardization and eligibility clauses and whose mitigation barriers are **FEFO** (First-Expired-First-Out) rotation and inter-lab sharing; **ISO**

22301:2019 business continuity alignment (business impact analysis, prioritized activities); **ISO 14001:2015** conformity for environmental aspects; and the **FIRM** risk classification, read strictly as a taxonomy rather than a scoring algorithm. The framework is institutionalized in a three-tier governance architecture — Academic Inventory Governance Board, Technical Standardization Committee, Digital Supply Chain Unit, with laboratory technicians at strictly operational level — and an Inter-Lab Policy Framework governing temporary asset loans, custody transfer, and responsibility tracking.

The study concludes, qualitatively, that the framework’s feasibility is conditionally strong across organizational, financial, technical, and environmental dimensions, gated by four analytical readiness gates (**G1–G4**). It delivers a **FIRM**-classified register of fifteen risks, each with a named owner and mitigation; a governance dashboard of fourteen key performance indicators defined with measurement methods and directional targets; and a four-phase implementation roadmap — institutional foundation and policy ratification (months 1–2), catalog standardization and data onboarding (months 3–4), a Biology Department pilot with workflow testing (months 5–6), and college-wide scaling behind a continuous digital-platform readiness gate.

The study contributes an integrated qualitative governance model for participatory laboratory inventory, aligned with **ISO** excellence standards and Saudi Vision 2030, offering a transferable template for Saudi and Gulf higher education grounded in organization-before-technology sequencing.

Keywords: participatory inventory management; educational laboratories; governance; risk assessment; Bow-Tie analysis; business continuity; circular economy; Saudi Vision 2030.

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List of Abbreviations and Terminology

List of Abbreviations

Abbreviation	Full Name
BCMS	Business Continuity Management System
BIA	Business Impact Analysis
CCPS	Center for Chemical Process Safety
CE	Circular Economy
CMM / CMMI	Capability Maturity Model / Capability Maturity Model Integration
COSO	Committee of Sponsoring Organizations of the Treadway Commission
CSR	Corporate Social Responsibility
EB	Escalation–Factor Barrier (EB1–EB3)
EF	Escalation Factor (EF1–EF3)
EMS	Environmental Management System
FEFO	First–Expired, First–Out

Abbreviation	Full Name
FIRM	Financial, Infrastructure, Reputational, Marketplace (risk classification taxonomy)
G1–G4	Analytical Readiness Gates 1–4
HSE	Health, Safety, and Environment
IEC	International Electrotechnical Commission
IoT	Internet of Things
ISO	International Organization for Standardization
ISO/IEC	Joint International Organization for Standardization / International Electrotechnical Commission standard series
ISO/TS	ISO Technical Specification
KPI	Key Performance Indicator
LCA	Life–Cycle Assessment
MB	Mitigation Barrier (MB1–MB3)
MTPD	Maximum Tolerable Period of Disruption
PB	Prevention Barrier (PB1–PB3)
PDCA	Plan–Do–Check–Act
PESTLE	Political, Economic, Social, Technological, Legal, Environmental (external–drivers taxonomy)
PMBOK	Project Management Body of Knowledge
PMI	Project Management Institute
RACI	Responsible, Accountable, Consulted, Informed (accountability matrix convention)
RFID	Radio–Frequency Identification
RMM	Risk Maturity Model
RQ	Research Question (RQ1–RQ4)
RR	Risk Register entry (RR–01–RR–15)

Abbreviation	Full Name
RTO	Recovery Time Objective
TE	Top Event (TE1, TE2)
USR	University Social Responsibility

List of Terminology

Term	Academic Definition (as used in this thesis)
Academic Inventory Governance Board	The apex decision body of the participatory inventory framework at the College of Science, holding policy–ratification, risk–register, continuity–objective, and performance–review authority; it governs the rules of sharing without executing operational tasks or superseding departmental budget authority (Section 4.1.2).
Barrier Ownership	The governance principle that every Bow–Tie prevention, mitigation, and escalation–factor barrier is assigned to a named, accountable organizational body, converting the risk model into an auditable allocation of responsibility (Sections 2.9.3 , 4.1.7).
Bow–Tie Analysis	A qualitative risk–assessment technique giving a graphical depiction of the pathways from the causes of an event to its consequences (IEC 31010:2019): threats act through prevention barriers upon a central Top Event, whose consequences are attenuated by mitigation barriers, with escalation factors threatening the barriers themselves.
Business Impact Analysis (BIA)	The process of analyzing the impact over time of a disruption on the organization, identifying prioritized activities, their dependencies, and recovery parameters (ISO 22301:2019, clause 8.2.2); applied qualitatively to laboratory teaching and research activities.
Circular Academic Procurement	The organization of university purchasing on circular–economy principles — demand aggregation, life–cycle criteria, and right–sized

Term	Academic Definition (as used in this thesis)
	acquisition — implemented in this framework as the joint/circular procurement rules of prevention barrier PB3, reducing incoming volume and aligning purchasing with consumption.
Compliance Obligations	The legal and other requirements applicable to an organization’s environmental aspects (ISO 14001:2015, clause 6.1.3), the fulfilment of which is periodically evaluated under clause 9.1.2; distinct from conformity with the standard itself.
Custody	The documented, transferable state of responsibility for a specific stock item or asset, including accountability for its condition, location, and return; custody is unambiguous at every moment and changes only through the custody–transfer protocol.
Custody–Transfer Protocol	The documented handover procedure governing every change of custody — condition record, custody acknowledgment, and chain–of–custody log — operating as escalation–factor barrier EB3 against custody ambiguity during inter–lab transfers (Section 4.1.6).
Digital Supply Chain Unit	The governance body owning shared visibility and data integrity: stewardship of the shared inventory registry, data–quality rules, cross–lab holdings visibility for eligibility checks, continuity and dashboard reporting, and maintenance of the requirements baseline for future smart–inventory platforms; it operates and reports but does not decide loans or purchases (Section 4.1.4).
Eligibility Clause	A purchasing rule requiring that a requisition be checked against the shared registry, and that existing stock be used or transferred where suitable, before any new purchase is approved; the operational core of prevention barrier PB2.
Environmental Aspect	An element of laboratory inventory activity that can interact with the environment — in this framework principally expired chemicals and redundant assets — as distinct from the environmental impact that may result (ISO 14001:2015 usage, clause 6.1.2).

Term	Academic Definition (as used in this thesis)
Escalation Factor	A condition that can defeat or degrade a barrier's performance — in this framework: unenforced policies (EF1), incomplete registry data (EF2), and custody ambiguity during transfers (EF3).
Escalation–Factor Barrier	A control that guards a barrier against its escalation factors — in this framework: a defined audit cadence (EB1), data–quality indicators (EB2), and the custody–transfer protocol (EB3).
FEFO Discipline	The enforced practice of consuming stock in First–Expired, First–Out order, executed at the operational level so that the earliest–expiring usable items leave storage first; the core of mitigation barrier MB1.
FIRM Scorecard	Hopkin's (2018) risk classification system categorizing risks by their impact on the organization's key dependencies — Financial, Infrastructure, Reputational, Marketplace; a taxonomy rather than a scoring algorithm, applied here with the declared adaptation of Marketplace as the university's service/stakeholder environment (M*).
Inter–Lab Loan	A governed, temporary transfer of an asset or chemical from the custody of one laboratory to another under the Inter–Lab Policy Framework, with documented request, approval, custody transfer, and return; the operational core of mitigation barrier MB2.
Inter–Lab Policy Framework	The ratified policy instrument governing temporary inter–lab asset loans and chemical redistribution: eligibility and scope, the request–approval workflow, the custody–transfer protocol, responsibility tracking, liability and recall rights, and the escalation ladder (Section 4.1.6).
Life–Cycle Perspective	The consideration of environmental aspects across acquisition, use, and end–of–life stages of inventory, applied as a perspective in procurement and operational control (ISO 14001:2015, clause 8.1); explicitly not a full life–cycle assessment.
Maximum Tolerable Period of Disruption (MTPD)	The time frame within which the impacts of not resuming a disrupted activity would become unacceptable (ISO 22301:2019); used qualitatively to reason about semester–locked practical teaching.

Term	Academic Definition (as used in this thesis)
Minimum Acceptable Capacity	The specified capacity at which a prioritized activity must be capable of resumption following a disruption (ISO 22301:2019); the 2019–edition successor concept to legacy minimum–business–continuity terminology.
Mitigation Barrier	A documented control positioned between a Top Event and its consequences that reduces consequence severity after loss of control has begun — in this framework: FEFO rotation rules (MB1), inter–lab sharing and redistribution before expiry (MB2), and governed disposal protocols (MB3).
Participatory Inventory Management	A governance arrangement in which multiple laboratories share visibility of, and governed access to, a common pool of chemical and asset stock, under institution–level rules for purchasing, custody, rotation, and redistribution — participation with defined decision rights, not informal cooperation.
Prevention Barrier	A documented control positioned on a threat pathway that terminates or weakens the pathway before loss of control — in this framework: standardization of the catalog and records (PB1), eligibility clauses for purchasing (PB2), and joint/circular procurement rules (PB3).
Prioritized Activity	A teaching or research activity whose disruption would exceed the institution’s tolerance within a short maximum tolerable period of disruption, and whose dependencies the continuity arrangements must protect (ISO 22301:2019 usage).
Qualitative Premise	The study’s stated proposition advanced in lieu of statistical hypotheses: that strengthening the independent dimensions — governance architecture, policy control, and standardization — through the proposed framework advances the dependent dimensions of operational efficiency, environmental sustainability, and business continuity along the maturity trajectory; evaluated structurally, not statistically.

Term	Academic Definition (as used in this thesis)
Readiness Gates (G1–G4)	Policy-controlled analytical checkpoints with explicit qualitative criteria, structuring the implementation roadmap: G1 policy ratification (governance constituted; policy core and risk register ratified; roles appointed); G2 data readiness (registry onboarding complete; catalog–standard conformity verified); G3 pilot workflow integrity (loan, custody, and FEFO workflows demonstrated qualitatively in the Biology Department pilot); G4 digital platform readiness (requirements baseline met before any smart–inventory procurement).
Recovery Time Objective (RTO)	The prioritized time frame, shorter than the maximum tolerable period of disruption, within which a disrupted activity must be resumed at a specified minimum acceptable capacity (ISO 22301:2019).
Risk Maturity Gap	The distance, expressed in the thesis’s adapted three–band trajectory, between the institution’s current inventory–governance capability and the capability required to sustain participatory, digitized, standards–aligned stock management; the formal statement of the research problem.
Risk Maturity Model (adapted three–band trajectory)	The thesis’s declared adapted terminology — Inform/Conform (compliance–driven, reactive), Managed/Normalized (standardized, documented), Perform (excellence–oriented, integrated, anticipatory) — anchored to Hillson’s (1997) risk maturity levels and the Capability Maturity Model scale (Paulk et al., 1993); no published model uses these exact level names.
Shared Registry	The unified college–level inventory registry operated by the Digital Supply Chain Unit, providing cross–laboratory visibility of holdings, the evidence base for eligibility checks, data–quality monitoring, and continuity reporting; the organizational precondition for any future digital inventory platform.
Technical Standardization Committee	The governance body owning the prevention barriers: it drafts and maintains the unified catalog and classification standard, the eligibility

Term	Academic Definition (as used in this thesis)
	clauses, and the FEFO policy standard, and interfaces with safety and compliance functions; it sets standards but approves no individual purchases and holds no budget authority (Section 4.1.3).
Top Event	The central node of the Bow-Tie: the moment of loss of control of the hazard — in this framework, chemical expiration beyond usable shelf life (TE1) and chronic asset underutilization (TE2), declared as adapted top events for the inventory–governance domain.

CHAPTER 1: INTRODUCTION

1.1. Research Foundation and Problem Refinement

1.1.1 Background and Institutional Context

Educational laboratories are among the most resource-intensive operational environments within higher education institutions. Unlike general classrooms, teaching laboratories concentrate high-value capital equipment, chemically diverse consumables, perishable reagents, and safety-critical materials within spaces that operate on fixed semester cycles and serve large student cohorts (Durgan et al., 2023; Freese et al., 2024). The material throughput of such environments — continuous procurement, storage, consumption, and disposal — makes their inventory management a matter of institutional consequence rather than a purely technical housekeeping function. Recent literature on sustainable and “green” laboratories has demonstrated that the environmental and financial footprint of laboratory operations is shaped less by individual purchasing decisions than by the organizational arrangements through which visibility, coordination, and accountability are structured (Freese et al., 2024; Gutierrez et al., 2020).

This study adopts precisely that managerial reframing: laboratory inventory failure is treated as an organizational and governance problem with an inventory attached, not as a technical problem solvable by better shelving, software, or individual diligence. Where institutions lack shared visibility of stock, standardized records, and enforceable rules for inter-unit coordination, the default organizational behavior is to purchase anew — even when an equivalent asset or unexpired chemical exists in a neighboring laboratory (Strom et al., 2020; Zhu & Liu, 2021). The equipment-sharing and core-facility literature has documented, in qualitative terms, that governed pooling arrangements yield documented savings and improved asset utilization precisely because they replace this default with structured visibility and allocation rules (Tu & Greever-Wilson, 2025; X. Wang & Qu,

2025). Similarly, the circular economy literature argues that resource loops close only where governance arrangements — not merely intentions — enable reuse, redistribution, and life-cycle-aware procurement (Kirchherr et al., 2017; Vergani, 2024). Higher education institutions have increasingly been analyzed as microcosms in which circular economy principles can be operationalized, with laboratories identified as priority sites for such interventions (Vergani, 2024).

Two contextual currents make this reframing especially urgent in the present setting. First, the international momentum behind Green Lab initiatives and sustainable laboratory practice has generated an expanding body of guidance on chemical inventory reduction, waste prevention, and life-cycle procurement in laboratory environments (Durgan et al., 2023; Freese et al., 2024; Gutierrez et al., 2020). Second, in the Saudi context, Vision 2030 establishes explicit expectations for fiscal efficiency, environmental sustainability, and digital transformation across public institutions, including universities (Alamoudi et al., 2023; Alshammari, 2025). Saudi higher education institutions are consequently under strategic pressure to demonstrate that their operational practices — including asset and facilities management — conform to international standards and support national transformation goals (Hassanain et al., 2019; Mohsen, 2025).

A large public higher education institution in Riyadh occupies a distinctive position within this landscape. As a major higher education environment with centralized academic operations, the institution concentrates its activities on a single integrated mega-campus, which in turn concentrates procurement volume and laboratory capacity within one institutional boundary. This concentration is analytically significant: the coordination failures that characterize decentralized inventory regimes, and conversely the gains available from participatory coordination, are both amplified at mega-campus scale. The institution's

explicit alignment with Saudi Vision 2030—spanning fiscal efficiency, sustainability, and digital transformation—provides the strategic mandate against which this study’s proposed framework is assessed (Alamoudi et al., 2023; Alshammari, 2025).

The contextual setting of this study is a large public science faculty, which hosts extensive teaching and research laboratories across multiple departments. Within this faculty, a life sciences department serves as the primary—embedded—unit of analysis. The department is characterized by a large and diverse inventory comprising instruments, glassware, consumables, and chemicals; high student throughput organized on fixed semester cycles; recurring consumable orders driven by chemically intensive courses; and episodic research demand superimposed on routine teaching loads. This combination of scale, diversity, chemical intensity, and cyclical demand makes the life sciences department a structurally representative case through which the faculty’s, and ultimately the institution’s inventory governance problem can be examined.

The prevailing inventory regime across the case setting can be characterized, qualitatively, as decentralized. Each department and laboratory maintains its own records, requisitions, and stock; purchases, stores, and disposes of materials independently; and operates without shared visibility into holdings elsewhere in the faculty or institution. No institutional policy governs inter-laboratory lending or transfer of assets and chemicals, and no standardized data structure exists across units. The consequences of this regime are structural rather than incidental: the default response to any unmet need is a new purchase, because the existence of an equivalent item elsewhere is organizationally invisible; instruments sit idle in one laboratory while neighboring needs go unmet; and small, isolated chemical stocks pass their shelf lives unnoticed, accumulating as financial, environmental, and health—and–safety burdens (Strom et al., 2020; Tu & Greever–Wilson, 2025). A fourth,

strategic dimension compounds these: without standardized processes and clearly assigned roles, the institution lacks the organizational baseline upon which any digitalization initiative — such as RFID- or IoT-enabled tracking platforms — could reliably be built. The digital readiness literature consistently indicates that technology investments in unstandardized organizational environments tend to fail or decay, and that organizational reform must precede technology adoption (Bellantuono et al., 2021; Rodríguez-Abitia & Bribiesca-Correa, 2021).

1.1.2 Problem Statement: The Risk Maturity Gap

The core problem addressed by this thesis is framed as a Risk Maturity Gap: the distance between the maturity band at which the institution's laboratory inventory governance currently operates and the maturity band required by its stated strategic ambitions. This section develops the problem through four structural components — waste as consequence, fragmented procurement as mechanism, absent integration as governance failure, and the maturity framing itself — before stating the problem formally.

Terminological declaration. This thesis employs the maturity labels Inform/Conform, Managed/Normalized, and Perform as its own adapted terminology. No published risk maturity model uses these exact level names; they are introduced here as a bespoke three-band trajectory and are explicitly anchored to verified antecedent models. The Inform/Conform band — compliance-driven, reactive, and decentralized — corresponds to the lower levels of (Hillson, D. A., 1997) Risk Maturity Model (Naive and Novice), in which risk handling is ad hoc, awareness is limited, and process discipline is absent. The intermediate Managed/Normalized band — standardized, documented, and consistently applied — corresponds to Hillson's Normalised level and to the Managed-to-Defined levels of the Capability Maturity Model scale (Paulk et al., 1993). The Perform band —

excellence-oriented, integrated, and anticipatory — corresponds to Hillson’s upper level (Natural) and, analogously, to the Quantitatively Managed and Optimizing levels of the Capability Maturity Model scale (Paulk et al., 1993) and the upper capability levels of the ISO/IEC 33020 process assessment tradition (33020 ISO/IEC, 2019). The adaptation is deliberate: a three-band trajectory is analytically sufficient for a design-level study, and the labels are chosen to describe observable organizational behavior (informing, conforming, performing) rather than to import the assessment machinery of any single published model.

(a) Resource waste as structural consequence. Within the prevailing decentralized regime, waste arises not from individual negligence but from organizational design. Duplicate purchasing occurs by default: because the existence of an asset or chemical elsewhere is invisible, the rational local response to any need is to procure. Asset utilization is depressed: instruments remain idle while neighboring demand is unmet, because no mechanism exists to match surplus with need. Expired chemicals accumulate: small, isolated stocks pass their shelf lives unnoticed within units that lack rotation discipline and shared visibility, generating financial write-offs alongside environmental and health-safety exposure (Freese et al., 2024; Strom et al., 2020; Tu & Greever-Wilson, 2025). Each of these outcomes is a predictable consequence of the regime’s structure rather than an anomaly within it.

(b) Fragmented procurement as organizational mechanism. The mechanism that converts decentralization into waste is fragmented procurement. When purchasing authority, requisition records, and stock custody are dispersed across autonomous units without a coordinating layer, each unit optimizes locally and the institution loses globally: aggregate demand is never consolidated, common catalog and classification standards

never emerge, and no actor possesses the mandate or the information to redirect existing stock toward emerging needs (Kirchherr et al., 2017; Zhu & Liu, 2021). Sustainable procurement scholarship emphasizes that such fragmentation defeats both fiscal and environmental objectives simultaneously, because life-cycle-aware purchasing presupposes the consolidated visibility that fragmentation destroys (14001 ISO/IEC, 2015).

(c) Absence of cross-departmental integration as governance failure. At the governance level, the case setting exhibits no institutional policy for inter-laboratory lending or transfer, no standardized data structure, and no assigned custodianship for shared assets. Equipment-sharing and core-facility research indicates that pooling arrangements succeed only where governance instruments — eligibility rules, allocation and scheduling procedures, custody and accountability protocols, and equitable benefit distribution — are formally specified; participation without decision rights and trust mechanisms decays into nominal compliance (Strom et al., 2020; X. Wang & Qu, 2025). The absence of these instruments within the host institution constitutes governance failure through which the waste consequences above are reproduced each procurement cycle.

(d) The maturity framing. Read against the adapted maturity trajectory, the institution currently operates within the Inform/Conform band: its inventory practices are reactive, compliance-oriented, and decentralized — corresponding to the Naive and Novice levels of (Hillson, D. A., 1997) model, in which processes are ad hoc, and risk is addressed only after it materializes. Its strategic ambitions, by contrast — Vision 2030 alignment, ISO 14001:2015 environmental management, and ISO 22301:2019 business continuity — presuppose the Perform band: integrated, anticipatory, and excellence-oriented governance in which risks are structured before they crystallize and continuity and environmental performance are engineered into operations (Hillson, D. A., 1997; 14001

ISO/IEC, 2015; 22301 ISO/IEC, 2019; Paulk et al., 1993). The distance between these bands is the Risk Maturity Gap, and it constitutes an institutional bottleneck: no amount of local effort or technology spending within the Inform/Conform regime can deliver the integrated visibility, standardized process, and anticipatory risk posture that Perform-level ambitions require (Bellantuono et al., 2021; Rodríguez-Abitia & Bribiesca-Correa, 2021).

Formal problem statement. *The problem addressed by this study is therefore stated as follows: within a large public science faculty at a Saudi higher education institution, laboratory inventory governance operates at a compliance-driven, reactive maturity band (Inform/Conform), characterized by decentralized purchasing, absent shared visibility, no inter-laboratory coordination policy, and no standardized data structures; this regime structurally reproduces duplicate procurement, depressed asset utilization, and expired-chemical accumulation, and it forecloses the operational, environmental, and continuity performance required by the institution's Vision 2030 commitments and ISO-aligned excellence ambitions (Perform band). The institution lacks an integrated organizational framework—specifying governance structures, roles, policies, and a phased transition pathway—through which this maturity gap can be diagnosed, assessed for feasibility and risk, and closed.*

1.1.3 Significance of the Study

1.1.3.1 Practical and Institutional Significance

The practical significance of this study lies in the alignment it establishes between a concrete operational reform — participatory inventory management in educational laboratories — and the international standards and national strategies to which the institution is already committed.

Alignment with international sustainability standards. The framework developed in this thesis is designed to elevate educational laboratory operations toward two management-system standards. (14001 ISO/IEC, 2015, p. 2015) requires organizations to determine their environmental aspects and associated impacts from a life-cycle perspective, to address compliance obligations, and to maintain emergency preparedness and response for environmental incidents ((14001 ISO/IEC, 2015), clauses 6.1.2, 6.1.3, 8.2). Chemical overstocking, unnoticed expiry, and unmanaged disposal are paradigmatic environmental aspects of laboratory operation, and a participatory inventory regime with FEFO-based rotation and governed redistribution speaks directly to the operational planning and control requirements of the standard ((14001 ISO/IEC, 2015), clause 8.1; Freese et al., 2024; Gutierrez et al., 2020). ISO 22301:2019, in turn, frames business continuity as the protection of prioritized activities against disruption, through business impact analysis, continuity strategies, and continuity solutions ((22301 ISO/IEC, 2019), clauses 8.2.2, 8.3). Digitized inventory visibility and inter-laboratory loan workflows function, in this framing, as continuity solutions that protect teaching and research activities during supply-chain interruptions — a relevance the standard explicitly invites through its emphasis on prioritized activities and minimum acceptable capacity ((22301 ISO/IEC, 2019), clause 8.2.2).

Institutional reputation protection. Through the lens of University Social Responsibility (USR) — the university-specific extension of corporate social responsibility — operational sustainability performance is inseparable from institutional reputation and stakeholder trust. Waste incidents, audit findings, or visible mismanagement of hazardous materials carry reputational consequences for a university that positions itself as a national leader in sustainability and women's education. A governed, auditable inventory framework is therefore also a reputation-protection instrument, and one that reduces exposure to “USR–

washing” critiques by grounding sustainability claims in verifiable operational arrangements rather than declarative policy (Ali et al., 2021).

Business continuity of teaching and research. Educational laboratories operate on fixed semester cycles with high student throughput; a disruption in the availability of chemicals, consumables, or instruments translates directly into disrupted teaching and interrupted research. By treating inventory visibility and inter-lab sharing as continuity strategies, the framework contributes to the resilience of the University’s core academic mission (Ayyildiz et al., 2025; 22301 ISO/IEC, 2019).

Contribution to Vision 2030. The framework’s emphasis on fiscal efficiency (eliminating duplicate procurement by default), environmental sustainability (preventing expired-chemical accumulation and enabling life-cycle-aware purchasing), and digital transformation readiness (standardized processes and data structures as a precondition for technology adoption) maps directly onto the three Vision 2030 expectation domains identified for Saudi public institutions (Alamoudi et al., 2023; Alshammari, 2025; Hassanain et al., 2019).

Decision-grade artifacts for administrators. Finally, the study delivers its practical contribution in the form of design artifacts rather than empirical products: a waste-baseline logic that specifies how decentralized waste would be characterized structurally; a feasibility matrix spanning organizational, financial, technical, and environmental dimensions; a risk register classifying transition risks; a governance charter specifying decision rights and accountability; and a phased implementation roadmap. These artifacts are designed to be decision-grade — sufficient for administrators to deliberate upon — without presupposing any field data collection (PMI, 2021).

1.1.3.2 Theoretical Significance

The theoretical contribution of this study rests on an integration that existing literature does not provide. Four relevant research streams have developed largely in isolation from one another. Circular economy scholarship in higher education has theorized resource loops, campus metabolism, and institutional microcosms (Kirchherr et al., 2017; Vergani, 2024). Green and sustainable laboratory scholarship has addressed chemical inventory reduction, waste prevention, and laboratory environmental practice (Durgan et al., 2023; Freese et al., 2024; Gutierrez et al., 2020). Equipment-sharing and core-facility scholarship has examined pooling governance, asset utilization, and sharing economics (Strom et al., 2020; Tu & Greever-Wilson, 2025; X. Wang & Qu, 2025; Zhu & Liu, 2021). Digital readiness and transformation scholarship has established the organizational preconditions under which digital platforms succeed or fail (Bellantuono et al., 2021; Rodríguez-Abitia & Bribiesca-Correa, 2021). These literatures rarely meet within a single analytical framework; they almost never converge on educational — as distinct from research — laboratories, where semester-locked teaching demand and student-cohort scale impose distinct structural constraints; and they are virtually absent from the Saudi and Gulf institutional context, where Vision 2030 creates a distinctive strategic environment (Alamoudi et al., 2023; Alshammari, 2025; Mohsen, 2025).

This study addresses that gap by integrating five analytical lenses — risk maturity modeling (Hillson, D. A., 1997; Paulk et al., 1993), Bow-Tie risk analysis (33020 ISO/IEC, 2019), business continuity management (22301 ISO/IEC, 2019), environmental management and ISO 14001 (Ali et al., 2021; 14001 ISO/IEC, 2015), and the FIRM risk classification taxonomy (Hopkin, 2018) — into a single feasibility-and-risk assessment framework for academic laboratory inventory governance. Laboratory risk scholarship has begun to apply structured

risk analysis to laboratory environments (Ayyildiz et al., 2025), but has not yet connected such analysis to maturity-based organizational reform of inventory governance.

A further contribution is methodological. The study applies the discipline of project management — feasibility assessment and risk assessment as structured evaluative practices — to a problem of internal university operational reform. Treating institutional reform as a project amenable to feasibility-and-risk discipline, rather than as a purely administrative exercise, offers a transferable methodological template for comparable operational transformations in higher education settings (PMI, 2021).

1.1.4 Research Objectives

This study pursues four structured objectives. Each is stated so that its attainment is verifiable through the qualitative deliverables of the thesis, and none depends on empirical field data.

1. Current-state assessment. To diagnose, qualitatively and structurally, the decentralized inventory management practices prevailing in a large public science faculty within a Saudi higher education institution—with a life sciences department as the embedded unit of analysis—and to characterize their structural risk consequences (duplicate purchasing, depressed asset utilization, expired-chemical accumulation, and absent digitalization baseline) as outcomes of organizational design rather than individual failure. Attainment is verified by the production of a coherent current-state structural account in Chapter 1 and its formalization through the maturity-gap diagnosis in [Subsection 2.9.3](#).
2. Feasibility and risk assessment. To assess the feasibility of a participatory inventory management framework across organizational, financial, technical, and environmental dimensions, and to classify and prioritize the transition risks that its

adoption would entail, using Bow–Tie analysis and FIRM classification as the structuring instruments. Attainment is verified by the production of a feasibility matrix and a classified risk register in Chapter 4 (Sections [4.2](#) and [4.3](#))(Hopkin, 2018; 33020 ISO/IEC, 2019; PMI, 2021).

3. Organizational framework development. To develop an organizational framework specifying governance structures, roles, policies, procedures, and performance indicators for participatory inventory management, including the explicit delimitation of technician roles at the operational–technical level and the alignment of role specifications with the leadership–and–roles clauses of ISO 14001:2015 and ISO 22301:2019 ((14001 ISO/IEC, 2015), clause 5.3;(22301 ISO/IEC, 2019), clause 5.3). Attainment is verified by the governance architecture specified in Chapter 4 (Section [4.1](#)).
4. Implementation roadmap. To construct a phased implementation roadmap that sequences the transition from the current maturity band toward the Perform band and establishes the organizational readiness baseline — standardized processes, defined roles, and structured data — required for subsequent digitalization (Bellantuono et al., 2021; Rodríguez–Abitia & Bribiesca–Correa, 2021). Attainment is verified by the roadmap and readiness–baseline specification delivered in Chapter 4 (Section [4.1](#)).

1.1.5 Research Questions

The study is guided by one main research question and four sub–questions, mapped one–to–one onto the objectives above. All questions are phrased as qualitative and design questions, not as empirical measurement questions.

Main research question: How should an organizational framework for participatory inventory management in educational laboratories within a large public higher education institution in Saudi Arabia be designed, assessed for feasibility and risk, and sequenced for implementation, such that it closes the maturity gap between the prevailing decentralized regime and the institution's ISO-aligned, Vision 2030 ambitions for operational and environmental sustainability?

- RQ1 (mapped to Ob.1): How can the current decentralized inventory management practices in the College of Science — with the Biology Department as the embedded case — be characterized structurally, and what are their organizational risk consequences?
- RQ2 (mapped to Ob.2): How can the feasibility of a participatory inventory management framework be assessed across organizational, financial, technical, and environmental dimensions, and how should the risks of the transition be classified and prioritized?
- RQ3 (mapped to Ob.3): What governance structures, roles, policies, procedures, and performance indicators should the organizational framework specify to enable participatory inventory management while respecting strict operational boundaries for technical staff?
- RQ4 (mapped to Ob.4): How should a phased implementation roadmap be structured so as to advance institutional maturity from the Inform/Conform band toward the Perform band and establish the readiness baseline required for digitalization?

1.1.6 Methodological Positioning, Scope, and Boundaries

Methodological positioning. This study is positioned as descriptive–analytical research conducted through qualitative, structural, policy, and governance analysis. Its objects of analysis are organizational arrangements — governance structures, roles, policies, procedures, and risk configurations — rather than populations, behaviors, or measurable outcomes. The descriptive component renders the prevailing decentralized regime with precision; the analytical component interrogates that regime through the five integrated lenses introduced above (risk maturity, Bow–Tie analysis, business continuity, environmental management and USR, and FIRM classification); and the design component specifies the framework, feasibility assessment, risk register, and roadmap that constitute the study’s deliverables. This positioning is consistent with the feasibility–and–risk assessment discipline of project management applied to internal organizational reform (PMI, 2021), and with qualitative approaches to institutional and policy analysis in higher education research (Knott et al., 2022).

Case–study logic. The study follows a single embedded case–study logic. The case is laboratory inventory governance within a large public science faculty at a Saudi higher education institution; the embedded unit of analysis is a life sciences department, selected because its scale, inventory diversity, chemical intensity, semester–locked teaching demand, and episodic research demand make it structurally representative of the faculty’s laboratory operations. Consistent with qualitative case–study conventions, the study claims analytic rather than statistical generalization: its propositions and design artifacts are intended to transfer, by reasoned analogy, to comparable laboratory–intensive units within the institution and to structurally similar higher education settings, not to extrapolate to populations. (Knott et al., 2022).

Explicit exclusion of empirical field data. It is stated explicitly and applies to every section of this thesis: this phase uses no field–study questionnaires, no survey instruments, no interview data, and no empirical statistics, and it neither uses nor assumes any numerical findings. Where the argument requires reference to magnitudes — for instance, the scale of waste under decentralization or the savings associated with equipment sharing — it proceeds by structural reasoning and by qualitative reference to the literature (for example, the documented savings reported for sharing arrangements in (Tu & Greever–Wilson, 2025)), never by fabricated or projected figures. The deliverables of this phase are design artifacts whose validity rests on internal coherence, standards alignment, and grounding in verified literature, and whose empirical testing is deliberately deferred to a subsequent phase.

Scope and boundaries. Four boundaries delimit the study. First, topical: the study addresses educational laboratory inventory only — instruments, glassware, consumables, and chemicals — and excludes facilities, buildings, and general campus asset management, except where these intersect with laboratory operations. Second, institutional: the study is confined to a single higher education institution, with a large public science faculty and a life sciences department as its focal setting; cross–institutional benchmarking is used only as secondary context, not as primary data. Third, level of design: the study operates at the design level, not the implementation level — it specifies what the framework should be and how its adoption should be sequenced and governed, but does not execute, pilot, or evaluate an implementation. Fourth, role boundary: consistent with the professional scope of laboratory technician practice, the framework assigns technicians strictly operational–technical functions — executing FEFO rotation, inter–lab loan workflows, and catalog and data entries — without administrative decision–making, procurement approval, financial authority, or policy–setting responsibility;

technicians may recommend and escalate but never decide beyond their technical capacity.

Transition to subsequent Chapters: Chapter 2 operationalizes the Risk Maturity Gap identified here in Chapter 1 by constructing the study’s integrated theoretical and risk assessment framework: the adapted three-band maturity model (Inform/Conform to Perform), Bow-Tie analyses of chemical expiration and asset underutilization as adapted top events, the ISO 22301:2019 business continuity reading of inventory visibility and inter-lab loans, and the ISO 14001:2015/USR/FIRM classification of framework consequences and risks. Chapter 4 then specifies the organizational and governance architecture through which the framework would operate: a Governance Board supported by a Technical Standardization Committee, a Digital Supply Chain Unit, laboratory technicians at the operational level, and an Inter-Lab Policy Framework governing temporary asset loans and FEFO-based chemical redistribution. Together, the chapters move from problem diagnosis (Chapter 1), through literature synthesis and theoretical modeling (Chapter 2) and research methodology (Chapter 3), to the structural feasibility study and governance design (Chapter 4), delivering the thesis’s contribution as a coherent, standards-aligned design artifact.

CHAPTER 2: LITERATURE REVIEW & THEORETICAL FRAMEWORK

2.1 Review Approach and Thematic Organization

This chapter reviews and synthesizes the scholarly and standards literature upon which the thesis's participatory inventory framework is constructed. Because the study is a qualitative, design-oriented structural analysis rather than an empirical measurement exercise, the review's purpose differs from that of a conventional hypothesis-testing thesis: it is not to establish the statistical state of a variable, but to extract *design lessons* — documented governance arrangements, failure modes, standardization practices, and risk-structuring techniques — and to locate, with precision, the qualitative governance gap that the proposed framework addresses.

The organization is thematic rather than chronological. A chronological presentation would misrepresent the intellectual structure of the field, in which a small number of foundational theoretical works — the circular-economy articulation of the (Ellen MacArthur Foundation., 2013), (Hillson, D. A., 1997) original risk maturity model, the capability maturity work of (Paulk et al., 1993), and (Hopkin, 2018) risk classification taxonomy — underpin a much larger body of recent, domain-specific scholarship concentrated in the period 2020–2026. The review therefore proceeds in five thematic streams, each corresponding to one design problem the framework must solve:

1. **Inventory management in educational and university laboratories** — the problem setting itself ([Section 2.2](#));
2. **Participatory and resource-sharing models** — the governance form the framework proposes ([Section 2.9.3](#));

3. **Circular economy, green procurement, and sustainability in higher education** — the environmental rationale and its policy context ([Section 2.9.4](#));
4. **Organizational readiness, digital transformation, and change** — the implementation conditions and sequencing logic ([Section 2.5](#));
5. **Risk and continuity frameworks** — the analytical instruments the study adapts ([Section 2.6](#)).

Each stream is treated in a uniform structure: the *trajectory* of the literature, the *key studies* with their substantive contributions, and the *limitation* that the present study addresses. This uniform treatment makes the comparative summary of [Section 2.7](#) possible and disciplines the gap statement of [Section 2.8](#), where the study's qualitative framework variables and its qualitative premise — advanced instead of statistical hypotheses — are formally stated.

2.2 Inventory Management in Educational and University Laboratories

2.2.1 Trajectory: from operational afterthought to managerial object

The literature on laboratory inventories in higher education has undergone a discernible reframing over the period covered by this review. Earlier treatment of laboratory stock was largely absorbed into facilities management, purchasing administration, or safety compliance; the more recent scholarship repositions the laboratory as a *resource-intensive organizational unit* whose material flows — reagents, consumables, instruments, glassware — constitute a managerial object in their own right, with financial, environmental, safety, and pedagogical consequences that exceed the purchasing transaction (Durgan et al., 2023; Freese et al., 2024). This reframing is the precondition for the present thesis: only if laboratory inventory is a governable organizational process, rather than a clerical residue of procurement, can a governance framework for it be designed at all. Four sub-stream's structure the stream: the resource-intensity and green-laboratory literature; the process-

discipline and traceability literature; the structured laboratory risk–analysis literature; and the Saudi laboratory context literature.

2.2.2 Key studies

Resource intensity and managerial reframing. (Freese et al., 2024) provides the stream’s most comprehensive orientation, surveying the material and energy intensity of research laboratories and documenting how over–purchasing, poor stock visibility, and absent rotation convert usable chemicals into avoidable waste; their analysis treats inventory practice, not individual carelessness, as the unit of intervention. (Durgan et al., 2023) complement this from the life–sciences laboratory, arguing that sustainable laboratory operation requires institutionalized practices — procurement discipline, sharing, and stock management — rather than one–off green campaigns, and explicitly framing sustainability as a management–system property. (Gutierrez et al., 2020) extend the argument to the university as an organizational system, examining how sustainability principles can be embedded in laboratory operations through procedural and governance mechanisms rather than through exhortation. Taking together, these works establish the thesis’s foundational premise: the drivers of chemical expiry, duplicate acquisition, and asset idleness are *structural* features of how laboratory inventory is organized, and they are therefore amenable to structural correction.

Process discipline and traceability. (Leoneti et al., 2019) apply business process management methodology to laboratory workflows, demonstrating that laboratory processes — including material and information flows — can be modelled, standardized, and improved with the same process discipline applied in industrial settings. This study matters to the thesis less for its specific process maps than for its warrant: it shows that the laboratory is not an exceptional domain exempt from process standardization, and that traceability of material flows is an achievable design target rather than an aspiration. The framework’s standardized catalog and records (prevention barrier PB1) and its

documented loan workflows are direct descendants of this process–management perspective.

Structured laboratory risk analysis. A distinct sub–stream brings formal risk–assessment technique to university laboratories. (Ayyildiz et al., 2025) apply structured multi–criteria risk assessment to laboratory environments, illustrating the trend toward systematic, criteria–based hazard evaluation rather than informal judgment. (Li et al., 2022) model laboratory safety risk through system–oriented analysis, emphasizing the interdependence of human, organizational, and material factors in laboratory accidents. (Zhao et al., 2023) contribute a structured risk–assessment approach for laboratory settings in the loss–prevention tradition, and (Papadopoli et al., 2020) examine biological–risk perception and safety compliance among laboratory personnel, underscoring that procedural compliance — not only engineered safeguards — determines realized safety performance. The collective lesson for this thesis is double–edged: laboratory risk scholarship is technically sophisticated, but it concentrates overwhelmingly on *safety hazards* (chemical, biological, physical) rather than on the *managerial hazards* — expiry, underutilization, custody failure — that the present framework takes as its top events. The thesis’s adaptation of the Bow–Tie method to inventory top events occupies precisely this unpopulated intersection ([Section 2.6](#)).

The Saudi laboratory context. (Hassanain et al., 2019) assess facilities and asset management practices in Saudi higher education, documenting the administrative structures through which Saudi universities manage physical assets and identifying the gap between asset–management aspiration and institutionalized practice. (Mohsen, 2025) examines laboratory management in the Saudi health–sciences education context, describing the operational routines and constraints under which Saudi educational laboratories actually run. Together these studies confirm the relevance of the problem setting — Saudi universities operate substantial laboratory capacity under developing

management structures — while stopping short of proposing governance designs for shared inventory: their object is description and assessment, not framework construction.

2.2.3 Limitation for the present purpose

Across the four sub-streams, a consistent limitation emerges. The green-laboratory literature diagnoses inventory dysfunctions convincingly but prescribes at the level of practice guidance — rotate stock, share where possible, procure responsibly — without specifying the organizational architecture (decision rights, policy instruments, custody rules, audit cadence) that would make such practices enforceable across an institution (Durgan et al., 2023; Freese et al., 2024). The process and risk literatures supply technique without governance: they show how to model and assess, but not who owns the controls, under what policy authority, and with what escalation paths (Ayyildiz et al., 2025; Leoneti et al., 2019). And the Saudi-context studies document the setting without designing for it (Hassanain et al., 2019; Mohsen, 2025). The present study addresses this limitation directly: it takes the diagnosed dysfunctions as *threats* in a formal risk architecture and assigns every countermeasure to a named organizational owner within a governance design tailored to a Saudi university setting.

2.3 Participatory and Resource-Sharing Models

2.3.1 Trajectory: from co-location to governed access

The sharing of laboratory resources has a long practical history in the form of core facilities and shared instrument rooms, but the literature's centre of gravity has shifted from describing co-located infrastructure toward analysing *governed access*: the rules, incentives, and trust mechanisms that determine whether shared resources are actually used equitably and sustainably (Strom et al., 2020; X. Wang & Qu, 2025). This trajectory parallels the broader sharing-economy literature's move from celebrating access-over-ownership to scrutinizing its governance preconditions (Zhu & Liu, 2021).

2.3.2 Key studies

Core and shared facilities. (Strom et al., 2020) analyze the operation of shared instrumentation facilities in materials research, showing that shared-access regimes raise utilization and broaden access only when booking, cost recovery, and stewardship responsibilities are institutionally specified — informal sharing arrangements decay. (Adami et al., 2021) examine shared resource operations in the biomolecular core-facility context, documenting the administrative infrastructure — tracking, scheduling, and accountability mechanisms — that professionalized sharing requires. Both studies establish the thesis’s stewardship principle: the value of shared stock is realized through availability and accountable custody, not through pooled ownership, and both therefore inform the Inter-Lab Policy Framework’s insistence that custody be unambiguous at every moment of a loan cycle.

Access-over-ownership logic. (Zhu & Liu, 2021) theorize the access-over-ownership model in consumption and production systems, articulating the conditions under which shared access displaces redundant acquisition and the conditions — transaction costs, trust deficits, responsibility ambiguity — under which it fails. This work supplies the conceptual grammar for the framework’s Principle of Stewardship over ownership: participation in a shared inventory is a governance arrangement with explicit allocation rules, not a pooling of property.

Governance cautions from instrument sharing. (X. Wang & Qu, 2025) study the governance of large scientific instrument sharing, identifying the failure modes of pooled-resource arrangements — free-riding, ambiguous responsibility for damage and maintenance, and eroded trust under weak platform rules — and the governance mechanisms that counter them. This is the stream’s most direct cautionary source for the present design: it predicts precisely the escalation factor the thesis labels custody ambiguity

(EF3) and thereby justifies the custody–transfer protocol (EB3), the damage/loss liability principle, and the loan limits and recall rights of the Inter–Lab Policy Framework.

Documented savings practice and acquisition trade–offs. (Tu & Greever–Wilson, 2025) document, in a clinical–biochemistry laboratory setting, the practice of reducing reagent and consumable waste through coordinated stock management and sharing arrangements; the study is cited here strictly qualitatively, as evidence that disciplined, coordinated inventory practice is operationally achievable in real laboratories — the thesis reports no figures from it. (Sorzano & Carazo, 2026) model the acquisition–versus–sharing trade–off for expensive scientific instrumentation, analyzing when shared access economically and operationally dominates purchase; their contribution is the analytical habit of treating acquisition as one option among governed alternatives rather than as the default — the same habit the framework’s eligibility clauses (PB2) institutionalize by requiring a shared–registry check before requisition.

2.3.3 Limitation for the present purpose

The sharing literature is, however, concentrated on research infrastructure — core facilities, large instruments, specialized platforms — rather than on the heterogeneous, high–throughput *teaching* inventory of consumables, glassware, and bench instruments that constitutes the present case (Adami et al., 2021; Strom et al., 2020). Its governance lessons, while transferable, are not pre–packaged for a university college in which dozens of semi–autonomous teaching laboratories share everyday stock under ordinary departmental budget authority; nor does it engage the Saudi higher–education administrative environment in which such rules must acquire force. The thesis’s contribution is to translate the sharing literature’s governance principles — specified stewardship, explicit decision rights, documented custody, liability allocation — into a ratified policy framework (the Inter–Lab Policy Framework) situated within a three–tier

governance architecture, and to extend the shared object from instruments to the full inventory including FEFO-governed chemical redistribution.

2.4 Circular Economy, Green Procurement, and Sustainability in Higher Education

2.4.1 Trajectory: from industrial ecology metaphor to campus operating logic

Circular economy (CE) scholarship provides the environmental-theoretic spine of the thesis. The foundational articulation — an economy restorative by design, in which materials circulate at their highest utility through nested loops of maintenance, reuse, and recovery rather than flowing linearly from extraction to disposal — was consolidated by the (Ellen MacArthur Foundation., 2013) and subsequently subjected to conceptual consolidation by (Kirchherr et al., 2017), whose review of the proliferating CE definitions established the reduce–reuse–recycle hierarchy and its governance preconditions as the concept’s durable core. The trajectory relevant here is the migration of CE from industrial systems into *higher education institutions as organizational sites*: campuses came to be analysed as microcosms in which material loops can be closed at institutional scale, and procurement came to be identified as the decisive upstream control point (Sönnichsen & Clement, 2020; Vergani, 2024).

2.4.2 Key studies

Campus circular economy. (Vergani, 2024) frames higher education institutions explicitly as microcosms of the circular economy, arguing that their bounded estates, concentrated material flows, and governance capacity make them unusually favourable sites for closed-loop practice — the analytical license for treating a university college’s laboratory inventory as a CE design object. (Giannoccaro et al., 2021) examine the conditions for implementing CE practices within organizational settings, emphasizing that circularity is an organizational capability requiring coordination mechanisms rather than a set of isolated technical fixes. (Salas et al., 2021) address CE implementation challenges in campus operations,

documenting the gap between circular ambition and operational embedding. (Qu et al., 2021) contribute the waste–system perspective, analysing campus material flows and the organizational arrangements for their reduction and recovery, while (Kumdokrub et al., 2023) bring analytical rigour to university waste and resource systems, and (Renfors, 2024) examines stakeholder and governance dimensions of campus sustainability transitions, reinforcing the finding that circular practice scales only through institutionalized coordination. Collectively, these studies validate the framework’s environmental design logic — joint purchasing as the *reduce* loop, pre–expiry redistribution as the *reuse* loop, FEFO discipline as the reduce–reuse interface — while remaining, as a body, stronger on ambition and system description than on enforceable governance instrument design.

Circular and sustainable procurement. (Sönnichsen & Clement, 2020) review circular and sustainable procurement systematically, establishing purchasing as the upstream determinant of downstream waste burdens: what and how an institution buys decides what it must later manage. This finding anchors the framework’s prevention–side environmental controls — eligibility clauses and joint/circular procurement rules (PB2, PB3) — and its adoption of the ISO 14001:2015 life–cycle perspective, which the thesis scrupulously maintains as a *perspective* on upstream and downstream stages rather than a full life–cycle assessment (14001 ISO/IEC, 2015). (Birleanu et al., 2025) examine centralized procurement organization in the public–sector context, illuminating the coordination benefits and governance costs of aggregation — directly relevant to the framework’s decision to constrain *how* departments buy through eligibility checks without usurping departmental budget authority. (Q. Wang et al., 2020) analyze procurement decision structures in supply management, providing purchasing–organization insight that informs the boundary between the framework’s ratified rules and existing university financial governance.

University social responsibility and reporting. Corporate social responsibility applied to universities — University Social Responsibility (USR) supplies the reputational and

legitimacy dimension. (Ali et al., 2021) review the USR field, establishing its conceptual contours: the integration of social and environmental concern into university operations with consequences for reputation, stakeholder trust, and legitimacy. (Ceulemans et al., 2015) analyze sustainability reporting in higher education, warning that disclosure decoupled from operational practice erodes rather than builds trust; (Alshuwaikhat & Abubakar, 2008) — a Saudi-authored study of campus sustainability — argue for an integrated approach in which environmental management, governance, and campus operations are mutually reinforcing rather than parallel activities. (Lakhno, 2024) sharpens the critique with the greenwashing question, demonstrating that advertised sustainability commitments unsupported by operations inflict reputational damage exceeding any communicative benefit. ISO 26000:2010, cited as orientation only — explicitly a guidance standard and not certifiable — completes the frame (26000 ISO/IEC, 2010). This literature directly shapes the framework’s architectural response to reputational risk: practice precedes reporting, so that any disclosure reports operational substance rather than aspiration.

Saudi Vision 2030 context. (Alamoudi et al., 2023) examine the integration of sustainability and Vision 2030 objectives into Saudi institutional practice, documenting the national policy environment within which Saudi universities now operate. (Alshammari, 2025) addresses transformation dynamics in Saudi higher education under Vision 2030, and (Alotaibi, 2026) examines digital and organizational change in Saudi educational institutions, together confirming that the reform themes of this thesis — fiscal efficiency, sustainability, digital transformation — are live national priorities rather than imported agendas. (Mohamed Hashim et al., 2022) analyze sustainable digital-transformation strategy in Saudi higher education specifically, establishing that Saudi universities’ transformation outcomes depend on organizational readiness and governance alignment — the Saudi-specific corroboration of the readiness literature reviewed in [Section 2.5](#).

2.4.3 Limitation for the present purpose

The campus–CE and USR literatures establish *why* a university should close material loops and substantiate its sustainability narrative, and the procurement literature establishes *where* the decisive control point lies; but neither specifies *how* a college–level governance apparatus should operationalize circularity in the mundane, high–volume domain of teaching–laboratory inventory — with which bodies, which ratified clauses, which custody rules, and which audit cadence (Ali et al., 2021; Sönnichsen & Clement, 2020; Vergani, 2024). The Vision 2030 literature, for its part, operates at national and institutional–strategy altitude and does not descend to laboratory inventory governance (Alamoudi et al., 2023; Mohamed Hashim et al., 2022). The present study fills this operational gap: it converts CE principles into named prevention and mitigation barriers (PB3, MB1, MB2, MB3), assigns them to governance bodies, and aligns them clause–by–clause with ISO 14001:2015’s aspect–control, life–cycle, and emergency–preparedness logic (14001 ISO/IEC, 2015).

2.5 Organizational Readiness, Digital Transformation, and Change

2.5.1 Trajectory: from technology adoption to readiness–first transformation

Higher–education digital–transformation scholarship has converged, over the review period, on a readiness–first thesis: transformation outcomes are determined less by technology selection than by organizational antecedents — process definition, governance clarity, data discipline, and change capability — and technology layered onto unstandardized processes reproduces fragmentation in digital form (Bellantuono et al., 2021; Rodríguez–Abitia & Bribiesca–Correa, 2021). This trajectory is the empirical–theoretic foundation of the thesis’s ordering claim that organizational maturity must precede digitalization, and of its deferral of smart–inventory platforms behind readiness gates.

2.5.2 Key studies

Readiness and maturity. (Rodríguez–Abitia & Bribiesca–Correa, 2021) assess digital–transformation readiness in higher education institutions, identifying the organizational dimensions — strategy, processes, people, data — on which readiness is won or lost. (Bravo–Jaico et al., 2025) extend readiness assessment with contemporary instrumentation, confirming the multidimensional character of transformation capability. (Shibambu, 2024) examines digital transformation in public–service organizations, supplying the public–sector governance dimension — accountability structures and administrative routines — that a public university shares. (Farias–Gaytan et al., 2023) analyze digital transformation in educational institutions through the change–and–capability lens, reinforcing that sustained transformation is a capability–building process rather than an acquisition event. These works jointly anchor the framework’s readiness gates and its treatment of the shared registry’s data discipline as the precondition for any future platform.

Change management. (Bellantuono et al., 2021) analyze digital–transformation implementation in higher education, showing that staged, capability–building transitions outperform big–bang adoption; (Vlachopoulos, 2021) examines organizational change in educational institutions, emphasizing the human and structural mediation of reform; (Sung & Kim, 2021) address the change–management conditions of organizational innovation adoption; and (Dean et al., 2024) study leadership of change in educational settings, documenting the staged, pilot–oriented sequencing through which university reform succeeds. This sub–stream directly justifies the framework’s gradualism principle — pilot–first in the Biology Department, readiness–gated scaling — and its roadmap sequencing.

Collaborative and participatory governance. (Ahn & Baldwin, 2024) analyze collaborative governance arrangements, demonstrating that participation decays into nominal compliance when decision rights and accountability are not explicitly allocated; (Lopes & Farias, 2022) examine participatory arrangements in public administration,

documenting the failure mode of delegated responsibility without corresponding rights; and (Gestel & Grotenbreg, 2021) study collaborative governance practice, identifying procedural clarity, trust, and equitable benefit distribution as the conditions of durable collaboration. This triad supplies the framework’s central governance wager: participatory inventory is sustainable only when collaboration is institutionalized as bounded roles with explicit decision rights — and it licenses the separation of execution from authority that bounds the laboratory technician role to strictly technical duties with escalation duties but no administrative, procurement, or financial authority.

Smart inventory technology. (Carpitella & Izquierdo, 2025) examine smart inventory management technologies, confirming that automated tracking delivers value only where inventory processes and data semantics are already standardized; (Wilke et al., 2023) analyze technology-assisted inventory management in health-system pharmacy, documenting the operational discipline — date-ordered rotation, accurate records — on which tracking technology depends; (Maulana et al., 2023) present RFID-based inventory system design for institutional settings, illustrating the technical substrate; and (Adirektawon et al., 2024) examine inventory and logistics management for laboratory consumables, documenting the fragility of consumable supply and the disruption costs of stock-outs and expired stock. Together these studies corroborate both the continuity rationale ([Section 2.6](#)) and the deferral of platform acquisition: the technology literature itself instructs that process standardization comes first.

Green behavior. (Fareed El-Tony & Choo, 2024) examine green behavior among university laboratory users, showing that individual sustainable behavior is shaped by institutional structures and norms rather than arising spontaneously — the behavioral complement to the framework’s structural wager that well-designed rules, competence requirements, and escalation duties convert individual bench-level action into institutional performance.

2.5.3 Limitation for the present purpose

This literature establishes the *necessity* of readiness—first sequencing and bounded participation but remains general: readiness models are institution—wide, change studies concern curricula and strategy more often than operational inventory regimes, and collaborative—governance theory is not pre—fitted to a college’s laboratory stock (Ahn & Baldwin, 2024; Rodríguez—Abitia & Bribiesca—Correa, 2021). The technology studies, concentrated in healthcare and engineering settings, address platforms more than the policy scaffolding that must precede them (Carpitella & Izquierdo, 2025; Wilke et al., 2023). The thesis’s contribution is to *particularize* it translates readiness theory into specific gates (process standardization, governance ratification, data—quality indicators) for a specific reform — participatory laboratory inventory — and translates collaborative—governance cautions into a concrete allocation of decision rights across a Board, a Committee, a Unit, custodian departments, and technicians.

2.6 Risk and Continuity Frameworks in Literature

2.6.1 Trajectory: from technique inventories to governance instruments

The final stream comprises the analytical instruments the thesis adapts. The trajectory across this literature runs from risk management as an isolated technical function toward risk management as an organizational capability embedded in governance — the movement ISO 31000:2018 codifies by framing risk management as integrated, customized, and continual rather than episodic (31000 ISO/IEC, 2018).

2.6.2 Key studies and standards

Risk maturity models. (Hillson, D. A., 1997) published the first risk maturity model, defining four levels — Naive, Novice, Normalized, Natural — each characterized along culture, process, experience, and application; (Hopkinson, 2017) developed a parallel

project risk maturity model on the same ladder logic. The capability–maturity lineage of (Paulk et al., 1993) — the five–level Initial–to–Optimizing scale — supplies the cognate process–institutionalization ladder, and ISO/IEC 33020:2019 formalizes capability levels in standards language. Because no published model uses the level names this thesis adopts, the study explicitly declares “Inform/Conform,” “Managed/Normalized,” and “Perform” as its own adapted three–band terminology, anchored to Hillson’s Naive/Novice, Normalized, and Natural levels respectively and to the corresponding capability–maturity ranges (Hillson, D. A., 1997; Paulk et al., 1993). The limitation of the maturity literature for the present purpose is that it diagnoses capability without prescribing the governance anatomy that raises the deficiency [Section 4.1](#)’s architecture addresses.

Bow–Tie method. (de Ruijter & Guldenmund, 2016) provide the definitive methodological review of the bow–tie method, establishing its qualitative nature, its canonical structure — Hazard, Top Event, Threats, Prevention barriers, Mitigation barriers, Consequences (Johnson et al., 2018), and Escalation factors — and its documented pitfalls. supply the standard terminology and construction discipline the thesis follows exactly, and IEC 31010:2019 formally defines the bow–tie as a graphical depiction of the pathways from the causes of an event to its consequences, classifying it among techniques for analyzing controls (31010 ISO/IEC, 2019). (Cormier et al., 2019) furnish the critical precedent for the thesis’s adaptation: they demonstrate bow–tie application to environmental management and *policy* problems, arguing that the method’s value lies in clarifying management controls and their ownership rather than in engineering calculation — the licence for transferring the method from process–safety hazards to inventory–management top events, an adaptation the thesis declares explicitly. The literature’s limitation is that bow–tie applications remain concentrated in safety engineering; managerial hazards such as chemical expiration and asset underutilization are not its standard objects, and the ownership handoff from barriers to governance bodies is asserted more often than executed.

The FIRM taxonomy. (Hopkin, 2018) presents the FIRM Scorecard in the Institute of Risk Management's standard textbook: a risk *classification* taxonomy categorizing risks by their impact on the organization's key dependencies — Financial, Infrastructure, Reputational, and Marketplace — with structural properties (Financial and Infrastructure predominantly internal; Reputational and Marketplace predominantly external) that carry analytical value beyond labelling. The thesis uses FIRM strictly as a taxonomy — not a scoring algorithm — and declares its reading of Marketplace as the university's service and stakeholder environment (Hopkin, 2018). Its limitation is that it classifies without assessing; the thesis therefore couples it with the maturity trajectory and the bow-tie rather than treating it as self-sufficient.

Standards as design references. Four standards function as design references rather than certification targets. ISO 31000:2018 supplies the umbrella risk-process framing (31000 ISO/IEC, 2018, p. 2018). ISO 22301:2019 contributes business-continuity logic in its 2019 vocabulary — business impact analysis (BIA), prioritized activities, maximum tolerable period of disruption (MTPD), recovery time objective (RTO), and minimum acceptable capacity — which the thesis applies qualitatively to identify scheduled practical teaching and time-sensitive research protocols as prioritized activities and shared visibility with inter-lab loans as Clause 8.3 continuity solutions; the thesis does not attribute to the 2019 edition terminology it removed (22301 ISO/IEC, 2019, p. 2019). ISO 14001:2015 contributes the environmental management system logic — environmental aspects versus impacts, compliance obligations, the life-cycle perspective, Clause 8.2 emergency preparedness, and the operative verb *conformity* rather than compliance (14001 ISO/IEC, 2015). ISO 26000:2010 is cited as non-certifiable guidance on social responsibility only (26000 ISO/IEC, 2010). The PMBOK Guide's treatment of risk within governance and value-delivery systems completes the project-management framing (PMI, 2021). The limitation of standards, for this purpose, is intrinsic: they specify requirements, not

institutional designs; the translation of clause logic into a named governance architecture for laboratory inventory is precisely the design work this thesis performs.

2.7 Comparative Summary of Previous Studies

[Table 2.1](#) consolidates the five thematic streams, contrasting each stream’s representative studies, typical methods, and typical objects of study with the specific limitation the present study addresses.

Table 2.1. Comparative summary of the five thematic literature streams

Thematic stream	Representative studies	Typical method	Typical object of study	Limitation this study addresses
Inventory management in educational/university laboratories	Freese et al. (2024); Durgan et al. (2023); Gutierrez et al. (2020); Leoneti et al. (2020); Ayyildiz et al. (2025); Hassanain et al. (2020)	Practice reviews and guidance; process modelling; quantitative/multi-criteria risk assessment; descriptive context studies	Laboratory material flows, chemical waste, safety hazards, facilities and asset management	Diagnosis without governance architecture: dysfunctions documented, but no design assigning countermeasures to named owners under ratified policy

Thematic stream	Representative studies	Typical method	Typical object of study	Limitation this study addresses
Participatory and resource-sharing models	Strom et al. (2020); Adami et al. (2021); Zhu & Liu (2021); Wang & Qu (2025); Sorzano & Carazo (2026)	Case analysis; conceptual/theoretic al modelling; governance analysis; acquisition trade-off modelling	Research core facilities, shared instruments, sharing-economy platforms	Concentration on research infrastructure, teaching-laboratory inventory; governance principles not translated into ratified college-level policy (custody, loans, FEFO redistribution)
Circular economy, green procurement, and sustainability in HE	Ellen MacArthur Foundation (2013); Kirchherr et al. (2017); Vergani (2024); Sönnichsen & Clement (2020); Ali et al. (2021); Ceulemans et al. (2015); Lakhno (2024); Alamoudi et al. (2023)	Conceptual consolidation; systematic reviews; case studies; reporting/governance analysis	Campus material loops, procurement systems, USR and sustainability reporting, national strategy	Altitude gap: principles and strategy without college-level operational instruments; circularity not yet specified as enforceable inventory barriers
Organizational readiness, digital transformation, and change	Rodríguez-Abitia & Bribiesca-Correa (2021); Bellantuono et al. (2021); Dean	Readiness/maturity assessment; empirical change studies; governance theory; technology	Institution-wide digital transformation, collaborative	Generality: readiness and participation principles not particularized to a laboratory-inventory

Thematic stream	Representative studies	Typical method	Typical object of study	Limitation this study addresses
	et al. (2024); Ahn & Baldwin (2024); Carpitella & Izquierdo (2025); Wilke et al. (2023); Fareed El-Tony & Choo (2025)	implementation studies	governance, smart inventory platforms	reform with specific gates and bounded roles
Risk and continuity frameworks	Hillson (1997); Paulk et al. (1993); Ruijter & Guldenmund (2016); CCPS & Energy Institute (2018); Cormier et al. (2019); Hopkin (2018); ISO (2018, 2019, 2015); IEC (2019)	Methodological reviews; standards specification; textbook synthesis	Risk maturity diagnosis, bow-tie control analysis, risk classification, management-system requirements	Technique without institutional embodiment: instruments diagnose, structure, and classify, but do not themselves constitute a governance design

Reading across the columns, three regularities emerge. First, applied literature is dominated by *quantitative and empirical measurement studies* — multi-criteria risk assessments, readiness instruments, waste-system analyses — whose outputs are measurements of existing states rather than designs for new arrangements (Ayyildiz et al., 2025; Bravo-Jaico et al., 2025). Second, the laboratory-sustainability literature is

overwhelmingly *guidance-oriented*: it prescribes good practice at the level of exhortation or professional recommendation, without specifying enforceable organizational mechanisms (Durgan et al., 2023; Freese et al., 2024). Third, the digitalization literature is *technology-focused*, treating platforms and tracking systems as the object of study and organizational preconditions as background (Carpitella & Izquierdo, 2025; Wilke et al., 2023). What none of the five streams contains is an *integrated qualitative governance design* for participatory laboratory inventory: a framework that simultaneously diagnoses institutional maturity, structures inventory risk pathways, specifies continuity and environmental conformity targets by standards analogue, classifies residual risk, assigns every barrier to a named organizational owner, and sequences implementation through readiness gates — still less one situated in Saudi higher education. That absence is the gap the thesis addresses.

2.8 Research Gap and the Study's Qualitative Framework Variables

2.8.1 Statement of the gap

The gap can now be stated precisely. The verified literature contains: (a) well-documented diagnoses of laboratory inventory dysfunction, without governance designs to correct them ([Section 2.2](#)); (b) governance principles for shared research infrastructure, untranslated to teaching-laboratory inventory and to Saudi university administration ([Section 2.3](#)); (c) circular-economy and procurement principles, undescended to college-level operational instruments ([Section 2.4](#)); (d) readiness-first transformation and collaborative-governance theory, unparticularized to this reform object ([Section 2.5](#)); and (e) risk and continuity instruments, unembodied in institutional designs ([Section 2.6](#)). No located study integrates these streams into a single qualitative governance framework for participatory inventory management in educational laboratories; none does so for a Saudi higher-education institution aligned with Vision 2030; and none couples a Bow-Tie barrier architecture to

an explicit organizational ownership structure under standards–derived conformity targets. The present study occupies this intersection.

2.8.2 Qualitative framework variables

Because the study is qualitative and design–oriented, it does not formulate statistical hypotheses over measured variables. It instead defines *framework dimensions* — qualitative axes along which the framework’s design intent is stated and against which its structural coherence is assessed — organized into three independent dimensions (the governance levers the framework manipulates) and three dependent dimensions (the outcomes the levers are designed to advance). [Table 2.2](#) defines each dimension, names the framework elements that operationalize it, and cross–references the thesis sections where it is treated.

Table 1.2. Qualitative framework variables/axes

Dimension	Type	Qualitative definition	Framework elements operationalizing it	Chapters & Sections
Governance Architecture	Independent	The degree to which inventory governance is embodied in named bodies with bounded, ratified decision rights — policy authority, standard–setting, data stewardship, and bounded operational execution — as opposed to diffuse informal practice	Three–tier Academic Governance Technical Standardization Committee, Digital Supply Chain Unit; technician role bounded to technical execution with escalation duties; RACI accountability matrix; barrier–ownership mapping	Chapter 4 (Sections 4.1.1 – 4.1.5 , 4.1.7); Chapter 2 (Section 2.9.6)

Dimension	Type	Qualitative definition	Framework elements operationalizing it	Chapters & Sections
Policy Control	Independent	The degree to which purchasing, sharing, and disposal behavior is constrained by ratified, checkable policy instruments rather than local discretion	Eligibility clauses (registry check before requisition; redistribution-before-disposal); FEFO policy standard; Inter-Lab Policy Framework (eligibility and scope, loan workflow, custody-transfer protocol, loan limits, recall rights, liability principle)	Chapter 4 (Sections 4.1.3 , 4.1.6); Chapter 2 (Section 2.9.1)
Standardization	Independent	The degree to which inventory information and workflows conform to common, version-controlled standards making stock visible, comparable, and auditable across laboratories	Unified catalog and classification standard (PB1); registry data-entry protocols; data-quality indicators (EB2); documented-information discipline at every workflow step	Chapter 4 (Sections 4.1.3 , 4.1.4 , 4.4.3); Chapter 2 (Section 2.9.1)
Operational Efficiency	Dependent	The degree to which the institution's aggregate stock delivers its intended academic value — assets utilized rather than idle, loans routine rather than exceptional, requisitions displaced by existing stock where suitable	Shared-visibility registry; inter-lab loan workflows; eligibility-checked purchasing; asset-utilization and loan-flow indicators	Chapter 4 (Sections 4.2.4 , 4.4.1)

Dimension	Type	Qualitative definition	Framework elements operationalizing it	Chapters & Sections
Environmental Sustainability	Dependent	The degree to which significant environmental aspects (expired chemicals, redundant assets) are controlled under a life-cycle perspective, waste is minimized through reduce-reuse loops, and fulfilment of compliance obligations is evaluated	FEFO rotation and pre-expiry redistribution (MB1, MB2); governed disposal protocols (MB3); joint/circular procurement rules (PB3); aspect identification and compliance-obligation evaluation per ISO 14001:2015 analogue	Chapter 4 (Sections 4.2.5 , 4.4.2); Chapter 2 (Section 2.9.5)
Business Continuity	Dependent	The degree to which prioritized teaching and research activities are protected against supply disruption through internally reconfigurable stock, within qualitative MTPD/RTO reasoning and minimum acceptable capacity logic	Qualitative BIA identifying prioritized activities; shared registry and inter-lab loans as Clause 8.3 continuity solutions; loan-escalation and communication procedures; exercise and review analogues; readiness-gated continuity indicators	Chapter 2 (Section 2.9.4); Chapter 4 (Sections 4.2.6 , 4.3 , 4.4.3)

Two properties of this variable structure deserve emphasis. First, the classification is *functional, not causal-statistical*: “independent” denotes the dimensions the framework’s design directly manipulates (governance embodiment, policy instruments, standardization), and “dependent” denotes the dimensions whose advancement the design intends — a design-logic dependency, not a regression claim. Second, every operationalizing element is traceable to the risk architecture: the independent dimensions correspond to the bow-

tie's prevention and escalation-factor barriers and their Chapter 4 ([Section 4.1](#)) owners, while the dependent dimensions correspond to the consequence classes the mitigation barriers address, classified under the FIRM taxonomy (Hopkin, 2018; Johnson et al., 2018). The variable structure is therefore not an add-on to the framework but a restatement of it in evaluable form.

2.8.3 The qualitative premise in lieu of statistical hypotheses

In place of testable statistical hypotheses, the study advances a single formally stated **qualitative premise**:

Strengthening the three independent dimensions — governance architecture, policy control, and standardization — through the proposed framework advances the three dependent dimensions — operational efficiency, environmental sustainability, and business continuity — along the adapted maturity trajectory from Inform/Conform through Managed/Normalized toward Perform.

The premise is stated to be testable *in principle*: at each readiness gate, the framework specifies the qualitative evidence — barrier deployment, data-quality standing, loan-workflow functioning, audit outcomes — against which advancement along the trajectory could be judged, and the KPI dashboard defines the indicators through which such judgment would later be disciplined (Chapter 4, Sections [4.2.6](#) and [4.4](#)). Within the present study, however, the premise is evaluated *structurally, not statistically*: the thesis demonstrates that the framework's design coherently connects each independent dimension to each dependent dimension through named mechanisms — standardization to efficiency through shared visibility; policy control to sustainability through eligibility and rotation rules; governance architecture to continuity through owned objectives, exercised procedures, and review cadence — and that the maturity literature predicts precisely this ordering, in which standardized, governed, measured organizations outperform reactive

ones (Hillson, D. A., 1997; Paulk et al., 1993). Whether the premise holds in operation is the question the framework's gate-governed implementation is designed to answer, and it is reserved accordingly for future empirical study following adoption (Chapter 3 and Chapter 4, Section [4.6](#)).

The chapter has thereby completed the argumentative movement from literature to design: the review extracted the design lessons of five thematic streams, demonstrated the absence of their integration, and converted that absence into a precisely stated gap, a defined variable structure, and a qualitative premise. The following chapter specifies the methodology by which the framework answering that gap was constructed and assessed.

2.9 Theoretical and Risk Assessment Framework

2.9.1 Architecture of the Integrated Framework

This section constructs the analytical apparatus through which the thesis reframes laboratory inventory failure within a large public higher education institution as a governable, assessable phenomenon. Chapter 1 defined the problem as a Risk Maturity Gap: the decentralized inventory regime operates below the capability required to sustain shared, digitized, environmentally responsible stock management. The present section specifies *how* that gap is diagnosed, structured, and addressed. Rather than adopting a single risk technique, the study proposes an integrated framework of five analytical lenses, each performing a distinct epistemic function and each governing a distinct element of the framework that Chapter 4 (Section [4.1](#)) will institutionalize. This compositional logic follows the project management discipline's treatment of risk as an organizational capability rather than an isolated calculation: the PMBOK Guide situates risk management within governance, tailoring, and value-delivery systems (Project Management Institute (PMI,

2021)), and ISO 31000:2018 likewise frames risk management as an integrated, customized component of organizational decision-making (31000 ISO/IEC, 2018).

The five lenses interlock sequentially. First, the Risk Maturity Model (RMM) diagnoses *where the institution is* — its current capability band relative to the demands of participatory inventory management (Hillson, D. A., 1997; Paulk et al., 1993). Second, the Bow-Tie method structures *the risk pathways the framework must control*, making explicit the causal chains from management weaknesses to loss events and the barriers that interrupt them (31010 ISO/IEC, 2019; Johnson et al., 2018). Third, ISO 22301:2019 specifies the *continuity outcomes* the framework must secure — the protection of prioritized teaching and research activities against supply-chain disruption (22301 ISO/IEC, 2019). Fourth, ISO 14001:2015, read together with the corporate and university social responsibility (CSR/USR) literature, specifies the *environmental and reputational outcomes* (Ali et al., 2021; 14001 ISO/IEC, 2015). Fifth, the FIRM Scorecard classifies the risk register by organizational dependency and impact area, providing a stable taxonomy for governance reporting (Hopkin, 2018).

The integration is deliberately non-redundant: each lens answers a question the others cannot. A maturity model cannot depict causal pathways; a Bow-Tie diagram cannot certify continuity performance; ISO 22301 says nothing about environmental aspects; ISO 14001 does not classify financial dependencies; and the FIRM taxonomy diagnoses nothing about capability. Their combination constitutes a complete assessment chain — diagnosis, structuring, outcome specification, and classification — consistent with ISO 31000:2018's principles of integration and customization (31000 ISO/IEC, 2018) and with the PMBOK Guide's insistence that risk processes be tailored to context (PMI, 2021). [Table 2.3](#) summarizes the architecture.

Table 2.3 Mapping of the five analytical lenses to framework functions and governing elements

Lens	Analytical function	Framework element it governs	Primary standard/reference
Risk Maturity Model (adapted Inform/Conform → Managed/Normalized → Perform bands)	Diagnoses institutional capability baseline and maturity gap	Baseline assessment; sequencing of reforms; readiness gates for digitalization	Hillson (1997); Paulk et al. (1993); ISO/IEC 33020:2019
Bow-Tie risk analysis	Structures threat– barrier–consequence pathways for inventory loss events	Barrier architecture (prevention, mitigation, escalation–factor barriers); barrier ownership handed to Section 4.1 roles	IEC 31010:2019 (IEC, 2019); CCPS & Energy Institute (2018); de Ruijter & Guldenmund (2016)
ISO 22301:2019 Business Continuity	Specifies continuity outcomes for prioritized activities	Business impact analysis (BIA) logic; continuity strategies (shared registry, inter-lab loans); exercise and evaluation analogues	ISO 22301:2019 (ISO, 2019); ISO/TS 22317:2021
ISO 14001:2015 + CSR/USR	Specifies environmental and reputational outcomes	Environmental aspect control; life-cycle perspective on procurement; compliance– obligation evaluation; reputation protection	ISO 14001:2015 (ISO, 2015); ISO 26000:2010 (ISO, 2010); Ali et al. (2021)

Lens	Analytical function	Framework element it governs	Primary standard/reference
FIRM Scorecard (taxonomy)	Classifies risks by dependency/impact area	Risk register categories (Financial, Infrastructure, Reputational, Marketplace—as– stakeholder– environment)	Hopkin (2018)

Three design commitments govern the use of these lenses. First, every adaptation of a published model is explicitly declared and anchored to its source; the thesis does not attribute its own terminology to standards bodies. Second, all analysis is qualitative: the framework yields classifications, maturity judgments, and barrier specifications, not numerical scores or empirical measurements. Third, the framework is written for a contextual case–study setting—a large public science faculty within a Saudi higher education institution, with a life sciences department as the embedded unit of analysis—but its constructs are stated generally enough to transfer to other educational laboratory environments (Takagi et al., 2024).

2.9.2 Risk Maturity Model for Academic Laboratories

2.9.2.1 Anchors and the declaration of adapted terminology

Risk maturity models assess an organization’s capability to manage risk, on the premise that effectiveness is a function of organizational culture, process, experience, and application rather than of any single tool (Hillson, D. A., 1997). Hillson’s original model — the first published RMM — defines four levels: Naive (unaware of the need for risk management), Novice (experimenting without structure), Normalized (structured processes embedded in routine business), and Natural (a risk–aware culture with proactive, integrated

practice), each characterized along the four attributes of culture, process, experience, and application (Hillson, D. A., 1997). A parallel lineage derives from software capability maturity: the five-level SEI/Capability Maturity Model (CMM) scale — Initial, Managed, Defined, Quantitatively Managed, optimizing — describes the institutionalization of process discipline from ad hoc practice to continuous optimization (Paulk et al., 1993). Contemporary standards formalize a cognate ladder: ISO/IEC 33020:2019 defines capability levels from Incomplete through Performed, Managed, Established, and Predictable to Innovating, and related project-domain frameworks corroborate the same logic of staged capability growth (Hopkinson, 2017).

No published model, however, uses the level names adopted in this thesis. This study therefore **explicitly declares “Inform/Conform,” “Managed/Normalized,” and “Perform” as its own adapted terminology**, a three-band trajectory constructed for the educational-laboratory context and anchored as follows: *Inform/Conform* corresponds to Hillson’s Naive and Novice levels (reactive, compliance-only practice) and to the CMM Initial and lower Managed levels; *Managed/Normalized* corresponds to Hillson’s Normalized level and the CMM Defined level, where standardized processes are documented and consistently applied; and *Perform* corresponds to Hillson’s Natural level and the CMM Quantitatively Managed–Optimizing range (also ISO/IEC 33020’s Predictable and Innovating levels), where risk-aware practice is anticipatory, measured, and continuously improved (Hillson, D. A., 1997; Paulk et al., 1993). The three-band compression is a deliberate design choice: five-level granularity exceeds what a qualitative, non-instrumented assessment of a single institutional setting can defensibly discriminate, whereas three bands map cleanly onto the reform sequence this thesis proposes.

2.9.2.2 The three-band trajectory in a laboratory context

[Table 2.4](#) operationalizes the bands for laboratory inventory governance, re-expressing Hillson's four attributes (culture, process, experience, application) as risk culture, inventory process, governance, and contextual evidence.

Table 2.4. Adapted three-band risk maturity trajectory for educational laboratory inventory (thesis's adapted terminology, anchored to (Hillson, D. A., 1997; Paulk et al., 1993))

Band	Risk culture	Inventory process	Governance	Evidence of maturity in a lab context
Inform/Conform (reactive compliance)	Risk treated as a documentation burden; incidents handled after occurrence; procurement decisions default to local convenience	Each laboratory keeps its own records, formats, and requisitions; no stock-rotation discipline; no shared visibility	No dedicated inventory governance body; responsibilities diffuse; policy absent or unenforced	Duplicate purchasing across neighboring laboratories; expired chemicals discovered at audit; idle instruments alongside unmet demand
Managed/Normalized (standardized control)	Risk recognized as manageable through structure; staff follow defined procedures	Standardized catalog and records; First-Expired-First-Out (FEFO) rotation rules documented;	Named bodies own standards and data; custody rules and escalation paths documented	Consistent data quality across laboratories; rotation executed as routine; requisitions

Band	Risk culture	Inventory process	Governance	Evidence of maturity in a lab context
	because they are defined	eligibility clauses applied before requisition		checked against a shared registry
Perform (excellence-oriented, anticipatory)	Risk awareness embedded in daily decisions; improvement proposals originate at all levels within role boundaries	Shared visibility exploited for redistribution before expiry; inter-lab loans routine; continuity procedures exercised	Governance reviews performance, audits barriers, and revises policy; continuity and environmental objectives integrated	Pre-expiry redistribution displaces new purchasing; loan workflows function during supply interruptions; audit findings decline and are acted upon

2.9.2.3 Maturity-gap diagnosis of the decentralized regime

Against this trajectory, the decentralized regime described in Section 1 sits squarely in the Inform/Conform band: each laboratory maintains its own records and requisitions, with no shared visibility, no inter-lab lending policy, and no standardized data structure. The regime's three structural consequences — duplicate purchasing as the default when existence elsewhere is unknown, depressed asset utilization while neighboring needs go unmet, and expired-chemical waste from small, isolated stocks whose shelf life lapses unnoticed — are not discrete failures but symptoms of a single capability deficit (Hillson, D. A., 1997). In maturity terms, the institution lacks the *process* attribute (standardization), the *experience* attribute (accumulated shared practice), and the *application* attribute (risk techniques used in decisions), while its *culture* remains compliance-driven. The diagnosis

matters because it determines sequencing: a maturity gap of this kind cannot be closed by procurement alone and specifically cannot be closed by technology acquisition.

2.9.2.4 Transition logic and the precedence of maturity over digitalization

Movement between bands is produced by three transitions, each corresponding to a design element of the proposed framework. First, **standardization** moves an institution from Inform/Conform toward Managed/Normalized: a common catalog, common record structures, and documented rotation and eligibility rules convert idiosyncratic local practice into an organizational process in the CMM sense of the Defined level (Paulk et al., 1993). Second, **governance** consolidates the Managed/Normalized band: named bodies with decision rights, custody rules, and audit cadence make the standardized process enforceable and self-correcting, addressing the accountability vacuum characteristic of Hillson's Novice state (Hillson, D. A., 1997). Third, **measurement and review** open the path to Perform: monitoring of barrier performance, internal audit, and management review — the Check and Act phases of the Annex SL management-system cycle — supply the feedback loops that distinguish anticipatory from merely compliant practice (14001 ISO/IEC, 2015; 31010 ISO/IEC, 2019).

This logic entails a strict ordering claim: **organizational maturity must precede digitalization**. The higher-education digital-transformation literature consistently reports that technology layered onto unstandardized processes and unclear roles reproduces existing fragmentation in digital form, and that readiness — process definition, governance clarity, data discipline — is the binding constraint on transformation outcomes (Bellantuono et al., 2021; Bravo-Jaico et al., 2025; Rodríguez-Abitia & Bribiesca-Correa, 2021). Applied here, a shared digital registry deployed into an Inform/Conform regime would merely digitize unstandardized records and ambiguous custody; the framework therefore treats digitalization as a Perform-band capability unlocked by, not substituted for,

standardization and governance reform. [Figure 2.1](#) depicts the maturity ladder and its transition drivers.



Figure 2.1. Adapted maturity ladder for educational laboratory inventory governance (thesis's adapted band terminology; anchors per (Hillson, D. A., 1997; 33020 ISO/IEC, 2019, p. 2019; Paulk et al., 1993)).

2.9.3 Bow–Tie Risk Analysis Adapted to Laboratory Safety and Inventory

2.9.3.1 Method origin, qualitative nature, and precedent for management–domain adaptation

The Bow–Tie method originates in cause–consequence diagramming of the early 1970s and was standardized by Shell in the early 1990s within its Hazard and Effects Management Process following the Piper Alpha disaster, subsequently spreading to aviation, mining, maritime, healthcare, water safety, and environmental management (de Ruijter & Guldenmund, 2016; Johnson et al., 2018). IEC 31010:2019 formally defines the bow–tie as a graphical depiction of the pathways from the causes of an event to its consequences, classifying it among techniques for analyzing controls (31010 ISO/IEC, 2019). The method is **qualitative by nature**: it structures reasoning about threats, controls, and consequences without requiring quantification, which makes it methodologically congruent with this thesis’s qualitative design (de Ruijter & Guldenmund, 2016; 31010 ISO/IEC, 2019).

Critically, the method has an established precedent beyond process safety: (Cormier et al., 2019) demonstrate its application to environmental *management and policy* problems, arguing that its value lies in clarifying management controls and their ownership rather than in engineering calculation. This precedent license is the transfer from physical–process hazards to inventory–management hazards, provided the adaptation is declared — as it is here. The adaptation also respects the method’s canonical pitfalls: the knot of the diagram is the Top Event (the moment of loss of control), not “the risk” as a whole; prevention barriers sit between threat and Top Event; mitigation barriers sit between Top Event and consequence (de Ruijter & Guldenmund, 2016; Johnson et al., 2018).

2.9.3.2 Specification of the adapted bow-tie

Using CCPS terminology exactly (Johnson et al., 2018), the adapted bow-tie is specified as follows.

Hazard. The management of chemical and asset inventories in educational laboratories — an ongoing operational activity with the potential to cause financial, environmental, health-and-safety, and academic harm when control is lost.

Top Events (loss of control). The thesis declares two adapted Top Events, corresponding to the regime's two dominant loss pathways:

- **TE1 — Chemical expiration beyond usable shelf life:** stock passes its expiry point while held, unnoticed, in decentralized storage.
- **TE2 — Chronic asset underutilization:** instruments and durable assets remain idle while demand elsewhere goes unmet, so the asset stock fails to deliver its intended academic value.

Threats (left side). Four initiating conditions, all documented in Chapter 1 as features of the decentralized regime: (T1) over-ordering without cross-lab visibility; (T2) absent stock-rotation discipline; (T3) unstandardized records concealing stock identity, quantity, and age; and (T4) siloed custody, in which assets and chemicals are controlled by individual laboratories with no transfer mechanism.

Prevention barriers (left side). Three barriers terminate or weaken threat pathways before loss of control: (PB1) *standardization of the catalog and records* — a common data structure making stock visible, comparable, and auditable; (PB2) *eligibility clauses for purchasing* — a mandatory check of the shared registry before any requisition is approved, so that existing stock displaces new purchase; and (PB3) *joint/circular procurement rules*

— institution-level aggregation and circular-economy criteria that reduce incoming volume and align purchasing with consumption (Sönnichsen & Clement, 2020).

Consequences (right side). Four consequence classes, each mapped to a FIRM category ([Section 2.9.5](#)): (C1) financial waste and expiry write-offs — *Financial*; (C2) hazardous-waste accumulation and health, safety, and environment (HSE) exposure — *Infrastructure* (the physical estate and its safe operation); (C3) teaching and research disruption when expired stock or unavailable assets interrupt scheduled practical work — *Marketplace*, read as the service/stakeholder environment; and (C4) reputational damage from waste incidents or adverse audit findings — *Reputational* (Hopkin, 2018).

Mitigation barriers (right side). Three barriers reduce consequence severity once loss of control has begun: (MB1) *FEFO (First-Expired-First-Out) rotation rules*, ensuring earliest-expiring stock is consumed first; (MB2) *inter-lab sharing and redistribution before expiry*, moving soon-to-expire chemicals and idle assets to laboratories with live demand; and (MB3) *governed disposal protocols*, routing unavoidable waste through documented, compliant channels rather than unsafe accumulation (Freese et al., 2024; Gutierrez et al., 2020).

Escalation factors and escalation-factor barriers. The method's final element accounts for conditions that degrade barrier performance (Johnson et al., 2018). Three escalation factors threaten the barriers above: (EF1) unenforced policies, hollowing out PB2 and MB1; (EF2) incomplete registry data, blinding PB1, PB2, and MB2 simultaneously; and (EF3) custody ambiguity during transfers, undermining MB2 by making lending laboratories bear uncompensated risk. Each receives its own barrier: (EB1) a defined **audit cadence** against EF1; (EB2) **data-quality indicators** against EF2; and (EB3) a **custody-transfer protocol** documenting responsibility at each handover against EF3.

2.9.3.3 Diagram and interpretation

Figure 2.2 renders the specification as a bow-tie diagram; the parallel structure for TE2 is stated in the text and shares the same barrier architecture.

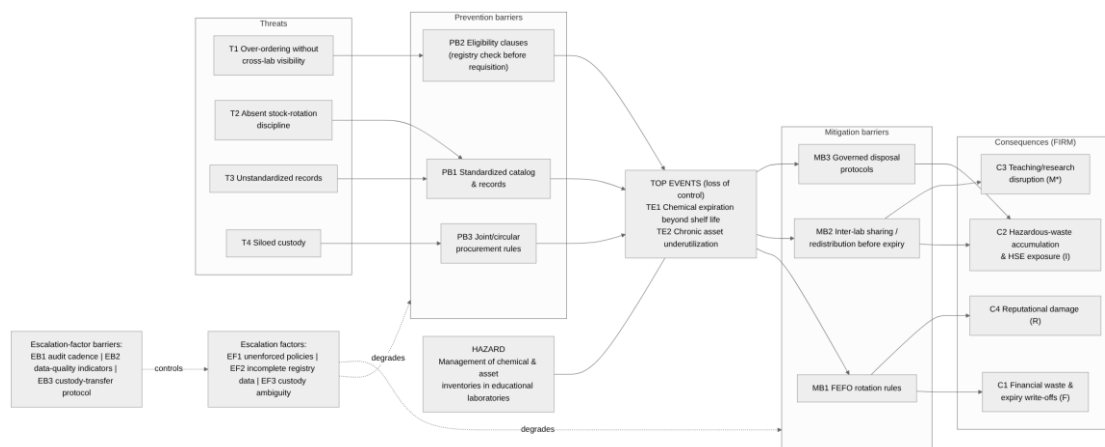


Figure 1.2. Adapted bow-tie for laboratory inventory management (CCPS & Energy Institute, 2018 terminology; method per IEC 31010:2019; FIRM categories per Hopkin, 2018; M = Marketplace read as service/stakeholder environment — thesis adaptation, Section 2.9.5

Reading the diagram from left to right clarifies the intervention logic. The threats are not random mishaps but structural properties of the decentralized regime; the prevention barriers therefore target *structural* corrections — shared data, registry-checked purchasing, circular procurement — rather than exhortations to individual care. The mitigation barriers accept that some expiration and underutilization will still occur and shorten the pathway to recovery: FEFO consumes risk-ordered stock, redistribution moves value to where demand exists, and governed disposal contains the residue. The escalation-factor layer performs the method's most governance-relevant function: it names the conditions under which nominally present barriers silently fail, and assigns each a monitoring control — audit cadence, data-quality indicators, custody-transfer protocol — thereby converting policy existence into policy enforcement (Cormier et al., 2019; Johnson et al., 2018).

The bow-tie suits this qualitative thesis for a further reason that anticipates Chapter 4 (Section 4.1): **every barrier is an ownable organizational artifact**, and a barrier that

nobody owns is a failed barrier by construction (de Ruijter & Guldenmund, 2016). The barrier architecture therefore functions as a requirements list for governance design — each prevention, mitigation, and escalation–factor barrier will be assigned, in Chapter 4 ([Section 4.1](#)), to a specific role (the Academic Inventory Governance Board, the Technical Standardization Committee, the Digital Supply Chain Unit, or operational–level technicians executing within their strictly technical capacity). The bow–tie thus supplies the risk skeleton onto which the governance anatomy is fitted.

2.9.4 Business Continuity and Resilience (ISO 22301)

2.9.4.1 Why continuity belongs in an inventory framework

Educational laboratory operations are unusually exposed to supply–chain interruption. Reagents, consumables, and instrument–specific parts arrive through procurement channels whose lead times the laboratory does not control, while the demand side — semester–locked practical courses, time–sensitive research protocols — is rigidly scheduled. The laboratory–inventory and logistics literature documents the fragility of consumable supply and the disruption that stock–outs and expired stock inflict on teaching and research services (Adirektawon et al., 2024; Wilke et al., 2023). Business continuity management (BCM) addresses exactly this exposure, and ISO 22301:2019 is its international requirements standard (22301 ISO/IEC, 2019). This study does not propose that the host institution’s laboratories operate a certifiable BCMS; it adopts the standard’s analytical logic—as a conformity target and design vocabulary—to ensure that the participatory inventory framework delivers continuity outcomes, following the standard’s Annex SL / Plan–Do–Check–Act (PDCA) architecture (22301 ISO/IEC, 2019).

2.9.4.2 Business impact analysis applied qualitatively to laboratory operations

Clause 8.2.2 of ISO 22301:2019 requires a business impact analysis (BIA): the process of analyzing the impact over time of a disruption, identifying prioritized activities, their

dependencies, and continuity parameters including the maximum tolerable period of disruption (MTPD) and the recovery time objective (RTO) (22301 ISO/IEC, 2019) ISO/TS 22317, 2021). Applied qualitatively to the College of Science, with the Biology Department as the embedded case, the BIA identifies two prioritized activities:

6. **Scheduled practical teaching** — laboratory sessions locked to semester timetables and cohort progression, dependent on consumables (reagents, media, glassware), functioning instruments, and prepared chemical stocks. Its MTPD is conceptually *short*: a practical session missed within a fixed semester cannot be postponed indefinitely, because curriculum sequencing and assessment calendars compress recovery options; the RTO must be shorter still — recovery within the teaching week, not the procurement cycle.
7. **Time-sensitive research protocols** — experiments whose biological materials, cell cultures, or instrument bookings impose continuity requirements independent of the academic calendar, dependent on specialized short-shelf-life reagents and shared instruments. Here the MTPD is protocol-specific: some protocols tolerate days of interruption; others tolerate none.

This reasoning is deliberately conceptual. Consistent with the standard's 2019 vocabulary, the framework speaks of MTPD, RTO, prioritized activities, and minimum acceptable capacity; it does not import metrics that the 2019 edition removed from its terms clause (22301 ISO/IEC, 2019). The qualitative BIA's product is not a table of hours but a ranking: which activities must be protected first, and which inventory depends on their protection entails.

2.9.4.3 Continuity strategies: shared visibility and inter-lab loans as internal substitutes

Clause 8.3 of ISO 22301:2019 requires the selection of strategies and solutions enabling prioritized activities to continue within their continuity objectives (22301 ISO/IEC, 2019).

The framework's central continuity insight is that **the institution's own distributed stock is its first-line substitute for external supply during disruption**. Two elements function as Clause 8.3 continuity solutions:

- **The shared-visibility digital registry** converts the aggregate of decentralized stocks into a single visible resource, so that a stock-out in one laboratory can be answered from another's holdings rather than from a disrupted supply chain.
- **The inter-lab loan and redistribution mechanism** operationalizes that visibility: the governed procedure by which stock actually moves to the prioritized activity that needs it, under custody-transfer rules that preserve accountability.

In continuity terms, these solutions raise the institution's minimum acceptable capacity during disruption: teaching proceeds at reduced-but-acceptable scope using internally redistributed stock while external procurement recovers. This is the inventory-specific expression of organizational resilience — absorbing supply shocks through internal resource reconfiguration rather than passive waiting (Bellantuono et al., 2021; PMI, 2021).

2.9.4.4 Plans, exercises, and evaluation analogues

The remaining operative clauses of ISO 22301:2019 map onto framework elements as analogues, not certification claims (22301 ISO/IEC, 2019). Clause 8.4 (business continuity plans and procedures, including response structure and warning/communication) corresponds to the framework's loan-escalation procedure and communication rules — who is alerted, through what channel, and with what authority, when a prioritized activity faces a stock shortfall. Clause 8.5 (exercise programme) corresponds to the periodic walkthrough of loan and continuity procedures, in which staff rehearse a simulated supply interruption; exercising is what converts documented procedure into recoverable capability. Clause 9 (performance evaluation — monitoring, internal audit, management review) maps onto the governance board's review function, closing the PDCA loop: barrier performance,

registry data quality, and continuity readiness are monitored, audited, and reviewed, with nonconformities feeding corrective action under Clause 10's logic. Clause 7's support requirements (competence, awareness, documented information) are mirrored in the role-based duties Chapter 4 ([Section 4.1](#)) assigns — for operational-level technicians, strictly technical duties (FEFO execution, loan-workflow execution, catalog entries) with escalation duties but no administrative or financial decision-making authority, consistent with the requirement that roles, responsibilities, and authorities be defined and bounded (Clause 5.3;(22301 ISO/IEC, 2019)).

The continuity lens thus reframes participatory inventory management from an efficiency measure into a resilience capability: shared stock is not merely cheaper stock; it is *available* stock when the external channel fails. This reframing carries the argument into the environmental and reputational domain, addressed next.

2.9.5 Environmental and Governance Integration (ISO 14001, CSR and FIRM Scorecard)

2.9.5.1 ISO 14001:2015 mapping

ISO 14001:2015 provides the environmental management system (EMS) requirements against which the framework's environmental outcomes are specified (14001 ISO/IEC, 2015). As a voluntary management-system standard, its operative verb is **conformity**, not compliance; "compliance" appears only within the defined term *compliance obligations* (the legal and other requirements an organization must or chooses to meet), and this thesis preserves that usage exactly (14001 ISO/IEC, 2015). The clause-level mapping proceeds as follows.

Environmental aspects versus impacts (Clause 6.1.2). The standard distinguishes an environmental *aspect* (an element of an organization's activities that can interact with the environment) from an environmental *impact* (the resulting change to the environment),

(14001 ISO/IEC, 2015). The framework designates two significant environmental aspects in the laboratory inventory domain: (a) *expired chemicals*, whose accumulation converts usable stock into hazardous waste requiring controlled disposal, with impacts on waste-treatment load and HSE exposure; and (b) *redundant assets*, whose premature disposal and replacement impose manufacturing, transport, and end-of-life burdens. The decentralized regime aggravates both: small, isolated stocks expire unnoticed, and idle assets are replaced rather than redeployed (Durgan et al., 2023; Freese et al., 2024).

Risks and opportunities (Clause 6.1). EMS planning must address risks and opportunities tied to significant aspects and compliance obligations. The framework's FIRM-classified risk register (Chapter 4, [Section 4.3](#)) supplies the risk side; circular procurement and redistribution supply the opportunity side, converting waste liabilities into resource loops (Kirchherr et al., 2017; Sönnichsen & Clement, 2020).

Operational planning and control with a life-cycle perspective (Clause 8.1). The standard requires operating criteria and control of procurement, design, and end-of-life from a **life-cycle perspective** — explicitly a *perspective* on upstream and downstream stages, not a full life-cycle assessment (LCA), a distinction this thesis maintains scrupulously (14001 ISO/IEC, 2015). Adopting that perspective, the framework's controls extend in both directions: upstream, eligibility clauses and joint procurement reduce incoming volume and favor durable, shareable, lower-hazard items; downstream, FEFO rotation, pre-expiry redistribution, and governed disposal manage end-of-life so that disposal is the last resort of a managed cascade rather than the default fate of forgotten stock.

Emergency preparedness (Clause 8.2). The standard requires planned responses to potential emergencies — here, chemical incidents such as spills or the discovery of degraded expired stock — including proportionate response, periodic testing where practicable, and review after incidents or tests (14001 ISO/IEC, 2015). The framework's

disposal protocols and operational escalation duties constitute this preparedness layer at laboratory level.

Evaluation of compliance (Clause 9.1.2). The framework assigns to its governance board the periodic evaluation of fulfilment of compliance obligations — hazardous-waste regulation, chemical-storage rules, institutional HSE policy — with results feeding management review (14001 ISO/IEC, 2015). This function is the environmental analogue of the ISO 22301 Clause 9 mapping ([Section 2.9.4](#)); the two are deliberately consolidated in a single review body to avoid duplicate governance.

2.9.5.2 Circular procurement as the upstream lever

The circular-economy literature supplies the operational content of the life-cycle perspective. Circular thinking replaces the linear take-make-dispose flow with nested loops of reduction, reuse, and recovery that keep materials at their highest utility (Ellen MacArthur Foundation., 2013; Kirchherr et al., 2017), and reviews of sustainable procurement identify purchasing as the decisive upstream control point: what and how an institution buys determines the waste it must later manage (Sönnichsen & Clement, 2020). In the laboratory domain, green-laboratory scholarship documents how over-purchasing, poor visibility, and absent rotation generate avoidable chemical waste, and how sharing and redistribution recover value that isolated storage destroys (Durgan et al., 2023; Freese et al., 2024; Gutierrez et al., 2020).

The framework concretizes the *reduce* and *reuse* loops in three mechanisms already specified by the bow-tie ([Section 2.9.3](#)): **joint purchasing** (reduce: aggregate demand, eliminate duplicate orders, right-size incoming volume); **pre-expiry redistribution** (reuse: move soon-to-expire chemicals and idle assets to laboratories with live demand); and **FEFO discipline** (reduce/reuse interface: consume stock in risk order so that expiry is structurally unlikely rather than accidentally avoided). Higher-education institutions are

increasingly analyzed as microcosms in which such loops can be closed at campus scale, and equipment-sharing scholarship shows that shared-access models raise utilization while reducing redundant acquisition (Adami et al., 2021; Strom et al., 2020; Vergani, 2024). Circular procurement is therefore not an ornamental sustainability commitment; it is the upstream prevention barrier (PB3) with an environmental justification derived from the EMS's life-cycle perspective (14001 ISO/IEC, 2015).

2.9.5.3 CSR/USR and reputation protection

Corporate social responsibility applied to higher education institutions is conventionally termed University Social Responsibility (USR): the integration of social and environmental concern into a university's operations, teaching, research, and community engagement, with effects on reputation, stakeholder trust, and legitimacy (Ali et al., 2021). ISO 26000:2010 provides guidance on social responsibility for all organization types; it is explicitly a guidance standard and **not certifiable**, and this thesis cites it as orientation, not as a conformity target (26000 ISO/IEC, 2010). Sustainability reporting in higher education has become the visible surface of USR, but the reporting literature warns that disclosure decoupled from operational practice erodes rather than builds trust (Alshuwaikhat & Abubakar, 2008; Ceulemans et al., 2015). The greenwashing critique sharpens this warning: institutions that advertise sustainability commitments their operations cannot substantiate incur reputational damage exceeding any benefit of the advertisement (Lakhno, 2024).

For the host institution—an entity whose public identity is bound to Saudi Vision 2030 commitments on fiscal efficiency, sustainability, and digital transformation—the reputational stakes of laboratory waste are asymmetric: a hazardous-waste incident or adverse audit finding would contradict the very narrative the institution projects. The framework's response is architectural rather than communicational: **it makes practice precede reporting**. By embedding environmental controls (aspect management, life-cycle

procurement, governed disposal) and their evaluation into routine governance, the framework generates the operational substance that any disclosure would later report (Ali et al., 2021; Lakhno, 2024). Reputation protection is thus a by-product of conformity with ISO 14001 logic, not a public-relations objective — the sequencing the USR literature identifies as the difference between substantive and symbolic responsibility (Ceulemans et al., 2015; Lakhno, 2024).

2.9.5.4 The FIRM Scorecard as classification taxonomy

The final lens organizes the risk register. The FIRM Scorecard, presented by (Hopkin, 2018) in the Institute of Risk Management's standard textbook, is a **risk classification system** that categorizes risks by their impact on the organization's key dependencies: **F — Financial, I — Infrastructure, R — Reputational, M — Marketplace** (Hopkin, 2018). Two clarifications govern its use here. First, FIRM is a *taxonomy, not a scoring algorithm*: it says where a risk bites, not how severely, and it is neither a likelihood–impact matrix nor a quantification device (Hopkin, 2018). It contrasts in kind with PESTLE (external drivers) and with the COSO categories (strategic, operations, reporting, compliance); it is chosen here because its dependency-based logic matches a register whose entries are operational dependencies of a laboratory system. Second, *Marketplace* requires declared adaptation: a public university has no marketplace in the commercial sense, so this thesis reads M as the institution's **service/stakeholder environment** — student experience, research competitiveness, and standing with regulators and funders — an adaptation declared here and used consistently thereafter (Hopkin, 2018).

The taxonomy's structural properties add analytical value beyond labelling. Financial and Infrastructure risks are predominantly *internal*; Reputational and Marketplace risks are predominantly *external*; and Financial and Marketplace impacts are comparatively easy to express monetarily, whereas Infrastructure and Reputational impacts resist quantification (Hopkin, 2018). Applied to the bow-tie consequences ([Section 2.9.3](#)), the classification

is: expiry write-offs and duplicate purchasing — **Financial**; asset idleness, custody failures, and hazardous-waste accumulation affecting the physical estate — **Infrastructure**; waste incidents and audit findings contradicting the Vision 2030 narrative — **Reputational**; and teaching/research disruption degrading student experience and research standing — **Marketplace (service/stakeholder environment)**. Because this thesis is qualitative by design, the quantifiability gradient serves only as a caution: the categories least amenable to numbers (I and R) are precisely those where preventive barriers must do the most work, since reputational and infrastructure losses, once realized, cannot be recovered by later financial compensation (Hopkin, 2018).

2.9.6 Theoretical Framework Synthesis and Operational Definitions

2.9.6.1 How the lenses integrate into a single assessment chain

The five lenses now compose a single chain of reasoning, each link supplying what the next requires. The **maturity bands set the baseline the bow-tie barriers must raise**: an institution in the Inform/Conform band cannot sustain barriers such as eligibility clauses or FEFO discipline, because those barriers presuppose standardized records and enforced policy; the barrier architecture therefore doubles as a maturity specification, and barrier deployment as the transition mechanism out of the lowest band (Hillson, D. A., 1997; Johnson et al., 2018). Conversely, the bow-tie gives maturity model operational content: advancing a band *means* installing and enforcing named barriers, not acquiring a generalized risk-awareness. **ISO 22301 and ISO 14001 supply the conformity targets**: continuity of prioritized activities within MTPD/RTO reasoning on one side, control of significant environmental aspects with a life-cycle perspective on the other (14001 ISO/IEC, 2015; 22301 ISO/IEC, 2019). **The FIRM taxonomy organizes the risk register** into which all threats, consequences, and barrier failures are entered, classifying every risk by the dependency it endangers (Hopkin, 2018). The result is an assessment framework

that can diagnose (maturity), structure (bow-tie), specify outcomes (ISO standards), and classify (FIRM) without overlap or gap.

Two integration rules preserve coherence. First, **every barrier has an owner, and ownership follows competence**: the escalation-factor analysis showed that unowned or unenforced barriers fail silently, so the barrier list is handed to Chapter 4 ([Section 4.1](#)) as an assignment problem. Second, **execution is separated from authority**: operational-level technicians execute the technical substance of several barriers — FEFO rotation, loan-workflow execution, catalog and registry entries, escalation of anomalies — but hold no administrative decision-making authority, no procurement approval, and no financial authority; barrier *ownership* rests with governance roles, while barrier *execution* rests with operational roles within their technical capacity. This separation derives from the standards shared Clause 5.3 requirement that roles, responsibilities, and authorities be defined and bounded (14001 ISO/IEC, 2015; 22301 ISO/IEC, 2019).

2.9.6.2 Operational definitions of key constructs

[Table 2.5](#) fixes the meaning of the framework’s core constructs for the remainder of the thesis; all definitions are qualitative and none implies measurement.

Table 2.5. Operational definitions of key constructs

Construct	Operational definition (as used in this thesis)
Participatory inventory management	A governance arrangement in which multiple laboratories share visibility of, and governed access to, a common pool of chemical and asset stock, under institution-level rules for purchasing, custody, rotation, and redistribution — participation with defined decision rights, not informal cooperation.
Risk maturity gap	The distance, expressed in the thesis’s adapted three-band trajectory, between the institution’s current inventory-governance capability and the capability

Construct	Operational definition (as used in this thesis)
	required to sustain participatory, digitized, standards-aligned stock management.
Prevention barrier	A documented control positioned on a threat pathway that terminates or weakens the pathway before loss of control (e.g., standardized catalog, eligibility clause, joint procurement rule).
Mitigation barrier	A documented control positioned between a Top Event and its consequences that reduces consequence severity after loss of control has begun (e.g., FEFO rotation, inter-lab redistribution, governed disposal).
Prioritized activity	A teaching or research activity whose disruption would exceed the institution's tolerance within a short maximum tolerable period of disruption, and whose dependencies the continuity arrangements must protect (ISO 22301:2019 usage).
Custody	The documented, transferable state of responsibility for a specific stock item or asset, including accountability for its condition, location, and return; custody is unambiguous at every moment and changes only through the custody-transfer protocol.
Eligibility clause	A purchasing rule requiring that a requisition be checked against the shared registry, and existing stock be used or transferred where suitable, before any new purchase is approved.
FEFO discipline	The enforced practice of consuming stock in First-Expired-First-Out order, executed at the operational level, so that the earliest-expiring usable items leave storage first.
Inter-lab loan	A governed, temporary transfer of an asset or chemical from the custody of one laboratory to another under the inter-lab policy framework, with documented request, approval, custody transfer, and return.
Environmental aspect	An element of laboratory inventory activity that can interact with the environment — in this framework, principally expired chemicals and redundant assets — as distinct from the environmental impact that may result (ISO 14001:2015 usage).

2.9.6.3 Transition to the governance architecture

This section has built the assessment framework while deliberately stopping short of assigning it to an organization. The bow-tie specified *which* barriers must exist and *why* they fail; the maturity model specified the capability trajectory those barriers must serve; the ISO lenses specified the conformity targets; and FIRM specified the register in which residual risks are recorded. What remains undetermined is *who* owns, executes, audits, and reviews each barrier — the governance question. Chapter 4 ([Section 4.1](#)) takes up exactly this handoff: it assigns the prevention, mitigation, and escalation-factor barriers specified here to a three-tier governance architecture — an Academic Inventory Governance Board, a Technical Standardization Committee, and a Digital Supply Chain Unit, with laboratory technicians executing at the operational level within strictly technical boundaries — and specifies the Inter-Lab Policy Framework governing custody transfers, loan approvals, and redistribution. The assessment framework thereby becomes what it was designed to be: the risk skeleton onto which a concrete governance anatomy is fitted.

CHAPTER 3 — RESEARCH METHODOLOGY

Chapters One and Two established the problem—the Risk Maturity Gap in educational laboratory inventory governance within a large public higher education institution in Saudi Arabia—and the verified literature and standards base on which the study reasons. The present chapter formalizes the methodology through which the study’s framework was designed, assessed, and sequenced. Because the thesis is a qualitative, structural, policy, and governance study, this chapter describes not a data-collection apparatus but an analytical one: the design logic, the documentary evidence base, the analytical toolset that stands in lieu of statistical sampling, the stepwise procedures by which the framework was constructed, and the boundaries, limitations, and integrity commitments within which all claims must be read. Nothing in this chapter introduces empirical content; the chapter’s function is to make the study’s reasoning auditable, so that every deliverable can be traced to a declared source, a declared procedure, and a declared verification rule (Al Qur’an, 2025; Knott et al., 2022).

3.1 Methodological Orientation and Research Design

This study is a **descriptive-analytical, qualitative, design-oriented single embedded case study** of laboratory inventory governance within a large public science faculty at a Saudi higher education institution, with a life sciences department as the embedded unit of analysis. Each element of that designation carries methodological content. The study is *descriptive* in that it renders the prevailing decentralized inventory regime with structural precision — its record-keeping practices, requisition pathways, custody arrangements, and procurement defaults — before evaluating it. It is *analytical* in that it interrogates that regime through five integrated lenses: risk maturity modeling (Hillson, D. A., 1997; Paulk et al., 1993), Bow-Tie risk analysis (de Ruijter & Guldenmund, 2016; 31010 ISO/IEC, 2019; Johnson et al., 2018), business continuity management (22301 ISO/IEC, 2019), environmental management and university social responsibility (Ali et al., 2021; 14001 ISO/IEC, 2015), and the FIRM risk classification taxonomy (Hopkin, 2018). It is *design-*

oriented in that its terminal products are not findings about a population but design artifacts: an organizational framework, a feasibility matrix, a classified risk register, a key performance indicator (KPI) set, and a phased implementation roadmap. And it is a *single embedded case study* in that one institutional case hosts one analytically privileged sub-unit, examined for what it reveals about the governance of the whole.

The case-study warrant follows the logic articulated in contemporary qualitative methodology: a case is selected not to represent a population statistically but to permit intensive, contextualized analysis of a phenomenon whose mechanisms are structural and whose generalization is *analytic* — the transfer of reasoned propositions to structurally similar settings — rather than statistical (Al Qur'an, 2025). The study's propositions are accordingly structural claims about how participatory inventory governance must be organized to function: that shared visibility requires a standardized record structure; that sharing without decision rights decays into nominal compliance (Ahn & Baldwin, 2024; X. Wang & Qu, 2025); and that organizational standardization must precede digitalization (Bellantuono et al., 2021; Rodríguez-Abitia & Bribiesca-Correa, 2021). These propositions are evaluated by documentary evidence, standards conformity, and internal coherence, and they transfer to comparable settings by reasoned analogy, not by extrapolation (Al Qur'an, 2025; Knott et al., 2022).

The study is also, in disciplinary terms, **policy and governance design research**: it treats an internal university operational reform as an undertaking amenable to the feasibility-and-risk discipline of project management, conducted before execution and tailored to context (PMI, 2021; Takagi et al., 2024). Its evidence is documentary — policies, record structures, standards texts, verified scholarship — and its contribution is a framework whose validity rests on structural soundness and standards alignment, awaiting gate-governed implementation for empirical confirmation.

In lieu of statistical hypotheses, the study restates its **qualitative premise**, first articulated in [Section 2.8](#). The premise links three independent dimensions — *Governance Architecture*, *Policy Control*, and *Standardization* — to three dependent dimensions — *Operational Efficiency*, *Environmental Sustainability*, and *Business Continuity*. It asserts, as a structural proposition rather than a testable coefficient, that strengthening the independent dimensions through the framework’s specified mechanisms (a ratified governance architecture with allocated decision rights; enforceable policy instruments such as the eligibility clauses and the FEFO standard; and a unified catalog and records structure) is designed to improve the dependent dimensions (displaced duplicate procurement and raised asset utilization; prevented expired–chemical waste and governed disposal; protected prioritized teaching activities during supply interruption), and that this linkage is mediated by the institution’s progression along the adapted maturity trajectory from Inform/Conform toward Perform (Hillson, D. A., 1997; Paulk et al., 1993). Every analytical procedure in [Section 3.5](#) is an operation upon one or more of these dimensions; the premise therefore functions as the study’s integrative logic, not as an empirical claim.

3.2 Case Context and Population–in–Context

The case is laboratory inventory governance within a large public science faculty at a Saudi higher education institution in Riyadh. As a major higher education environment with centralized academic operations, the institution operates on a single integrated mega-campus that concentrates procurement volume and laboratory capacity within one institutional boundary—a concentration that amplifies both the coordination failures of decentralization and the gains available from participatory coordination. ([Section 1.1](#)). The College of Science hosts extensive teaching and research laboratories across multiple departments. Within it, the **Biology Department** serves as the embedded unit of analysis, selected as an information-rich case because its structural features present the college’s inventory problem in full: a large and diverse inventory spanning instruments, glassware,

consumables, and chemicals; high student throughput on fixed semester cycles; recurring consumable orders driven by chemically intensive courses; and episodic research demand superimposed on routine teaching loads. The selection logic is purposive and structural — maximum structural variation within a single department — not probabilistic (Knott et al., 2022). The institutional environment is shaped by Saudi Vision 2030’s expectations of fiscal efficiency, environmental sustainability, and digital transformation in public institutions, which supply the strategic mandate against which the framework is assessed (Alamoudi et al., 2023; Alshammari, 2025; Hassanain et al., 2019).

Because the study is structural rather than behavioral, the conventional notion of a “population” of respondents is reframed. **The unit of analysis is the inventory regime itself** — the full configuration of policies, record structures, role definitions, custody arrangements, procurement workflows, and disposal pathways through which laboratory materials are governed — not the people who operate it. Human actors enter the analysis only as occupants of structurally defined roles (Board, Committee, Unit, custodian supervisors, laboratory technicians), and the framework specifies their decision rights and boundaries rather than measuring their attitudes or behaviors. The **population-in-context** is therefore the complete set of educational laboratory inventory units within the College of Science: every departmental laboratory whose instruments, glassware, consumables, and chemicals fall under the decentralized regime. The Biology Department functions within this population as the information-rich embedded case — the unit through which the regime’s mechanisms are examined in detail and in which the roadmap’s pilot phase ([Section 4.1.6](#)) is located — while the framework’s governance architecture, policies, and workflows are designed for the population as a whole. This reframing is the methodological counterpart of the thesis’s central claim that the problem is organizational design, not individual performance: where the object of reform is a regime, the object of study is the regime’s structure (Ahn & Baldwin, 2024; Al Qur’an, 2025).

3.3 Data Sources and Collection Procedures

The study draws on five categories of documentary and structural sources, and only these:

1. **Institutional policy and procurement documents.** The prevailing rules governing purchasing, requisition, custody, and disposal in the case setting, together with the university's strategic alignment documents under Vision 2030. These supply the current-state characterization of the decentralized regime ([Section 1](#)) and the delegation structures through which the governance architecture of [Section 4.1](#) is constituted.
2. **Inventory record structures and catalog practices.** The existing forms, registers, and departmental record-keeping conventions through which holdings are documented. These supply the structural evidence for prevention barrier PB1 (the unified catalog and records standard) and for the data-quality problem formalized as escalation factor EF2.
3. **Standards texts.** ISO 14001:2015 (ISO, 2015), ISO 22301:2019 (ISO, 2019), ISO 31000:2018 (ISO, 2018), IEC 31010:2019 (IEC, 2019), and ISO 26000:2010 (ISO, 2010), read as requirement and guidance texts whose clauses the framework adopts by structural analogue.
4. **Verified scholarly literature.** The Chapter 2 base: peer-reviewed work on green and sustainable laboratories, equipment sharing and core facilities, circular economy in higher education, organizational readiness and digital transformation, collaborative governance and change management, sustainable procurement, laboratory risk, and Saudi higher education. Every cited work was verified against publisher records before use.

5. **Documented international practice for benchmarking.** Published accounts of governed equipment sharing, redistribution, and laboratory inventory practice — including shared–facility operation (Strom et al., 2020), instrument–sharing governance with its documented cautions (X. Wang & Qu, 2025), and documented redistribution and shared–access practice (Tu & Greever–Wilson, 2025) — used strictly as qualitative precedent for mechanisms, never as sources of transferable magnitudes.

The collection and treatment procedures are four. **Document analysis** renders the current–state regime and its policy environment (procedure of [Section 4.1.5](#), step 1). **Structural mapping** converts that account into the maturity–gap diagnosis, the Bow–Tie pathway structure, and the governance architecture (steps 1, 3, 4). **Comparative benchmarking** tests each proposed mechanism against documented practice in comparable settings, as corroboration or caution (steps 3, 5). **Framework synthesis** integrates the five lenses into the unified design, feasibility assessment, risk register, KPI set, and roadmap (steps 3–8).

It is stated explicitly: **this thesis uses no questionnaires, no interviews–with–results, no sampling, and no field measurement of any kind.** Where international benchmarking reports quantified outcomes elsewhere (for example, (Tu & Greever–Wilson, 2025)), those accounts are used only to establish that a mechanism is documented practice; no figure is imported, projected, or simulated for the case setting.

Qualitative rigor is adapted to this documentary design through four commitments. **Credibility** is pursued through triangulation across documentary domains: every load–bearing structural claim is corroborated across at least two independent source categories — for example, the feasibility of eligibility–check controls rests jointly on the procurement literature, the standards’ operational–control clauses, and documented practice (14001 ISO/IEC, 2015; Sönnichsen & Clement, 2020; Strom et al., 2020). **Dependability** is

pursued through an audit trail of analytical decisions: every adaptation of a model (the Inform/Conform–Perform maturity labels; chemical expiration and asset underutilization as adapted Bow–Tie top events; the Marketplace–as–service–environment reading of FIRM) is declared at the point of use, anchored to its published antecedent, and justified (Hillson, D. A., 1997; Hopkin, 2018; Johnson et al., 2018). **Confirmability** is pursued through terminology discipline — one meaning per term throughout the thesis — and through verification of all sources against publisher records before citation. **Thematic saturation** is interpreted, following the saturation logic articulated by (Hennink & Kaiser, 2022), as *coverage of documentary domains*: the literature base was treated as sufficient when additional reading within each thematic stream ([Section 2.1](#)) ceased to introduce new structural mechanisms, new counter–considerations, or new design requirements for the framework; the concept is applied here to documentary domains, not to interview data, which this study does not collect. Analytical quality practices follow the reflexive, theme–developing discipline articulated by (Braun & Clarke, 2021)— applied to documentary synthesis rather than to transcripts — and the case–analysis practices for rigorous qualitative inference synthesized by (Knott et al., 2022); internal consistency of the analysis — coherence between the problem account, the framework, and the evaluation instruments — is checked in the sense of (Cole, 2024), whose account of consistency as a quality criterion in qualitative work is applied here to the alignment of constructs, claims, and design artifacts across sections.

3.4 The Analytical Toolset instead of Statistical Sampling

The study’s research questions are **design questions**: how should a framework be structured (RQ3), how should its feasibility and risks be assessed (RQ2), how should the current state be characterized structurally (RQ1), and how should adoption be sequenced (RQ4). Statistical sampling cannot answer such questions at the pre–implementation stage, for three reasons. First, there is no operating framework from which outcome data could

be sampled; any measurement would measure the regime being replaced, not the design being assessed. Second, the phenomena at issue — decision rights, barrier integrity, policy enforceability, gate criteria — are structural properties whose adequate description is categorical and relational, not distributional (31000 ISO/IEC, 2018; PMI, 2021). Third, the study's claims are conditional design claims ("feasible once gate G1 is met"), whose evidentiary basis is conformity of the design to standards and documented practice, not probabilistic inference (14001 ISO/IEC, 2015; 33020 ISO/IEC, 2019). The study therefore substitutes an analytical toolset for a sampling plan. Each tool answers the class of design questions that statistics could not:

- **Bow-Tie analysis** (de Ruijter & Guldenmund, 2016; 31010 ISO/IEC, 2019; Johnson et al., 2018) structures risk pathways. It decomposes the regime's failure modes into Hazards, adapted Top Events (chemical expiration; asset underutilization — the adaptation declared in [Section 2.9.3](#)), Threats (T1–T4), Prevention barriers (PB1–PB3), Mitigation barriers (MB1–MB3), Consequences (C1–C4), Escalation factors (EF1–EF3) and escalation-factor barriers (EB1–EB3), using the terminology of CCPS and Energy Institute (Johnson et al., 2018) exactly. Bow-tie is classified by IEC 31010:2019 as a technique for analyzing controls, and it is qualitative by nature — a property that suits this study (de Ruijter & Guldenmund, 2016; 31010 ISO/IEC, 2019). Its extension from process safety into management and policy analysis follows documented precedent (Cormier et al., 2019).
- **The FIRM taxonomy** (Hopkin, 2018) classifies risks and consequences by the organizational dependency each endangers — Financial, Infrastructure, Reputational, Marketplace — with the declared adaptation that Marketplace is read as the university's service and stakeholder environment. FIRM is used strictly as a classification taxonomy, never as a scoring algorithm (Hopkin, 2018).

- **ISO 31000:2018** frames the risk process — identification, analysis, evaluation, treatment — within which the register of [Section 2.9.2](#) is constructed and owned (31000 ISO/IEC, 2018).
- **ISO 14001:2015 and ISO 22301:2019 clause analogues** supply conformity targets: environmental aspect determination with a life-cycle perspective, compliance obligations and their evaluation, emergency preparedness ((14001 ISO/IEC, 2015), clauses 6.1.2, 6.1.3, 9.1.2, 8.2); business impact analysis (BIA) logic, prioritized activities, maximum tolerable period of disruption (MTPD), recovery time objective (RTO), minimum acceptable capacity, and exercise-programme logic ((22301 ISO/IEC, 2019), clauses 8.2.2, 8.2.3, 8.5). Alignment is by structural analogue, not certification.
- **Risk maturity models** (Hillson, D. A., 1997; Paulk et al., 1993) supply the baseline and trajectory: the thesis's adapted three-band labels — Inform/Conform, Managed/Normalized, Perform — are anchored to Hillson's Naive-to-Natural levels and the capability scale of (Paulk et al., 1993), and are declared as adapted terminology nowhere attributed to a published model.
- **Qualitative matrices, analytical readiness gates, and policy controls** are the evaluation instruments proper: the feasibility matrix with its Strong/Conditional/Contingent rating vocabulary ([Section 4.1](#)), gates G1–G4 with structural criteria verified by inspection of documented information ([Section 4.6](#)), and the KPI definitions with method, source, owner, frequency, and directional target ([Section 4.1.7](#)).

[Table 6.3](#) maps each research question to its analytical tools, the sections where they are applied, and the qualitative output each produces.

Table 3.1. Mapping of research questions to analytical tools, application sites, and qualitative outputs

Research question	Analytical tool(s)	Where applied	Qualitative output produced
RQ1 — Structural characterization of the decentralized regime and its risk consequences	Document analysis; structural mapping; risk maturity models (Hillson, 1997; Paulk et al., 1993); Bow-Tie threat-pathway structuring (IEC, 2019)	Sections 1.1–1.2 (current-state account); 2.2 (maturity-gap diagnosis); 2.3 (threats and top events)	The Risk Maturity Gap diagnosis; the adapted three-band maturity trajectory; the Bow-Tie threat structure (T1–T4) and consequence classes (C1–C4)
RQ2 — Feasibility assessment and risk classification of the transition	Bow-Tie barrier analysis (CCPS & Energy Institute, 2018); FIRM taxonomy (Hopkin, 2018); ISO 31000:2018 process framing (ISO, 2018); qualitative feasibility matrix with Strong/Conditional/Contingent ratings and gates G1–G4 (PMI, 2021)	Sections 2.3–2.5 (barriers, continuity and environmental readings); 4.2 (feasibility); 4.3.3 (risk register)	The consolidated feasibility matrix with the conditionally strong verdict; the classified risk register (RR-01–RR-15) with verbally defined High/Moderate/Low priority bands
RQ3 — Governance structures, roles, policies, procedures, and performance indicators	ISO 14001:2015 and ISO 22301:2019 clause analogues (leadership and roles, competence, documented information, performance evaluation; ISO, 2015, clauses 5.3, 7.2–7.5, 9.1; ISO, 2019, clauses 5.3, 7.2–7.5, 9.1); collaborative–	Section 4.1 (governance architecture); Section 4.1.7 (KPI definitions and dashboard)	The three-tier governance architecture with allocated decision rights and the technician non-authority clause; the policy core (PB1–PB3, MB1–MB3, EB1–EB3); the KPI set (KPI-O1–O4, KPI-E1–E4, KPI-G1–G6) each with

Research question	Analytical tool(s)	Where applied	Qualitative output produced
	governance literature (Ahn & Baldwin, 2024; Lopes & Farias, 2022); policy–control design (eligibility clauses, FEFO standard, Inter–Lab Policy Framework)		method, source, owner, frequency, directional target
RQ4 — Phased implementation roadmap toward the Perform band	Maturity–trajectory sequencing (Hillson, 1997; Paulk et al., 1993); readiness–gate logic (Section 4.6); project–management tailoring and progressive elaboration (PMI, 2021; Takagi et al., 2024); change–management literature (Vlachopoulos, 2021; Dean et al., 2024); digital–readiness literature (Rodríguez–Abitia & Bribiesca–Correa, 2021; Bellantuono et al., 2021)	Section 4.1.6 (roadmap); Section 4.6 (gate definitions)	The four–phase roadmap (Phase 1 policy ratification, Phase 2 standardization and onboarding, Phase 3 pilot, Phase 4 scaling and continuous improvement), each phase terminating at a readiness gate with named transition risks discharged

3.5 Analytical Procedures

The analysis proceeded through eight ordered steps. Each step is specified by its input, its procedure, its output, and the verification rule by which the output was checked before the next step began.

1. **Problem structuring (the Risk Maturity Gap).** *Input:* the institutional policy and record–structure sources ([Section 3.3](#), categories 1–2) and the descriptive account

of the decentralized regime. *Procedure:* structural characterization of procurement defaults, custody arrangements, record practices, and disposal pathways, followed by diagnosis of the regime against the adapted maturity trajectory. *Output:* the Risk Maturity Gap problem statement and the four structural consequences (duplicate purchasing, depressed asset utilization, expired–chemical accumulation, absent digitalization baseline). *Verification rule:* every consequence must be traceable to a structural feature of the regime, not to individual behavior; no magnitude may be asserted without a documented source.

2. **Literature synthesis.** *Input:* the verified scholarly base (category 4). *Procedure:* thematic organization of the literature into the streams of Chapter 2; extraction of documented mechanisms, success and failure conditions, and design requirements relevant to participatory inventory governance. *Output:* the thematic synthesis and comparative summary of [Section 2.7](#), and the design requirements carried into framework integration. *Verification rule:* documentary–domain saturation in the sense defined in [Section 3.3](#) (Hennink & Kaiser, 2022); every source verified against publisher records; consistency of extracted requirements with the problem account (Cole, 2024).
3. **Framework integration (five lenses).** *Input:* the problem diagnosis and the synthesized design requirements. *Procedure:* integration of risk maturity modeling, Bow–Tie analysis, business continuity, environmental management and USR, and FIRM classification into a single assessment structure; construction of the Bow–Tie pathway diagrams with adapted top events; alignment of the framework with ISO 14001:2015 and ISO 22301:2019 by clause analogue. *Output:* the integrated framework of [Section 2.9.1](#), including barriers PB1–PB3, MB1–MB3, EB1–EB3 and escalation factors EF1–EF3. *Verification rule:* every threat pathway terminates in a named prevention barrier; every consequence pathway carries at least one mitigation

barrier; every escalation factor is paired with an escalation-factor barrier; all Bow-Tie terms conform to CCPS and Energy Institute (Johnson et al., 2018).

4. **Governance architecture design.** *Input:* the integrated framework and the collaborative-governance requirements from step 2. *Procedure:* specification of the three-tier architecture (Academic Inventory Governance Board, Technical Standardization Committee, Digital Supply Chain Unit), of custodian-department rights and obligations, of the technician operational mandate, and of the Inter-Lab Policy Framework with its loan workflow and custody-transfer protocol. *Output:* the governance architecture and policy core of [Section 4.1](#). *Verification rule:* every barrier has a named owner within the architecture; every decision right is allocated to exactly one body; the technician role is bounded to execution and escalation with no administrative decision-making, procurement approval, financial authority, or policy-setting power; role specifications conform to the clause 5.3 analogues of both anchor standards ((14001 ISO/IEC, 2015), clause 5.3;(22301 ISO/IEC, 2019), clause 5.3).
5. **Feasibility matrix assessment.** *Input:* the governance design and the three admissible evidence kinds (structural analysis, standards conformity, documented practice). *Procedure:* decomposition of feasibility into four dimensions and their sub-criteria; rating of each sub-criterion against the Strong/Conditional/Contingent vocabulary; consolidation of named conditions into readiness gates G1–G4. *Output:* the consolidated feasibility matrix ([Table 9.4](#)) with the conditionally strong verdict. *Verification rule:* every Conditional rating name it governing condition explicitly; every rating cites its evidence base; no rating depends on resources the college does not possess; the reasoning discipline of feasibility analysis as pre-execution structured judgment is maintained (PMI, 2021).
6. **Risk register construction.** *Input:* The Bow-Tie barrier architecture, the gate conditions, and the change-management and collaborative-governance literature.

Procedure: analytical derivation of operational risks from threats, escalation factors, and consequence pathways; derivation of transition risks from documented change themes; FIRM classification; prioritization into verbally defined High/Moderate/Low bands; assignment of owners and mitigations. *Output:* the classified risk register ([Table 4.6](#), RR-01–RR-15). *Verification rule:* every registered risk traces either to a Bow-Tie element or to a cited change theme; every barrier appears in at least one register row; FIRM is used for classification only, never scoring (Hopkin, 2018); no numeric likelihood or impact values appear; technician assignments are execution-level only, with accountability resting with custodian supervisors or the Unit.

7. **KPI definition.** *Input:* the barrier architecture, the register, and the standards' performance-evaluation clauses. *Procedure:* specification of each indicator under the definition-before-data principle — definition, measurement method, data source, owner, frequency, directional target — across the operational (KPI-O), environmental (KPI-E), and governance (KPI-G) families. *Output:* the KPI set and governance dashboard specification of [Section 4.1.7](#). *Verification rule:* every KPI has a method and a named owner within the [Section 4.1](#) architecture; every KPI maps to at least one barrier and is informed by at least one register entry; targets are directional only, with no numeric baseline or threshold asserted; the conformity/compliance terminology distinction is maintained exactly ((14001 ISO/IEC, 2015), clauses 9.1.1–9.1.2;(22301 ISO/IEC, 2019), clause 9.1).
8. **Roadmap sequencing.** *Input:* the maturity trajectory, the gates, the register's transition risks, and the change-management literature. *Procedure:* derivation of the four-phase sequence from the maturity-band transitions; assignment of every activity to a named governance body; termination of each phase at its readiness gate; mapping of gate closures to discharged transition risks. *Output:* the phased implementation roadmap of [Section 4.1.6](#) ([Phase 1](#)– [Phase 4](#) with schedule

designations; G1–G4 as phase terminators). *Verification rule:* the sequence respects the organization–before–technology ordering (Carpitella & Izquierdo, 2025; Rodríguez–Abitia & Bribiesca–Correa, 2021); no successor phase begins before its predecessor’s gate closes; every phase names the transition risks it treats and the KPIs it activates; month ranges are schedule designations, not measured durations.

The eight steps form a single chain of custody for the study’s reasoning: each output becomes a named input downstream, and each verification rule is stated so that an external reader can re–perform the check. This auditability is the methodological substance of the chapter: in a documentary design study, the audit trail of analytical decisions is what a field protocol is to empirical work (Braun & Clarke, 2021; Knott et al., 2022).

3.6 Boundaries and Limitations

Spatial boundary. The study is confined to a large public science faculty within a Saudi higher education institution, with a life sciences department as the embedded unit of analysis. Cross–institutional material appears only as documented benchmarking precedent (category 5 sources), never as primary data.

Temporal boundary. The study is a design–phase study conducted within the current policy cycle. The roadmap’s month ranges ([Phase 1](#), months 1–2; [Phase 2](#), months 3–4; [Phase 3](#), months 5–6; [Phase 4](#), continuous) are schedule designations fixed by the study’s terms of reference, not observed durations; no implementation has occurred within the study’s timeframe, and none of its findings depends on one having occurred.

Subject–matter boundary. The study addresses educational laboratory inventory only — instruments, glassware, consumables, and chemicals. It excludes facilities and buildings maintenance, research–only core facilities (whose sharing arrangements appear only as benchmarking precedent), and the detail of commercial procurement law, which the

framework references only through the eligibility and joint–procurement rules it proposes within institutional authority.

Methodological limitations. Four limitations are acknowledged. First, the framework has **no empirical validation yet**: it is a design artifact whose feasibility verdict is conditional and whose definitive test is the gate–governed implementation it specifies; the thesis claims structural soundness and standards alignment, not demonstrated outcomes. Second, the **single–institution design** means that contextual features of the host institution—the mega–campus concentration, the Vision 2030 alignment—shape the analysis; transfer to other institutions proceeds by analytic generalization and requires the receiving institution to re–verify the framework’s structural assumptions against its own governance (Al Qur’an, 2025). Third, **standards alignment is by structural analogue, not certification**: the framework adopts the clause logic of ISO 14001:2015 and ISO 22301:2019 as design targets, and no claim of conformity assessment, audit, or certification under either standard is made (14001 ISO/IEC, 2015; 22301 ISO/IEC, 2019). Fourth, **generalization is analytic**: the study’s propositions are structural claims transferable by reasoned analogy to comparable laboratory–intensive settings, not statistical inferences to a population (Al Qur’an, 2025; Knott et al., 2022).

3.7 Ethical and Integrity Considerations

Human subjects. The study collects no human–subject data: no questionnaires, no interviews, no observations of identifiable persons, and no behavioral records are used anywhere in the thesis. Consequently, no consent instruments are required for the documentary phase. Should the framework proceed to implementation, subsequent phases involving participants — pilot operation, training, or post–implementation evaluation — would be routed through the university’s institutional review procedures before any data collection, and the present study pre–commits to that routing.

Institutional permissions. Document analysis of institutional policy and record structures is conducted under institutional permission and within the university's governance conventions; no confidential personal data are accessed, and the analysis addresses structures and roles, never identified individuals.

Citation integrity. Every source cited in this thesis was verified against publisher records before use; no reference, finding, or quotation is asserted that cannot be traced to a verified text. Where published practice elsewhere is quantified, the quantification remains with its authors and is never imported into the case setting (for example, (Tu & Greever-Wilson, 2025)).

Research-integrity commitment against fabricated or assumed data. The study adopts, as an explicit methodological principle, the prohibition of fabricated, projected, or assumed data. Where evidence is unavailable — as pilot outcomes, baselines, and numeric targets necessarily are at the design stage — the study says so and designs the instrument by which the evidence would later be produced (the readiness gates, the KPI definitions, the exercise logic of ISO 22301:2019 clause 8.5), rather than simulating the evidence itself (22301 ISO/IEC, 2019). This principle is not merely an ethical posture but a quality criterion of the method: in a design study whose deliverables are decision-grade artifacts for university leadership, the credibility of the entire framework depends on every claim carrying an accurate statement of its evidentiary status — structural reasoning, standards conformity, or documented practice — and on nothing claiming the authority of measurement that was never performed (Braun & Clarke, 2021; Cole, 2024). The thesis's terminology discipline, its declared adaptations, and its refusal of unearned precision are the operational form of that commitment, and they bind every section of this study equally.

CHAPTER 4: STRUCTURAL AND FEASIBILITY STUDY

4.1 Organizational and Governance Architecture

Section 1 characterized the decentralized inventory regime of a large public science faculty within a Saudi higher education institution—with a life sciences department as the embedded unit of analysis—as a Risk Maturity Gap; Section 2 converted that diagnosis into an integrated framework spanning an adapted three-band maturity trajectory, a Bow-Tie barrier architecture, an ISO 22301:2019 continuity reading of shared visibility and inter-lab loans, and an ISO 14001:2015/USR/FIRM classification of environmental and reputational outcomes (Hillson, D. A., 1997; Hopkin, 2018; 14001 ISO/IEC, 2015; 22301 ISO/IEC, 2019; 31010 ISO/IEC, 2019). The present section addresses Research Objective O3 (organizational framework development) and prepares O4 (implementation roadmap) by answering the question the Bow-Tie method itself poses who owns each barrier, and with what authority (de Ruijter & Guldenmund, 2016; Johnson et al., 2018). The answer is a three-tier governance design — an Academic Inventory Governance Board, a Technical Standardization Committee, and a Digital Supply Chain Unit — operating above an operational level at which laboratory technicians execute defined technical workflows and bound together by an Inter-Lab Policy Framework governing temporary asset loans and First-Expired-First-Out (FEFO) chemical redistribution. Consistent with the study’s binding methodology, everything specified here is a design artifact: a reasoned, standards-anchored proposal with no empirical claims attached.

4.1.1 Design Principles of the Governance Architecture

Organizational design for participatory inventory cannot proceed by fiat; each structural choice requires an explicit principle defensible against the governance literature and the management-system standards the framework adopts. Six principles govern architecture.

Principle 1 — Separation of decision and execution. Policy, decision rights, and standard-setting are assigned to governance bodies, and execution to operational actors, so that no role both makes and marks their own work. This is the organizational expression of the management-system requirement that roles, responsibilities, and authorities be defined, assigned, and communicated ((14001 ISO/IEC, 2015), clause 5.3;(22301 ISO/IEC, 2019), clause 5.3), and it reflects the collaborative-governance finding that participation decays into nominal compliance when decision rights and accountability are not explicitly allocated (Ahn & Baldwin, 2024; Lopes & Farias, 2022). In practice: the Board decides policy, the Committee drafts standards, the Unit operates data infrastructure, and technicians execute technical workflows — each tier checking the tier adjacent to it.

Principle 2 — Stewardship over ownership. Participatory inventory rests on an access-over-ownership logic: the value of laboratory stock is realized through availability and use, not through departmental possession. The equipment-sharing and core-facility literature shows that shared-access regimes raise utilization only when stewardship — booking, custody, maintenance responsibility — is institutionally specified rather than assumed (Adami et al., 2021; Strom et al., 2020; Zhu & Liu, 2021), while the sharing-economy governance literature warns that pooled-resource arrangements fail through free-riding, ambiguous responsibility, and eroded trust when platform rules are weak (X. Wang & Qu, 2025). The architecture therefore keeps every shared asset under the stewardship of a custodian department, with loans regulated by the Inter-Lab Policy Framework ([Section 4.1.6](#)) rather than by collegial goodwill.

Principle 3 — Proportionate authority. Authority is allocated commensurate with accountability and competence; no role carries authority beyond what its competence warrants ((14001 ISO/IEC, 2015), clause 5.3;(22301 ISO/IEC, 2019), clause 5.3). The framework operationalizes this by giving the Board policy authority but no operational tasks, the Committee standard-setting authority but no purchasing decisions, the Unit data

stewardship but no loan or procurement decisions, and technicians execution responsibility with escalation duties but no administrative or financial authority. Proportionate authority is also a maturity instrument: it is precisely the absence of bounded, named roles that holds the decentralized regime in the Inform/Conform band (Hillson, D. A., 1997).

Principle 4 — Auditability by design. Every consequential action — a catalog change, eligibility check, a loan approval, a custody transfer, a disposal — must produce documented information at the moment it occurs, not retrospectively. Both anchor standards require controlled documented information as the evidentiary substrate of a management system (ISO, 2015, clause 7.5; ISO, 2019, clause 7.5), and auditability is what converts policy existence into the policy enforcement that the Bow-Tie’s escalation-factor analysis demands (Johnson et al., 2018). Auditability is thus designed into workflows as automatic logging, not appended as a separate reporting burden.

Principle 5 — Barrier ownership. Section 2 established that a barrier nobody owns is a failed barrier by construction (de Ruijter & Guldenmund, 2016), and that the Bow-Tie’s management value lies in making control ownership explicit (Cormier et al., 2019; Johnson et al., 2018). Every prevention, mitigation, and escalation-factor barrier is therefore assigned below to a named organizational owner; the complete mapping is consolidated in [Section 4.1.7](#).

Principle 6 — Gradualism and pilot-first sequencing. The framework is designed for phased adoption — pilot-first within the Biology Department, then scaled across the College of Science, with readiness gates drawn from Section 2’s maturity trajectory. This reflects the change-management evidence that university reform succeeds through staged, capability-building transitions (Dean et al., 2024; Vlachopoulos, 2021) and the project-management principle that implementation be tailored and progressively elaborated to context (PMI, 2021; Takagi et al., 2024). Gradualism also disciplines digitalization: technology acquisition follows, never precedes, standardized processes and clear roles.

Taken together, the six principles position the architecture as an instance of collaborative governance: semi-autonomous units pooling resources under shared rules whose legitimacy depends on procedural clarity, trust, and equitable benefit distribution (Ahn & Baldwin, 2024; Gestel & Grotenbreg, 2021). The framework’s design wager is that participatory inventory within the host institution is sustainable only when collaboration is institutionalized as bounded roles with explicit decision rights, rather than left as informal cooperation (Lopes & Farias, 2022).

4.1.2 The Academic Inventory Governance Board

The **Academic Inventory Governance Board** (hereafter “the Board”) is the apex decision body for participatory inventory management at the College of Science. It is a governance organ, not an operational one: its mandate is to own the rules of sharing, not to move stock.

Mandate. The Board holds five delegated mandates. First, *policy approval*: it ratifies, amends, or retires all framework policies, including the Inter-Lab Policy Framework and the Committee’s standards. Second, *eligibility-clause ratification*: the mandatory shared-registry check before requisition and the redistribution-before-disposal rules acquire force only upon Board ratification, because they constrain departmental purchasing behavior and so require authority above any single department. Third, *risk-register ownership*: the Board owns the framework’s risk register, classified under the FIRM taxonomy (Financial, Infrastructure, Reputational, Marketplace — read in the university adaptation as the service and stakeholder environment) as a classification taxonomy, not a scoring algorithm (Hopkin, 2018). Fourth, *continuity objectives*: the Board sets and confirms the continuity objectives for prioritized teaching and research activities — the qualitative maximum tolerable period of disruption (MTPD), recovery time objective (RTO), and minimum acceptable capacity reasoning of [Section 2.9.4](#) — consistent with the standard’s assignment of business continuity objectives to top management ((22301 ISO/IEC, 2019),

clauses 5.3, 6.2). Fifth, *performance review*: the Board conducts the framework’s audit cadence and management review — escalation–factor barrier EB1 against unenforced policy ([Section 2.9.3](#)).

Composition. The Board is composed of roles, not personalities: a college leadership delegate (chair), one representative from each participating department, the college safety and compliance officer, and the heads of the Committee and the Unit as standing members — balancing decision legitimacy, operational knowledge, and the safety–and–environmental voice required wherever environmental aspects and compliance obligations are governed ((14001 ISO/IEC, 2015), clauses 5.3, 6.1.2–6.1.3).

Decision rights and escalation. The Board decides: policy ratification and amendment; eligibility–clause adoption; risk–register acceptance; continuity objectives; adjudication of disputes escalated from custodian departments; and corrective actions arising from audit and review, following the Annex SL improvement logic ((14001 ISO/IEC, 2015), clause 10;(22301 ISO/IEC, 2019), clause 10). Delegated downward are all operational matters: standard drafting to the Committee, registry operation to the Unit, workflow execution to technicians, and individual loan approvals to custodian departments under Board–ratified rules. Escalated upward are matters that cross departmental boundaries or exhaust lower–level authority: unresolved loan disputes, repeated eligibility–clause violations, systemic data–quality failures, and continuity–objective revisions.

Cadence. The Board meets each academic term for ordinary business — risk–register review, policy amendments, dispute records — and convenes an annual management review analogous to clause 9.3 of both anchor standards, at which barrier performance, audit results, data–quality indicators, and continuity readiness are reviewed and corrective actions assigned ((14001 ISO/IEC, 2015), clause 9.3;(22301 ISO/IEC, 2019), clause 9.3). Extraordinary sessions address incident–driven reviews, following the emergency–preparedness review logic of (14001 ISO/IEC, 2015, p. 2015) clause 8.2.

Boundaries. Two boundaries are explicit. First, the Board does not execute operational tasks: it never approves individual loans, edits registry records, or directs stock rotation. Second, it does not bypass departmental budget authority: it governs the *rules of sharing* — eligibility, custody, review — while purchasing decisions and their financing remain with departments under existing university financial regulations. The Board constrains how departments buy (through the ratified eligibility check) without commanding what they may fund, keeping the framework compatible with established financial governance while still interrupting the duplicate–purchasing pathway identified as Threat T1 in [Section 2.9.3](#).

4.1.3 The Technical Standardization Committee

The **Technical Standardization Committee** (hereafter “the Committee”) owns the framework’s prevention barriers: where the Board decides, the Committee *drafts and maintains the technical content* of what is decided. Its logic follows from Section 2’s maturity analysis: standardization is the first transition out of the Inform/Conform band, and it requires a standing body with the technical competence to define one catalog where the decentralized regime maintained many (Hillson, D. A., 1997; Paulk et al., 1993). The Committee carries four standing duties.

1. **Unified catalog and classification standard.** The Committee defines and maintains the common data structure for chemicals, instruments, glassware, and consumables: naming conventions, classification hierarchies, units of measure, hazard annotations, and the minimum attribute set every registry record must carry (identity, quantity, location, custody, acquisition date, and — for chemicals — expiry date and hazard class). This duty owns prevention barrier PB1 (Johnson et al., 2018), and the standard is drafted for Board ratification and thereafter maintained under version control as documented information ((14001 ISO/IEC, 2015), clause 7.5).

2. **Eligibility clauses.** The Committee drafts the two clauses that convert shared visibility into purchasing discipline: (a) the *mandatory shared-registry check before requisition* — no requisition for a loanable item class may proceed without a documented registry check for serviceable stock elsewhere in the college; and (b) the *redistribution-before-disposal rule* — no item may enter a disposal pathway until the registry has been checked for live demand elsewhere. These clauses own prevention barrier PB2 and operationalize circular-economy logic at the point of purchase, privileging reuse of existing stock over new acquisition (Ellen MacArthur Foundation., 2013; Kirchherr et al., 2017; Sönnichsen & Clement, 2020).
3. **FEFO policy standard.** The Committee defines First-Expired-First-Out as a policy standard rather than a shelf habit: the formal definition (the item with the earliest expiry date is issued, consumed, or offered for redistribution first), labeling and date-marking requirements, rotation discipline, and the expiry-flagging thresholds at which technicians must escalate. The green-laboratory and laboratory-supply literature identifies unnoticed shelf-life lapse as a principal driver of chemical waste and date-ordered rotation as the standard operational control against it (Durgan et al., 2023; Wilke et al., 2023). This duty owns the *standard* dimension of mitigation barrier MB1; execution remains with technicians ([Section 4.1.5](#)).
4. **Safety and compliance interface.** The Committee aligns all standards with hazardous-substance rules and with the framework's environmental requirements: operational planning and control of significant environmental aspects ((14001 ISO/IEC, 2015), clause 8.1), emergency preparedness and response for chemical incidents ((14001 ISO/IEC, 2015), clause 8.2), and evaluation of compliance obligations ((14001 ISO/IEC, 2015), clauses 6.1.3, 9.1.2). The college safety and compliance officer sits on the Committee in an advisory capacity to guarantee this interface.

Composition and working mode. The Committee comprises senior technical staff nominated by participating departments, a registry–standards liaison from the Unit, and the safety and compliance officer. It works by drafting cycles: each standard or clause is drafted, circulated to departments for comment, revised, and submitted to the Board for ratification — drafting by the technically closest staff, ratification by the Board, and operation by the Unit instantiating [Principle 1](#) at the level of the standards themselves.

Boundary. The Committee sets standards; it does not approve individual purchases, does not adjudicate loans, and holds no budget authority. Its products constrain behavior only after Board ratification — a boundary that prevents the accumulation of de facto administrative power in a technical body, a failure mode the collaborative–governance literature associates with blurred mandates (Gestel & Grotenbreg, 2021).

4.1.4 The Digital Supply Chain Unit

The **Digital Supply Chain Unit** (hereafter “the Unit”) owns shared visibility and data integrity — the informational substrate on which every other governance function depends. Its defining insight, drawn from Section 2, is that incomplete registry data is an escalation factor (EF2) capable of blinding the eligibility clause, the redistribution mechanism, and the catalog standard simultaneously; data quality is therefore a barrier to be owned, not a by-product to be hoped for (Johnson et al., 2018). The Unit carries four standing duties.

1. **Shared inventory registry stewardship.** The Unit operates the college’s shared inventory registry: it defines data–entry protocols derived from the Committee’s catalog standard, onboards departmental inventories, and administers the data–quality rules — completeness, currency, and consistency indicators — that constitute escalation–factor barrier EB2. Stewardship here means responsibility for the integrity of the shared record, not ownership of the stock the record describes ([Section 4.1.1](#), [Principle 2](#); (Zhu & Liu, 2021)).

2. **Visibility and reporting.** The Unit maintains the cross-laboratory holdings view that makes the eligibility check possible and produces the reporting the Board's review cadence requires: data-quality trends, expiry-flag summaries, loan-flow records, and continuity-relevant holdings reports. In continuity terms, this reporting is what allows the institution to know its minimum acceptable capacity during a supply disruption — which prioritized activities can be served from internal stock, and for how long ((22301 ISO/IEC, 2019), clauses 8.2.2, 8.3). The Unit reports; it does not interpret reports into decisions.
3. **Platform readiness.** The Unit maintains the requirements baseline for a future smart-inventory platform (for example, barcode- or RFID-assisted tracking). Structured data, defined workflows, and role clarity constitute the organizational readiness that the digital-transformation literature identifies as the binding constraint on technology value in higher education (Bellantuono et al., 2021; Bravo-Jaico et al., 2025; Rodríguez-Abitia & Bribiesca-Correa, 2021), and smart-inventory research confirms that automated tracking delivers value only where inventory processes and data semantics are already standardized (Carpitella & Izquierdo, 2025). The readiness function thus treats the platform as a Perform-band capability unlocked by readiness gates, not a shortcut around them.
4. **Liaison with university IT and procurement.** The Unit is the framework's interface to university-level information technology and procurement services: it negotiates hosting, access, and interoperability arrangements and channels procurement-system requirements upward, without itself acquiring procurement authority — keeping college-level participatory inventory compatible with institution-wide systems, a condition the public-sector digitalization literature identifies as decisive for sustainable reform (Mohamed Hashim et al., 2022; Shibambu, 2024).

Boundary. The Unit operates the registry and reports on it; it does not decide loans or purchases — those rest with custodian departments under Board–ratified policy and with departments subject to the eligibility clause. The Unit may decline to certify a registry check as complete when data–quality rules are unmet — a negative, procedural power — but may not direct a department’s procurement outcome. This bounded mandate keeps informational power from converting into decisional power, preserving [Principle 3](#) (proportionate authority;(22301 ISO/IEC, 2019), clause 5.3).

4.1.5 Laboratory Technicians at the Operational Level

The framework assigns laboratory technicians a role that is deliberately narrow and deliberately strong: narrow, because it is confined to the operational and technical level; strong, because within that confinement technicians are the named executors of the framework’s most consequential barriers. The role is specified exactly here because the architecture’s integrity depends on technicians neither exceeding their authority nor carrying responsibility without the competence and support the standards require ((14001 ISO/IEC, 2015), clauses 7.2–7.3;(22301 ISO/IEC, 2019), clauses 7.2–7.3).

Duties. Technicians execute three defined workflow families.

1. **FEFO execution.** Technicians perform first–expired–first–out shelf discipline: date–checking on receipt and issue, physical rotation so earliest–expiring items issue first, expiry labeling per the Committee’s standard, and flagging of items approaching expiry. This is the operational enactment of mitigation barrier MB1; the technician’s rotation work is where the barrier either holds or fails (Durgan et al., 2023; Wilke et al., 2023).
2. **Inter–lab loan workflow execution.** For loans approved by custodian departments under the Inter–Lab Policy Framework ([Section 4.1.6](#)), technicians prepare items for transfer, complete condition records, log dispatches and returns,

and receive items back with return-condition checks. They execute the custody-transfer protocol (EB3) at the bench level; they do not approve, refuse, or negotiate loans.

3. **Catalog entries and registry data upkeep.** Technicians make accurate, timely registry entries — receipts, issues, transfers, disposals — conforming to the Committee’s catalog standard and the Unit’s data-entry protocols. Because incomplete registry data degrades multiple barriers at once (EF2), this data discipline is itself barrier work, not clerical residue.

Explicit non-authority clause. The technician role carries **no administrative decision-making authority, no procurement approval, no financial commitments, no policy-setting role, and no unilateral loan approval.** Technicians execute within approved workflows and **escalate exceptions** — damaged items, overdue loans, imminent expiry clusters, data discrepancies — to the Digital Supply Chain Unit and their custodian supervisor per protocol. Escalation is a duty, not a discretion: the framework specifies the triggers, channels, and expected content of escalations so that anomalies reach decision-holders quickly and in documented form, mirroring the warning-and-communication logic of ISO 22301:2019 clause 8.4 (22301 ISO/IEC, 2019). Technicians may recommend — bench-level observation is the framework’s richest early-warning source — but never decide beyond their technical capacity.

Competence and awareness. Both anchor standards require that persons performing work under the management system be competent on the basis of education, training, or experience, and be aware of the policy, their contribution, and the consequences of nonconformity ((14001 ISO/IEC, 2015), clauses 7.2–7.3;(22301 ISO/IEC, 2019), clauses 7.2–7.3). The framework accordingly specifies role-based competence requirements — FEFO discipline, custody-transfer documentation, registry data standards, and chemical–

handling safety — maintained through onboarding and periodic refreshers administered by custodian departments with Unit support materials.

The bounded role as governance strength. The technician’s boundary should not be read as a limitation; the analysis of this thesis suggests the opposite. Bounded roles make barrier ownership auditable: when FEFO fails, the failure is traceable to a defined executor, standard, and escalation path rather than dissolving into the diffuse responsibility of the Inform/Conform band (Hillson, D. A., 1997). Separating execution from decision also protects technicians from authority inflation — the documented failure mode of participatory arrangements that delegate responsibility without rights (Ahn & Baldwin, 2024; Lopes & Farias, 2022) — while the escalation duty gives the operational level a formal voice in governance without decision rights, the architecture’s concrete answer to the requirement that participation be real but bounded (Gestel & Grotenbreg, 2021).

4.1.6 The Inter-Lab Policy Framework

The **Inter-Lab Policy Framework** is the operative instrument of participatory inventory: the Board-ratified policy governing temporary inter-laboratory asset loans and FEFO-based chemical redistribution. It is the organizational form of mitigation barrier MB2 and escalation-factor barrier EB3, and the element that most directly engages the sharing-governance caution that pooled assets fail through ambiguous responsibility: every loan must therefore carry an explicit, documented allocation of custody at every state (Strom et al., 2020; X. Wang & Qu, 2025). The policy is specified in five components.

(a) Eligibility and scope

The policy distinguishes *loanable* from *excluded* item classes. Loanable classes comprise durable instruments and equipment, glassware, and consumables whose transfer does not compromise their function, together with chemical stocks eligible for redistribution under the FEFO rules. Excluded are: controlled and regulated substances, whose movement is

governed by external regulation and institutional hazardous–substance rules rather than by this policy; calibrated–critical instruments, whose relocation would invalidate calibration, unless the Committee has approved a specific transfer protocol for the instrument class; and items under active booking by the custodian’s own scheduled teaching, against which the custodian’s recall right applies ([Section 4.1.6](#) (Inter–Lab Policy Framework)). The classification is drafted by the Committee, ratified by the Board, and encoded in the registry by the Unit, so that eligibility is checkable at the moment of request rather than negotiable after it ((14001 ISO/IEC, 2015), clause 8.1;(Johnson et al., 2018)).

(b) Loan request–approval workflow

The workflow is specified as numbered steps, each producing documented information at the moment of execution ((14001 ISO/IEC, 2015), clause 7.5):

1. **Registry availability check.** The borrowing laboratory’s designated staff query the shared registry for the required item class; the registry response — holdings, location, custody — is logged automatically. This is the eligibility clause (PB2) operating in its loan–direction mode.
2. **Borrower request.** The borrower submits a request stating item, quantity, purpose (course or protocol), requested duration, and collection arrangements; requests are routed to the custodian department, with the Unit copied for logging.
3. **Custodian approval.** The custodian department approves or declines under Board–ratified rules, weighing its own scheduled demand, item–class eligibility, and outstanding loan load. Approval authority rests with the custodian supervisor; technicians do not approve. Declined requests state the ratified rule applied.
4. **Loan terms.** An approved loan is issued with duration, a condition baseline (from [Section 4.1.6](#) (Scope & Eligibility)), and return criteria, logged in the registry by the executing technician.

5. **Execution and logging.** Technicians prepare, hand over, and log the loan per the custody-transfer protocol; the registry loan state moves to *on-loan* with custodian and borrower recorded.
6. **Return and closure.** On return, technicians perform the return-condition check and log closure or escalate damage; the loan state closes.

(c) Custody transfer protocol

Custody transfer is the policy's evidentiary core, designed against escalation factor EF3 (custody ambiguity). Every handover is documented through three artifacts: a *condition record* (the item's state at transfer, constituting the condition baseline), a *custody acknowledgment* (the receiving party's signed or system-logged acceptance), and a *chain-of-custody log* (the time-ordered record of custody states from dispatch to return). The governing principle is that **custody is responsibility for care, not transfer of ownership**: the lending department retains ownership and stewardship, while the borrower holds custodial responsibility for the loan's duration ([Section 4.1.1](#), [Principle 2](#); (Zhu & Liu, 2021)). For chemical redistribution, the custody protocol operates jointly with FEFO: near-expiry stock moves first, so that a transfer is, where possible, a consumption transfer — the receiving laboratory consumes stock that would otherwise expire in the custodian's store (Durgan et al., 2023; Freese et al., 2024). Consumption transfers close without return; returnable transfers follow the full chain-of-custody cycle.

(d) Responsibility tracking

The policy defines four custody states and assigns accountability in each: *in-custody* (custodian department accountable; technicians maintain records), *in-transit* (accountability assigned per the custody acknowledgment, defaulting to the borrower once logged), *on-loan* (borrower accountable for care, return, and damage reporting), and *returned-damaged* (an exception state triggering escalation, not informal settlement). Exceptions

follow a defined escalation ladder — **technician** → **Digital Supply Chain Unit** → **custodian supervisor** → **Board** — with each rung activated when the lower rung cannot resolve within its authority: technicians' flag, the Unit routes and documents, the custodian supervisor decides within policy, and the Board adjudicates cross-departmental disputes ((22301 ISO/IEC, 2019), clause 8.4 analogue).

(e) Risk controls

Five controls protect the lending regime. **First**, the *damage/loss liability principle*: the party holding custody when damage or loss occurs bears responsibility for remediation through departmental channels, with the chain-of-custody log as the evidentiary basis — a design response to the free-riding and responsibility-ambiguity failure modes of sharing arrangements (X. Wang & Qu, 2025). **Second**, *loan limits*: per-item-class caps on simultaneous outward loans protect the custodian's own teaching base. **Third**, *recall rights*: the custodian may recall loaned items when its own scheduled teaching requires them — the ISO 22301:2019 priority of prioritized activities over sharing convenience, since continuity solutions exist to protect prioritized activities, not to redistribute their dependencies away ((22301 ISO/IEC, 2019), clause 8.3). **Fourth**, the *audit trail*: every workflow step produces registry-logged documented information, so loans are reconstructible at audit without reliance on memory or email. **Fifth**, *review*: aggregate loan-flow and damage records feed the Board's termly review, closing the PDCA loop on the policy itself ((14001 ISO/IEC, 2015), clauses 9.3, 10). [Figure 4.1](#) renders the workflow and its escalation ladder.

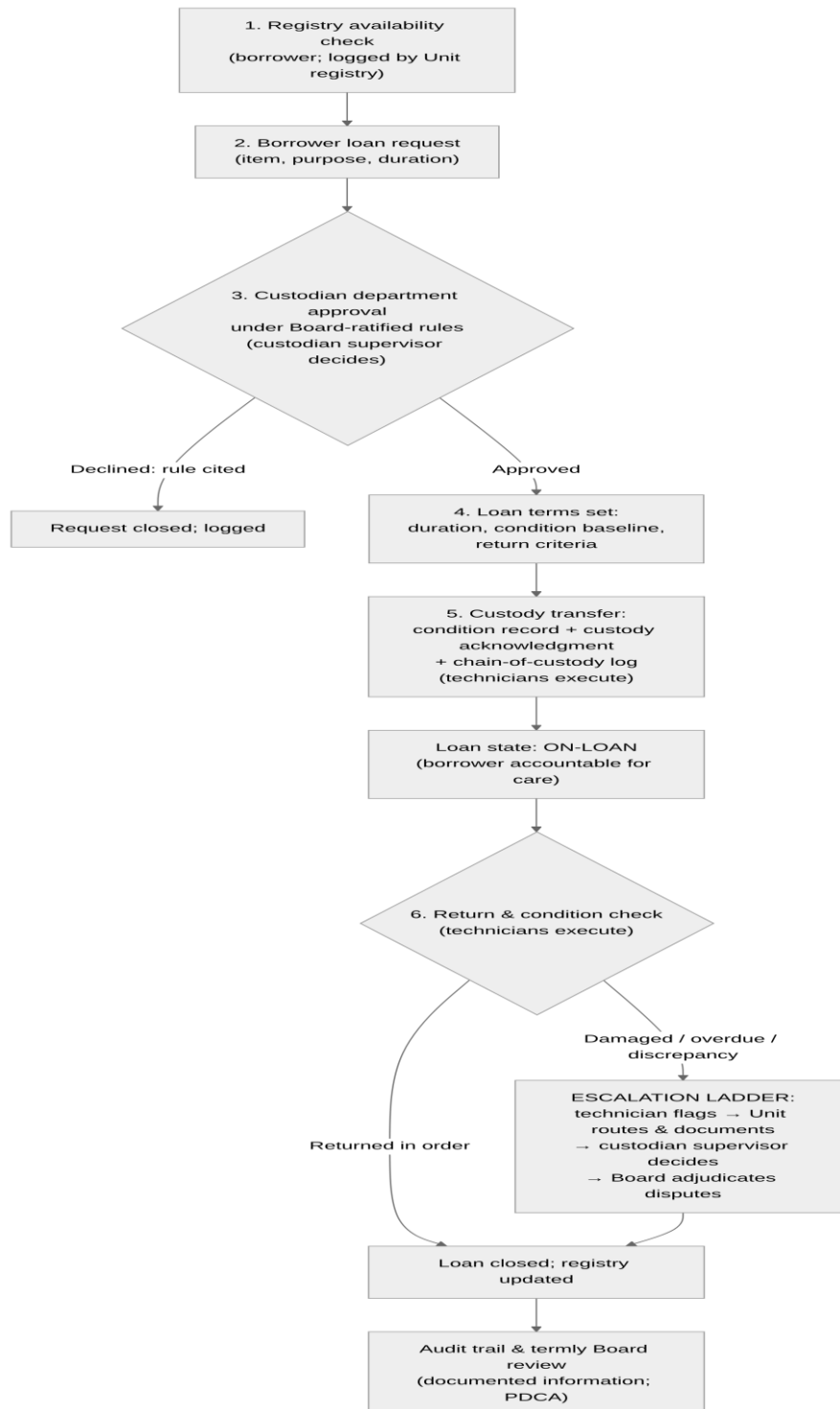


Figure 4.1. Inter-lab loan workflow and escalation ladder under the Inter-Lab Policy Framework (design specification; custody states and controls per [Section 4.1.6](#)).

4.1.7 Governance Interfaces and Accountability Matrix

The architecture functions only if its interfaces are as explicit as its bodies. The Committee and the Unit report to the Board; custodian departments interface with the Board through their representatives and with the Unit through registry protocols; technicians report within their custodian departments and escalate to the Unit per protocol; and the Board reports to college leadership through its chair. Information flows upward as documented reporting (Unit reports, Committee drafts, escalation records) and downward as ratified policy and standards — never as informal instruction, which would defeat auditability by design ((14001 ISO/IEC, 2015), clause 7.5;(22301 ISO/IEC, 2019), clause 7.5).

[Table 4.1](#) consolidates accountability across the framework’s key processes in a RACI–style matrix (R = Responsible, executes; A = Accountable, owns the outcome; C = Consulted; I = Informed), following the roles–and–authorities discipline of clause 5.3 of both anchor standards(14001 ISO/IEC, 2015; 22301 ISO/IEC, 2019).

Table 4.1. RACI-style accountability matrix for key framework processes

Process	Governance Board	Technical Standardization Committee	Digital Supply Chain Unit	Custodian Department	Laboratory Technicians
Catalog standard– setting	A (ratifies)	R (drafts, maintains)	C (registry feasibility)	C (departmental comment)	I
Eligibility check before requisition	I	A (clause owner)	R (operates/verifies check)	C (must comply)	C (data accuracy)

Process	Governance Board	Technical Standardization Committee	Digital Supply Chain Unit	Custodian Department	Laboratory Technicians
Loan approval	I	I	C (logs; data support)	A/R (custodian supervisor approves)	I (no approval role)
FEFO execution	I	C (standard owner)	I (flag reports)	A (supervisor accountable)	R (rotation, flagging)
Custody transfer	I	I	C (chain-of-custody log)	A	R (records, handover)
Registry upkeep	I	C (data standard)	A (stewardship)	C	R (entries)
Expiry escalation	I	I	A (routes, coordinates)	C (decides redistribution)	R (flags, escalates)
Audit & management review	A/R (cadence, review)	C	R (reporting support)	C	I

Note on accountability versus ratification: in Table 4.1, accountability (A) denotes ownership of the process as operated; where a rule itself requires ratification — as with eligibility clauses — ratification authority remains with the Governance Board as specified in [Section 4.1.2](#), while the Committee retains accountability for the clause’s content, maintenance, and correct operation. The two assignments are complementary, not conflicting.

Two features of the matrix deserve note. **First**, no row assigns technicians an A, and their R assignments are confined to execution and escalation — the matrix is the formal proof of the non-authority clause of [Section 4.1.5](#). **Second**, accountability for every prevention, mitigation, and escalation-factor barrier from Section 2 is traceable through these rows to a named body, satisfying [Principle 5](#). [Figure 4.2](#) presents the organizational chart; [Table 4.2](#) closes the loop with the explicit barrier-ownership mapping.

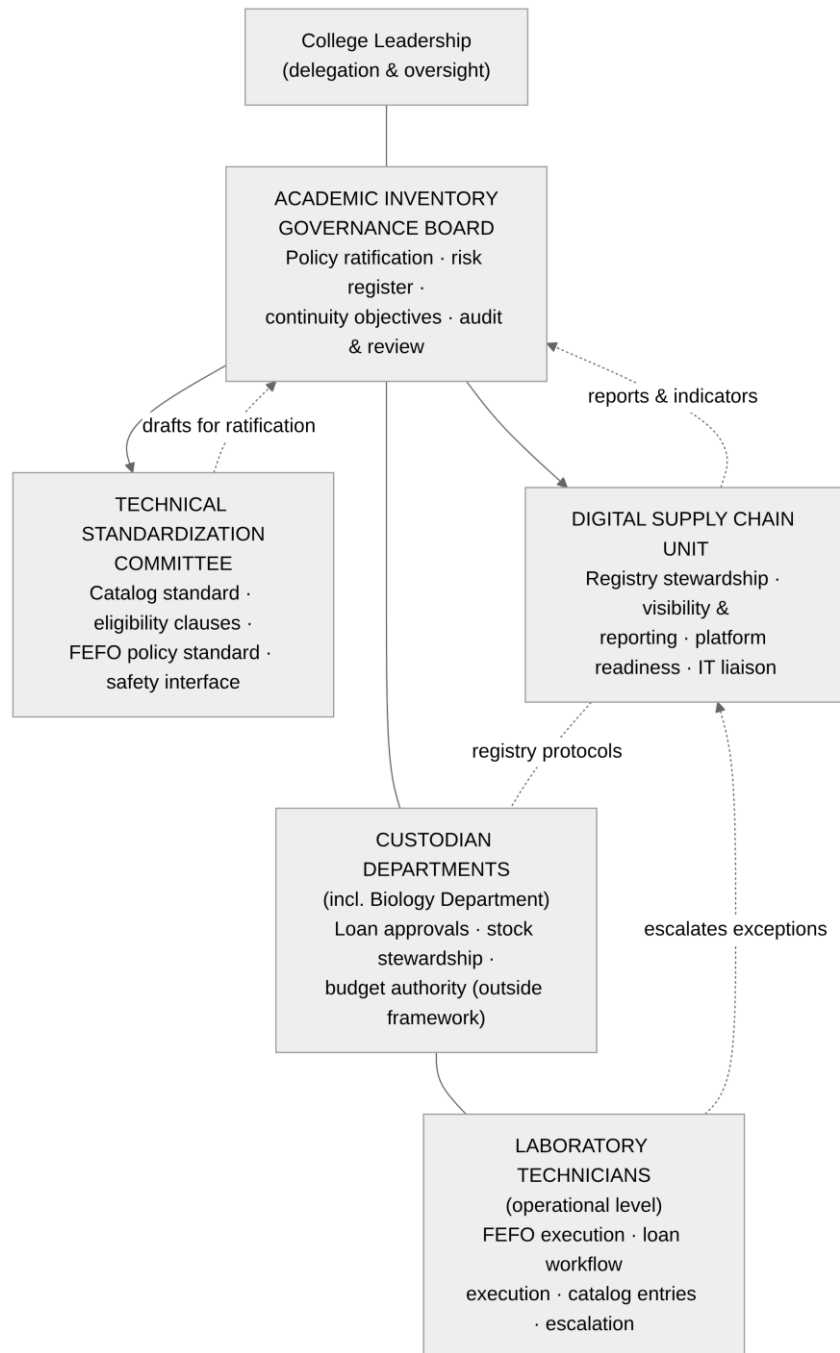


Figure 2.2. Organizational chart of the participatory inventory governance architecture (solid lines: reporting/governing; dashed lines: drafting, reporting, escalation, and protocol interfaces).

Table 4.2. Barrier-ownership mapping from the [Section 2.9.3](#) Bow-Tie architecture to [Section 4.1](#) bodies

Barrier (Section 2.9.3)	Organizational owner	Execution level
PB1 Standardized catalog & records	Technical Standardization Committee	Technicians (entries); Unit (registry)
PB2 Eligibility clauses	Committee (drafts); Board (ratifies)	Unit (check operation); custodians (compliance)
PB3 Joint/circular procurement rules	Board (ratifies); Committee (drafts)	Departments, via Unit procurement liaison
MB1 FEFO rotation	Committee (standard); custodian supervisor (accountable)	Technicians (rotation, flagging)
MB2 Inter-lab sharing / redistribution	Board (Inter-Lab Policy Framework)	Custodians (approval); technicians (execution)
MB3 Governed disposal protocols	Committee, with safety & compliance officer	Departments under Unit reporting
EB1 Audit cadence	Governance Board	Unit (reporting support)
EB2 Data-quality indicators	Digital Supply Chain Unit	Technicians (entry discipline)
EB3 Custody-transfer protocol	Board (policy); Committee (protocol content)	Technicians (condition records, logs)

This architecture operationalizes Section 2’s framework in the precise sense its design principles demand: the Bow-Tie’s barrier list has been converted into an ownership list, the maturity model’s standardization-and-governance transitions have been embodied in standing bodies, and the continuity and environmental requirements of ISO 22301:2019 and ISO 14001:2015 have been located in specific mandates — continuity objectives and review in the Board, aspect control and the emergency interface in the Committee, capacity visibility in the Unit, and conformity-supporting execution in the technician role(14001 ISO/IEC, 2015; 22301 ISO/IEC, 2019; Johnson et al., 2018). [Phase 1](#) (Governance Design) therefore closes where Objective O4 opens: the

implementation roadmap of later phases will sequence this architecture's adoption — pilot-first in the Biology Department, readiness-gated by the maturity bands, digitalization deferred until the institution moves from Inform/Conform toward Managed/Normalized — so that implementation becomes the staged realization of a governed design rather than a leap into technological substitution (Dean et al., 2024; PMI, 2021; Rodríguez-Abitia & Bribiesca-Correa, 2021).

4.2 Multi-Dimensional Feasibility Assessment

[Phase 1](#) of this thesis diagnosed the decentralized inventory regime of a large public science faculty within a Saudi higher education institution as a Risk Maturity Gap (Section 1), constructed an integrated framework to close that gap (Section 2), and institutionalized the framework in a three-tier governance architecture—an Academic Inventory Governance Board, a Technical Standardization Committee, and a Digital Supply Chain Unit, with laboratory technicians executing bounded operational workflows ([Section 4.1](#)). [Phase 2](#) now subjects that design to evaluation before any implementation is proposed, beginning with the present section: a multi-dimensional feasibility assessment across organizational and governance, financial and fiscal, technical and operational, and environmental and sustainability dimensions. The assessment addresses Research Objective O2 (evaluation of the participatory inventory approach) and supplies the analytical structure — the rating vocabulary and the readiness gates G1–G4 — upon which [Section 2.9.2](#)'s risk register, [Section 4.1.7](#)'s indicator set, and [Section 4.1.6](#)'s implementation roadmap are built. Consistent with the study's binding methodology, the assessment is wholly qualitative: it reasons from the structural analysis of [Phase 1](#), from the requirements of the anchor standards (14001 ISO/IEC, 2015; 22301 ISO/IEC, 2019), and from documented practice in the verified literature, and it advances no empirical claims of any kind.

4.2.1 Assessment Logic: Qualitative Feasibility in a Design Study

Feasibility assessment conventionally invokes measured evidence — pilot results, cost figures, adoption statistics. None of these is available to, or appropriate for, a pre-implementation design study, and this thesis does not simulate them. The project management discipline itself licenses the alternative adopted here: the PMBOK Guide treats feasibility analysis as structured judgment about alignment between a proposed undertaking and the organization’s strategy, governance, capability, and constraints, conducted before execution begins and tailored to context (Project Management Institute (PMI, 2021; Takagi et al., 2024). The correct question in such a setting is not “what score does the design achieve?” but “does the design fit the institution’s governance, resources, processes, and obligations — and where it does not yet fit, what must be true for it to fit?” Feasibility is therefore judged by three kinds of evidence, and only these:

1. **Structural analysis from Phase 1.** The maturity–gap diagnosis ([Section 2.2](#)), the Bow–Tie barrier architecture ([Section 2.9.3](#)), and the governance design ([Section 4.1](#)) specify what the framework demands of the institution and what the institution already provides; a feasibility judgment is, in the first instance, a comparison of design demand against institutional supply.
2. **Standards conformity.** Where the framework adopts the requirements of ISO 22301:2019 and ISO 14001:2015 — business impact analysis (BIA) logic, prioritized activities, competence and awareness provisions, environmental aspect control, evaluation of compliance obligations — conformity is itself evidence of feasibility, because the standards encode internationally consolidated practice for exactly the organizational capabilities at issue (14001 ISO/IEC, 2015; 22301 ISO/IEC, 2019; 31000 ISO/IEC, 2018).
3. **Documented practice in verified literature.** Feasibility claims are corroborated where the mechanism specified — eligibility checks before requisition, shared–

access regimes, date-ordered stock rotation, governed disposal — is documented as functioning practice in comparable laboratory, campus, or public-sector settings (Durgan et al., 2023; Sönnichsen & Clement, 2020; Strom et al., 2020; Zhu & Liu, 2021).

To express these judgments without pretending to measurement, the study defines a three-level qualitative rating vocabulary, used consistently throughout Sections [4.2](#) – [4.5](#):

- **Strong** — feasible under current conditions, with existing resources, roles, and authority; no policy precondition must be satisfied first. A Strong rating asserts that nothing in the design exceeds what the institution can do today by decision of competent existing bodies.
- **Conditional** — feasible once a specified policy condition or readiness gate is met. A Conditional rating names the condition explicitly: it is not a reservation but a design statement, identifying precisely which ratification, appointment, or standard converts the sub-criterion from latent to actual.
- **Contingent** — feasibility depends on factors outside the framework's direct control (for example, university-level information technology provision); the element requires monitoring rather than a single gate, and the framework is designed so that its core functions do not depend on the contingent element succeeding.

Complementing the ratings, the study defines **analytical readiness gates** as policy-controlled checkpoints with explicit criteria: points in the adoption sequence at which a named governance body verifies, against documented evidence, that defined conditions hold before the next phase is activated. Gates are analytical rather than empirical: their criteria are structural (policies ratified, roles appointed, records conformant, workflows demonstrated), verified by inspection of documented information in the sense of clause 7.5 of both anchor standards (14001 ISO/IEC, 2015; 22301 ISO/IEC, 2019), not by sampled metrics. Four gates — G1 policy ratification, G2 data readiness, G3 pilot workflow integrity,

and G4 digital platform readiness — are specified in [Section 4.6](#) and structure the roadmap of [Section 4.1.6](#). Every judgment in Sections [4.2](#) – [4.5](#) closes by stating its rating and, where Conditional or Contingent, the exact governing condition, so that the section’s conclusions are auditable against the same evidentiary discipline the framework demands of the institution.

4.2.2 Organizational & Governance Feasibility

The organizational question is whether the governance architecture of [Section 4.1.1](#) can be constituted and sustained within the College of Science as it exists. The structural analysis suggests that it can, for three reasons.

First, the architecture is **ratifiable within existing governance**: it creates no statutory body, no new faculty rank, and no authority that crosses university financial regulations. The Board, the Committee, and the Unit are constituted by delegation from existing college leadership, with mandates attached to roles the college already possesses in analogous form (departmental councils, safety committees, administrative support units). This is a deliberate design property: Section 4.1.1’s [Principle 3](#) (proportionate authority) confined everybody to authority commensurate with existing accountability, precisely so that constitution would require delegation rather than legislation ((14001 ISO/IEC, 2015), clause 5.3;(22301 ISO/IEC, 2019), clause 5.3). The collaborative–governance literature supports this logic: participatory arrangements succeed where decision rights, procedural clarity, and facilitation by legitimate authority are present, and decay into nominal compliance where participation is invited without allocated rights (Ahn & Baldwin, 2024; Gestel & Grotenbreg, 2021; Lopes & Farias, 2022). The architecture allocates rights explicitly — the Board decides, the Committee drafts, the Unit operates, custodian departments approve loans, technicians execute and escalate — which is exactly the condition the literature identifies as decisive.

Second, the architecture is **enforceable through instruments the standards already define**. Policy existence is not policy enforcement: Section 2 identified unenforced policy as escalation factor EF1 and assigned escalation–factor barrier EB1 — an audit cadence with management review — against it. Both anchor standards supply the machinery in clauses 9.2 (internal audit) and 9.3 (management review), adopted here by analogue as termly Board review, annual management review, and documented corrective action under the Annex SL improvement cycle ((14001 ISO/IEC, 2015), clauses 9.2–9.3, 10;(22301 ISO/IEC, 2019), clauses 9.2–9.3, 10). Enforceability thus rests on documented information and review cadence rather than on any new disciplinary power, keeping the framework compatible with academic self–governance.

Third, the **institutional setting is an enabler rather than an obstacle**. The host institution’s single integrated mega–campus concentrates the science faculty’s laboratories in physical and administrative proximity, so that loans and redistribution operate within one campus rather than across a distributed estate—a structural advantage for custody transfer and supervision that the equipment–sharing literature treats as non–trivial (Adami et al., 2021; Strom et al., 2020). At the strategic level, Saudi Vision 2030’s emphasis on fiscal efficiency, sustainability, and digital transformation provides institutional sponsorship: reforms of this kind are legible to university leadership as contributions to national priorities, and the Saudi higher–education literature documents both the pull of that alignment and the governance effort it demands (Alamoudi et al., 2023; Alshammari, 2025).

The dimension is nonetheless rated **Conditional**, not Strong, because two governing conditions must be met before the architecture exists in fact: (a) **ratification** — college leadership must constitute the Board and ratify the catalog standard, eligibility clauses, FEFO standard, and Inter–Lab Policy Framework (gate G1); and (b) **leadership sponsorship** — a visible, sustained mandate, since the evidence is unambiguous that cross–unit pooling arrangements fail where sponsorship lapses and departments revert to

siloed defaults (Ahn & Baldwin, 2024; X. Wang & Qu, 2025). Neither condition requires resources the college lacks; both require decisions only it can take.

4.2.3 Financial & Fiscal Feasibility

The financial assessment proceeds mechanism—first, because the study’s methodology excludes monetary quantification: the question is not how much the framework saves but whether its cost–avoidance mechanisms are structurally sound and whether the framework imposes new fiscal burdens. Three mechanisms are examined.

Duplicate–procurement displacement. Section 1 identified duplicate purchasing as the default behavior of a regime in which existence elsewhere is unknowable (threat T1). Prevention barrier PB2 — the eligibility clause requiring a documented shared–registry check before any requisition for a loanable item class — interrupts this pathway at the point of decision: a purchase that would duplicate serviceable stock becomes visible as such before funds are committed. Prevention barrier PB3 extends the logic to joint and circular procurement rules, aggregating recurring consumable demand so that small, isolated, expiry–prone orders give way to planned collective purchasing. The sustainable–procurement literature documents exactly this control logic — visibility and eligibility discipline at the requisition point — as the operative mechanism by which organizations displace redundant acquisition (Sönnichsen & Clement, 2020; Q. Wang et al., 2020), and the circular–economy literature establishes privileging reuse over new acquisition as the canonical first loop of circular practice (Ellen MacArthur Foundation., 2013; Kirchherr et al., 2017).

Resource–allocation optimization. Mitigation barrier MB2 — inter–lab sharing and pre–expiry redistribution under the Inter–Lab Policy Framework — substitutes access for ownership: the value of stock is realized through use rather than possession. The documented practice of shared facilities and core laboratories shows that such regimes

raise asset utilization and defer capital acquisition where stewardship, booking, and custody are institutionally specified (Adami et al., 2021; Strom et al., 2020; Zhu & Liu, 2021), and documented laboratory practice reports material savings from redistribution and shared access — referenced here qualitatively, without quoting figures, because the transferability of the mechanism, not its magnitude elsewhere, is what a design study can claim (Tu & Greever–Wilson, 2025). The cautionary evidence is equally relevant: pooled–resource arrangements erode through free–riding and ambiguous responsibility when platform rules are weak, which is why MB2 is inseparable from the custody–transfer protocol EB3 and the liability controls of [Section 4.1.6](#) (X. Wang & Qu, 2025).

Fiscal neutrality. The framework is designed to require no new budgetary line beyond transitional coordination costs. Governance duties are attached to existing roles ([Section 4.1](#), [Principle 3](#)); the shared registry is specified to run on existing university information technology infrastructure, with the Unit liaising rather than procuring; and the technician duties are re–specifications of work technicians already perform, not additions to headcount. The cost logic is qualitative cost–avoidance: every duplicate purchase displaced is an avoided expenditure; every near–expiry stock redistributed before lapse is an avoided write–off and an avoided hazardous–waste disposal; every instrument borrowed rather than purchased is a deferred capital acquisition. Such claims are structural — they assert that a loss pathway has been closed, not that a sum has been measured — and are therefore the strongest claim a pre–implementation study can honestly make.

The dimension is rated **Conditional**. The condition is gate G1: the cost–avoidance mechanisms acquire force only upon ratification of the eligibility clauses (PB2) and joint procurement rules (PB3), because they constrain departmental purchasing behavior and so require authority above any single department ([Section 4.1.2](#)). A secondary condition is fiscal recognition within existing budget processes — that displaced purchases genuinely

displaced rather than merely delay requisitions — which the Board’s termly review monitors as policy conformity, not accounting measurement.

4.2.4 Technical & Operational Feasibility

The technical question is divided into two: whether the specified workflows are within the demonstrated competence of the staff who must execute them, and whether the institution is ready for the digital platform the framework defers. The answers differ, and the difference structures this dimension’s rating.

Staff capability within the operational boundary. The duties assigned to laboratory technicians — FEFO rotation and expiry flagging, loan workflow execution, custody-transfer documentation, and catalog entries conforming to the Committee’s standard — are routine technical competencies of laboratory operations, not new professional skills: date-ordered rotation is standard practice in well-run laboratory and clinical supply settings (Durgan et al., 2023; Wilke et al., 2023), and condition recording and chain-of-custody logging are ordinary features of shared-facility operation (Strom et al., 2020). Crucially, the competence claim is bounded by design: technicians hold no administrative decision-making authority, no procurement approval, no financial authority, and no policy-setting role; they execute within approved workflows and escalate exceptions per [Section 4.1.6](#). Feasibility must therefore be judged only against technical execution, not against decision capacity that was never assigned. Both anchor standards supply the support machinery that makes execution reliable: persons performing work under the management system must be competent on the basis of education, training, or experience, and aware of the policy, their contribution, and the consequences of nonconformity ((14001 ISO/IEC, 2015), clauses 7.2–7.3;(22301 ISO/IEC, 2019), clauses 7.2–7.3). The framework’s role-based competence requirements — FEFO discipline, custody documentation, registry data standards, chemical-handling safety — apply those clauses directly, and their delivery

through onboarding and periodic refreshers administered by custodian departments imposes no capability the college does not already possess.

Data standardization. Prevention barrier PB1 — the unified catalog and records standard — is a one-time structural effort (naming conventions, classification hierarchies, units of measure, hazard annotations, the minimum attribute set) followed by routine upkeep through ordinary registry entries. The effort is front-loaded but bounded: drafting work by technically close staff under the Committee, not a systems project. The principal risk to PB1 is not difficulty but decaying incomplete registry data as escalation factor EF2 — which is why data quality is institutionalized as escalation-factor barrier EB2 with the Unit as steward, rather than left as an assumption (Johnson et al., 2018).

Platform readiness as the Contingent element. The one component of this dimension that is not currently feasible is the smart-inventory platform (barcode- or RFID-assisted tracking and related Internet of Things instrumentation), and the framework treats this as a design finding rather than a deficiency. The higher-education digital-transformation literature consistently reports that technology layered onto unstandardized processes and unclear roles reproduces fragmentation in digital form, and that organizational readiness — process definition, governance clarity, data discipline — is the binding constraint (Bellantuono et al., 2021; Bravo-Jaico et al., 2025; Rodríguez-Abitia & Bribiesca-Correa, 2021). Smart-inventory research confirms the sequencing claim in the inventory domain specifically: automated tracking delivers value only where inventory processes and data semantics are already standardized (Carpitella & Izquierdo, 2025), and documented RFID-assisted stock control presupposes exactly the standardized records and rotation discipline the framework installs first (Wilke et al., 2023). The platform is therefore a Perform-band capability gated by G4, and its feasibility additionally depends on university-level IT provision outside the framework's control.

The dimension is rated **Conditional** overall: staff capability, FEFO executability, and data standardization are Conditional on gates G1–G2 (ratified standards; completed registry onboarding with data–quality conformity per EB2), while platform readiness is **Contingent**, monitored through the Unit’s requirements baseline until the digital readiness gate is met.

4.2.5 Environmental & Sustainability Feasibility

The environmental question is whether the framework’s waste–reduction and aspect–control mechanisms satisfy the requirements the study has adopted from ISO 14001:2015, and whether they are institutionally feasible within the host institution. The assessment follows the standard’s own logic.

Aspect identification and operational control. Under clause 6.1.2, the organization must determine the environmental aspects of its activities — and their potential impacts — considering a life–cycle perspective, and must identify significant aspects for control ((14001 ISO/IEC, 2015), clause 6.1.2). The framework’s structural analysis identifies two significant environmental aspects of educational laboratory inventory: expired–chemical stocks destined for hazardous–waste streams (consequence C2) and redundant asset acquisition with its embedded production and disposal burdens. The standard’s *life–cycle perspective* is, precisely, a perspective — the requirement to consider upstream acquisition and downstream end–of–life when planning controls, not to perform a full life–cycle assessment — and the framework honors it as such: procurement planning (PB2, PB3) addresses the acquisition end of the life cycle and governed disposal (MB3) the end–of–life end, through operational planning and control with defined operating criteria under clause 8.1 ((14001 ISO/IEC, 2015), clause 8.1).

Waste–reduction mechanisms. The three mitigation barriers form a sequenced control chain against the expired–chemical pathway: MB1 (FEFO rotation) reduces the incidence of expiry in place; MB2 (pre–expiry redistribution) converts residual near–expiry stock into

consumption transfers where live demand exists elsewhere; MB3 (governed disposal) ensures that what cannot be consumed enters a documented, conformity-controlled pathway rather than informal accumulation. Each mechanism is documented practice in the green-laboratory literature: date-ordered rotation and inventory visibility as the principal operational controls on chemical waste, redistribution before expiry as the standard circular response, and responsible purchasing and governed disposal as the institutional complements (Durgan et al., 2023; Freese et al., 2024; Gutierrez et al., 2020). The mechanisms are feasible within the host institution because they require discipline and policy, not plant or capital.

Compliance obligations and emergency preparedness. Clause 6.1.3 requires the organization to determine its compliance obligations — the legal and other requirements applicable to its environmental aspects, including hazardous-substance regulation — and clause 9.1.2 requires periodic evaluation of compliance — the fulfilment of those obligations; the Committee’s safety and compliance interface owns exactly this function ((14001 ISO/IEC, 2015), clauses 6.1.3, 9.1.2). For chemical incidents, clause 8.2 requires planned responses to identified emergency situations, periodic testing where practicable, and review after emergencies or tests; the framework locates this preparedness within the Committee’s standards and the Board’s incident-driven review cadence ((14001 ISO/IEC, 2015), clause 8.2). Because ISO 14001:2015 is a voluntary management-system standard, the thesis speaks throughout of *conformity* with the standard and *evaluation of compliance* with obligations — a distinction maintained exactly.

Institutional context. The Saudi institutional literature documents a policy environment increasingly attentive to campus sustainability and facilities stewardship under Vision 2030, alongside the practical gap between that ambition and operational routine — a gap this framework is designed to close at the laboratory level (Alshammari, 2025; Hassanain et al., 2019; Mohsen, 2025). Alignment with green-laboratory practice also carries a

reputational dimension under the FIRM taxonomy (consequences C3–C4), though FIRM functions here strictly as a classification taxonomy, not a scoring algorithm (Hopkin, 2018).

The dimension is rated **Conditional** on gate G1 (ratification of the FEFO standard, the Inter–Lab Policy Framework, and disposal protocols) and gate G3 (demonstrated workflow integrity in the Biology Department pilot). It is not rated Strong because aspect control exists only once the operating criteria are ratified policy; it is not Contingent because no factor outside the college’s authority is required.

4.2.6 Consolidated Feasibility Matrix and Readiness Gates

[Table 4.3](#) consolidates the assessment. Each dimension is decomposed into sub–criteria; each sub–criterion carries a qualitative rating from the vocabulary of [Section 4.1](#), a structural justification with its evidence base, and the governing barrier, policy, or standards clause that converts the sub–criterion from latent to actual.

Table 4.3. Consolidated qualitative feasibility matrix (ratings: Strong / Conditional / Contingent per Section 4.1)

Sub–criterion	Qualitative rating	Justification (structural)	Governing barrier / policy / clause
Organizational & governance			
Governance ratifiability	Conditional	Board/Committee/Unit constitutable by delegation within existing college governance; no new statutory bodies; collaborative governance succeeds where decision rights are explicit (Ahn & Baldwin, 2024; Lopes & Farias, 2022)	Gate G1; ISO 5.3 analogues (ISO, 2015; ISO, 2019)
Policy enforceability	Conditional	Enforceability via audit cadence and management review machinery the	EB1; ISO 9.2–9.3, 10 analogues;

Sub-criterion	Qualitative rating	Justification (structural)	Governing barrier / policy / clause
		standards already define; rests on documented information, not new disciplinary power	clause 7.5 documented information
Sponsorship & strategic alignment	Conditional	Vision 2030 alignment provides institutional sponsorship; sustained leadership mandate is the documented success condition for pooling arrangements (Alamoudi et al., 2023; Alshammari, 2025; Wang & Qu, 2025)	Board chairing; leadership delegation; Section 4.1.2
Financial & fiscal			
Duplicate–procurement displacement (cost avoidance)	Conditional	Eligibility check at requisition point is documented procurement–control practice; mechanism is structural, independent of setting (Sönnichsen & Clement, 2020)	PB2; PB3; Inter–Lab Policy Framework (a)
Resource–allocation optimization (access over ownership)	Conditional	Shared–access regimes raise utilization where custody is specified; cautionary evidence requires strong platform rules (Strom et al., 2020; Zhu & Liu, 2021; Wang & Qu, 2025; Tu & Greever–Wilson, 2025)	MB2 with EB3; loan limits; recall rights; liability principle
Fiscal neutrality	Conditional	Duties attached to existing roles; registry on existing IT infrastructure; no new budgetary line beyond transitional coordination	Principle 3 (Section 4.1.1) ; Unit IT liaison (Section 4.1.4)
Technical & operational			
Staff competence (bounded execution)	Conditional	FEFO, custody documentation, and registry entries are routine technical competencies; competence and awareness machinery	ISO 7.2–7.3 analogues (ISO, 2015; ISO, 2019);

Sub-criterion	Qualitative rating	Justification (structural)	Governing barrier / policy / clause
		adopted from standards (Durgan et al., 2023; Wilke et al., 2023)	Section 4.1.5 non-authority clause
FEFO executability	Conditional	Date-ordered rotation is documented standard practice; requires ratified standard and expiry-flagging thresholds	MB1 standard (Committee); technician execution
Data standardization	Conditional	One-time structural drafting plus routine upkeep; decay risk controlled by institutionalized data-quality ownership	PB1; EB2; ISO 7.5 analogues
Digital platform readiness	Contingent	Organizational readiness must precede technology; platform value presupposes standardized processes and data semantics; depends on university IT provision (Rodríguez-Abitia & Bribiesca-Correa, 2021; Bellantuono et al., 2021; Carpitella & Izquierdo, 2025; Wilke et al., 2023)	Gate G4; Unit requirements baseline (Section 4.1.4)
Environmental & sustainability			
Aspect control (life-cycle perspective)	Conditional	Expired chemicals and redundant acquisition identifiable as significant aspects; control via operational planning with a life-cycle perspective — a perspective, not a full LCA	ISO 14001 cl. 6.1.2, 8.1 (ISO, 2015); PB2/PB3; MB3
Waste-reduction mechanism chain	Conditional	FEFO → pre-expiry redistribution → governed disposal is documented green-laboratory practice (Durgan et al., 2023; Freese et al., 2024; Gutierrez et al., 2020)	MB1 → MB2 → MB3 sequence

Sub-criterion	Qualitative rating	Justification (structural)	Governing barrier / policy / clause
Conformity evaluation & emergency preparedness	Conditional	Compliance–obligation determination and periodic evaluation owned by the Committee’s safety interface; emergency preparedness adopted from the standard (Alshammari, 2025; Hassanain et al., 2020)	ISO 14001 cl. 6.1.3, 9.1.2, 8.2; Committee safety interface

Overall verdict. Reading the matrix as a whole, the analysis suggests that the framework’s feasibility is **conditionally strong**: no sub-criterion is rated infeasible, no rating depends on resources the college does not possess, and every Conditional rating names a condition that is itself a decision within the college’s authority. The single Contingent element — the smart-inventory platform — is deliberately peripheral: the framework’s preventive, mitigative, and enforceability functions operate fully on ratified policy and a registry on existing infrastructure, with digitalization as an unlocked capability rather than a foundation. The verdict thus operationalizes Phase 1’s central ordering claim: the binding constraint on participatory inventory within the host institution is not technical or fiscal but organizational—ratification, sponsorship, and data discipline—and organizational constraints are charged as exactly the kind a governance framework can close (Hillson, D. A., 1997; PMI, 2021; Rodríguez–Abitia & Bribiesca–Correa, 2021).

The conditions named across the matrix consolidate into four **analytical readiness gates** — policy-controlled checkpoints with explicit criteria, verified by inspection of documented information:

- **G1 — Policy ratification.** The Board is constituted by college leadership; the unified catalog standard, the eligibility clauses, the FEFO policy standard, and the Inter-Lab Policy Framework are ratified; roles are appointed and communicated per the clause 5.3 analogue; and the classified risk register ([Section 2.9.2](#)) is adopted as a

standing Board instrument. G1 releases every Conditional rating whose mechanism requires ratified policy.

- **G2 — Data readiness.** Departmental inventory onboarding to the shared registry is complete for the pilot scope, and registry records conform to the Committee’s catalog standard as verified by the Unit’s data–quality indicators (EB2). G2 releases the eligibility check, the visibility function, and redistribution, all of which are blind on incomplete data (EF2).
- **G3 — Pilot workflow integrity.** The Biology Department pilot demonstrates — qualitatively, through executed and documented cases rather than metrics — the loan workflow, custody–transfer protocol (EB3), and FEFO execution (MB1) operating as designed, following by analogue the exercise–programme logic of ISO 22301:2019 clause 8.5 (22301 ISO/IEC, 2019). G3 releases college–wide scaling.
- **G4 — Digital platform readiness.** The Unit’s requirements baseline for a smart–inventory platform is met: standardized processes, conformant data, and demonstrated workflow stability constitute the organizational readiness the digitalization literature identifies as prerequisite (Bellantuono et al., 2021; Carpitella & Izquierdo, 2025). G4 releases platform procurement consideration — and only consideration, since provision remains Contingent.

These gates are the connective tissue of [Phase 2: Section 2.9.2](#)’s risk register takes the gate conditions as its control targets — the risks that would prevent a gate from being met are the register’s transition risks; [Section 4.1.7](#)’s indicators monitor the same conditions continuously, operationalizing EB1 and EB2 as standing surveillance of gate criteria after they are first passed; and [Section 4.1.6](#) sequences implementation as the ordered passage of G1 through G4 along the maturity trajectory from Inform/Conform toward Perform. The feasibility verdict of this section is therefore not a conclusion but a contract: the framework

is feasible, conditionally, and the conditions are now named, owned, and ready to be scheduled.

4.3 Classified Risk Register and Mitigation Strategy

[Section 4.2](#) assessed the feasibility of the participatory inventory framework across organizational, financial, technical, and environmental dimensions, concluding with a conditionally strong verdict gated by the readiness gates G1–G4. Feasibility, however, answers only whether the framework *can* be adopted; it does not enumerate what could defeat it. The present section addresses Research Objective O4’s risk component by constructing the framework’s classified risk register: a traceable, qualitatively prioritized inventory of the transition risks that threaten adoption and the operational risks that threaten steady-state performance, each assigned an owner within the [Section 4.1](#) governance architecture and a named mitigation control. Consistent with the study’s binding methodology, the register contains no numeric likelihood–impact scores, no sampled probabilities, and no empirical frequencies. Its risks are derived analytically from the Bow–Tie structure of Section 2 and the organizational–change literature, classified under the FIRM taxonomy (Hopkin, 2018), and prioritized through verbally defined qualitative bands, so that the register functions as a governance instrument rather than a calculation artifact (31000 ISO/IEC, 2018; 31010 ISO/IEC, 2019).

4.3.1 Register Construction Method

4.3.1.1 Analytical risk identification without field data

A risk register conventionally draws on incident histories, loss databases, or expert elicitation. None of these is available to a design study proposing a framework that does not yet operate; inventing such data would violate the study’s methodological commitments and misrepresent the epistemic status of its claims. The register is therefore constructed

by **analytical derivation** from three declared sources, each of which yields a distinct stratum of risk.

First, the **Bow–Tie structure of Section 2** supplies the operational risk universe directly. Each threat (T1 over-ordering without cross-lab visibility; T2 absent stock-rotation discipline; T3 unstandardized records; T4 siloed custody), each escalation factor (EF1 unenforced policies; EF2 incomplete registry data; EF3 custody ambiguity), and each consequence class (C1–C4) names a failure mode that the framework’s barriers (PB1–PB3, MB1–MB3, EB1–EB3) are designed to interrupt (31010 ISO/IEC, 2019; Johnson et al., 2018). A barrier that can fail is a risk that must be registered: the escalation–factor layer exists precisely because nominally present barriers silently degrade, and the register’s operational entries are, in effect, the escalation–factor analysis made explicit and ownable (de Ruijter & Guldenmund, 2016; Johnson et al., 2018).

Second, the **organizational–change and collaborative–governance literature** supplies the transition risk universe — risks that arise not from the framework’s design but from the act of adopting it. The higher–education change literature documents that university reform initiatives stall at policy–ratification bottlenecks, encounter departmental resistance when reforms redistribute visible control over resources, and decay into nominal compliance when procedural burden outruns perceived benefit (Dean et al., 2024; Sung & Kim, 2021; Vlachopoulos, 2021). The collaborative–governance literature adds that pooled–resource arrangements fail through eroded trust, blurred mandates, and inequitable benefit distribution when participation is invited without decision rights being renegotiated (Ahn & Baldwin, 2024; Gestel & Grotenbreg, 2021; Lopes & Farias, 2022). Each transition risk in the register is traceable to one of these documented themes; none is asserted ad hoc.

Third, **laboratory–risk scholarship** supplies the disciplinary precedent that licenses structured, qualitative risk analysis in university laboratory settings at all. (Ayyildiz et al., 2025) demonstrate the application of systematic risk–analysis methods to university

laboratories, treating laboratory operations as analyzable socio–technical systems rather than collections of individual hazards. This precedent positions the register as continuous with an established laboratory–risk research stream while adapting its object from physical–safety hazards to inventory–governance failure modes — an adaptation consistent with the Bow–Tie method’s documented extension into management and policy domains (Cormier et al., 2019).

The identification process is framed by ISO 31000:2018, which specifies risk management as an integrated, structured, and customized component of organizational governance, comprising risk identification, analysis, evaluation, and treatment within a defined scope and context (31000 ISO/IEC, 2018). Within that framing, the register’s method is deliberately congruent with the qualitative bow–tie tradition: the method structures reasoning about threats, controls, and consequences without quantification (de Ruijter & Guldenmund, 2016; 31010 ISO/IEC, 2019), and the register inherits that discipline. Risk *analysis* is performed by tracing each candidate risk to its threat, escalation factor, or consequence pathway; risk *evaluation* is performed by the qualitative prioritization defined below; risk *treatment* is the mitigation strategy column, each entry of which names a policy control already specified in Sections 2 and 3 (31000 ISO/IEC, 2018).

4.3.1.2 Classification: the FIRM taxonomy

Every registered risk is classified under the FIRM taxonomy — Financial, Infrastructure, Reputational, Marketplace — as presented by (Hopkin, 2018) and adopted in [Section 2.9.5.4](#) with one declared adaptation: Marketplace is read as the university’s *service and stakeholder environment* (student experience, research competitiveness, standing with regulators and funders), since a public university has no commercial marketplace (Hopkin, 2018). Two properties of the taxonomy discipline its use here. First, FIRM is a **classification taxonomy, not a scoring algorithm**: it locates the dependency a risk endangers and says nothing about likelihood or magnitude (Hopkin, 2018). The register

therefore uses FIRM strictly for categorization and derives priority from the separate qualitative bands defined below — never from any arithmetic combination of the two. Second, the taxonomy’s internal/external structure (Financial and Infrastructure predominantly internal; Reputational and Marketplace predominantly external) carries a governance implication developed in [Section 4.3.2](#): internal–category risks are controllable by framework policy, whereas external–category risks must be managed through monitoring, reporting, and university social responsibility (USR) practice (Ali et al., 2021; Hopkin, 2018).

4.3.1.3 Qualitative prioritization: the High / Moderate / Low bands

Prioritization is required so that governance attention and audit cadence are allocated where barrier failure would be most consequential. The register uses three verbally defined bands, applied by analytical judgment against the Bow–Tie structure:

- **High priority.** The risk is *plausible under normal operations* — that is, it requires no unusual coincidence of adverse conditions to materialize, because the decentralized regime’s documented features already create its preconditions — **and** its realization would defeat a named prevention or mitigation barrier or trigger a C–class consequence directly. High–priority risks demand a standing mitigation control plus monitoring through the escalation–factor barriers.
- **Moderate priority.** The risk is plausible primarily under stress conditions (peak teaching periods, onboarding surges, semester transitions), **or** its realization would degrade but not defeat a barrier, leaving at least one intact barrier on the consequence pathway. Moderate–priority risks demand a named policy control and periodic review rather than standing surveillance.
- **Low priority.** The risk requires a conjunction of independent failures to materialize, **or** its effects are contained within bounded scope by an existing escalation–factor

barrier, such that escalation and documented resolution suffice without dedicated standing controls.

The choice of verbal bands over numeric scoring warrants explicit justification, because risk registers in the project-management tradition are commonly presented as likelihood-times-impact matrices with ordinal or pseudo-cardinal scores. Three considerations govern the departure here. First, numeric scores imply an evidentiary basis — incident frequencies, calibrated expert probabilities, loss magnitudes — that this design study does not possess and cannot simulate without fabrication; a number entered without such a basis is not precision but theater. Second, ordinal risk products are known to conceal rank reversal and false equivalences: risks with identical products can differ radically in their governance meaning, and the arithmetic obscures the difference (Hopkin, 2018; 31000 ISO/IEC, 2018). Third, and most importantly for this framework, the actionable content of a risk assessment lies in its *traceable structure* — which barrier is threatened, by which pathway, owned by whom — and that content is carried equally well, and more honestly, by verbal bands with stated rationales. The laboratory-risk literature’s qualitative strand confirms that structured, non-numeric analysis supports defensible prioritization in university laboratory settings (Ayyildiz et al., 2025; Cormier et al., 2019). Should the framework later accumulate operational history within the host institution, the bands could be revisited; at design time, verbal bands are the methodologically honest instrument.

Three properties of this scheme are deliberate. It is **non-numeric**: no likelihood indices, impact scores, or risk products appear anywhere in the register, consistent with the taxonomy-not-algorithm reading of FIRM (Hopkin, 2018) and with the thesis’s qualitative mandate. It is **barrier-relative**: priority is defined by reference to the barrier architecture, so that a risk’s band states what it would do to the framework, not merely how it feels to assessors. And it is **auditable**: each band assignment in [Table 4.5](#) carries a one-line rationale, so the Board’s termly review can contest and revise the judgment rather than

inherit it silently — the evaluation-and-treatment discipline ISO 31000:2018 prescribes (31000 ISO/IEC, 2018).

4.3.2 FIRM Classification of the Risk Universe

Before individual risks are registered, [Table 4.5](#) maps the risk *universe* — the families of risk that Sections 1–[4.1](#) imply — onto the four FIRM categories, identifying for each category the organizational dependency at stake, the risk families entering the register, and the linked Bow-Tie consequence class. The mapping restates the declared Marketplace adaptation (M^*) and is used thereafter without further qualification (Hopkin, 2018).

*Table 4.5. FIRM classification map of the participatory inventory risk universe (taxonomy per (Hopkin, 2018); M = Marketplace read as service/stakeholder environment — declared adaptation) **

FIRM category	Dependency at risk	Risk families entering this register (preview)	Linked consequence class (C1–C4)
F — Financial (internal)	Fiscal efficiency of laboratory procurement and stockholding; Vision 2030 fiscal-efficiency commitments	Duplicate-purchasing pathway reactivation (eligibility-check bypass); expiry write-offs (FEFO drift, expiry clusters); premature platform investment; loan damage/loss remediation	C1 financial waste and expiry write-offs
I — Infrastructure (internal)	The physical laboratory estate and the integrity of custody, records, and tracking processes	Registry data decay; incomplete data onboarding; competence gaps; custody disputes;	C2 hazardous-waste accumulation and HSE exposure

FIRM category	Dependency at risk	Risk families entering this register (preview)	Linked consequence class (C1–C4)
		disposal nonconformity; audit–finding recurrence	
R — Reputational (external)	the host institution’s standing as a Vision 2030–aligned, sustainability–committed institution	Waste incidents or adverse audit findings contradicting the sustainability narrative; compliance–fatigue–driven policy decay becoming visible at external audit	C4 reputational damage
M* — Marketplace (external; service/stakeholder environment)	Student experience, teaching continuity, research competitiveness, regulator/funder standing	Custodian recall conflicts; overdue returns disrupting borrower teaching; continuity exposure during supply interruption if redistribution fails	C3 teaching/research disruption

The internal/external structure of the taxonomy carries the register’s first governance implication. Financial and Infrastructure risks are **internal**: their causes lie inside the framework’s jurisdiction, and they are therefore controllable by framework policy — by barrier reinforcement, workflow rules, competence requirements, and audit (Hopkin, 2018). Every F– and I–classified risk in the register is accordingly assigned a mitigation that the Board, Committee, Unit, or custodian departments can enact directly. Reputational and Marketplace risks are **external** in the sense that their realization depends on the perceptions and experiences of stakeholders outside the framework’s direct command — students, researchers, regulators, funders, and the public to which the university’s sustainability narrative is addressed (Hopkin, 2018). These risks cannot be abolished by policy; they are managed indirectly, through the operational substance that prevents waste

incidents and teaching disruption from occurring, and through the monitoring, reporting, and USR practice that keeps disclosure anchored to verified operations rather than aspirational claims (Ali et al., 2021; Ceulemans et al., 2015). The greenwashing critique sharpens this asymmetry: for an institution whose public identity is bound to Vision 2030 sustainability commitments, the reputational cost of a substantiation gap exceeds the reputational benefit of any announcement, so R-classified risks are treated as *derivative* risks — they materialize when internal F/I controls fail visibly, and their mitigation therefore lies upstream in the internal categories (Lakhno, 2024).

This classification also explains the register’s composition. Because the framework’s barriers are internal instruments, the majority of registered risks fall in the F and I categories; the R and M* entries function as the register’s outward face, recording where internal failure would propagate to the institution’s standing and service environment. The Board, as register owner, thereby sees in a single view both what it controls and what it is accountable for (Hopkin, 2018).

4.3.3 The Risk Register

[Table 4.6](#) presents the register itself: fifteen risks, identified as RR-01 through RR-15, spanning the adoption phase (transition risks, RR-01 through RR-06) and steady-state operation (operational risks, RR-07 through RR-15). Every entry is traceable in one of two directions. Operational risks are traceable to the Bow-Tie structure: each names the barrier it threatens (PB, MB, or EB, with identifier) and, through that barrier, the threat pathway it reopens and the consequence class it admits. Transition risks follow two patterns: those that precede the barrier architecture’s existence (RR-01, RR-02) carry “—” in the barrier column with the *threatened future barrier* noted, while those that represent the trial, degradation, or contested execution of a specific barrier during adoption (RR-03 through RR-06) name that barrier directly; both patterns are traceable to documented themes in the change-management and collaborative-governance literature (Ahn &

Baldwin, 2024; Dean et al., 2024; Lopes & Farias, 2022; Sung & Kim, 2021; Vlachopoulos, 2021; X. Wang & Qu, 2025). Ownership assignments follow [Section 4.1](#) exactly: the Board, the Committee, the Unit, custodian departments, and — only as execution-level owners, never as decision owners — laboratory technicians, whose two execution-level assignments (RR-08, RR-10) carry the explicit note that accountability rests with the custodian supervisor and the Unit, consistent with the non-authority clause of [Section 4.1.5](#).

Table 4.6. Classified risk register for the participatory inventory framework (transition risks RR-01–RR-06; operational risks RR-07–RR-15)

Risk ID	Risk description	FIRM category	Associate d Bow– Tie barrier	Risk owner	Qualitative priority	Specific mitigation strategy
RR-01	Policy ratification delay. The catalog standard, eligibility clauses, FEFO standard, and Inter-Lab Policy Framework stall in drafting or ratification, leaving the framework without enforceable content; traceable to the ratification–bottleneck theme in university change management	I	— (future PB1, PB2, MB1, EB3 left unratified)	Board	High — the entire barrier architecture depends on ratification; delay leaves every threat pathway open.	Readiness gate G1 (policy ratification) held as a hard checkpoint in the Section 4.1.6 roadmap; Board constitution scheduled first; drafting cycles time-boxed with departmental comment windows; Vision 2030 sponsorship framing to sustain leadership attention (Vlachopoulos, 2021).

Risk ID	Risk description	FIRM category	Associate d Bow– Tie barrier	Risk owner	Qualitative priority	Specific mitigation strategy
	(Vlachopoulos, 2021; Dean et al., 2024).					
RR–02	Departmental resistance to shared visibility and custody rules. Departments perceive the shared registry and loan regime as a loss of control over “their” stock and withhold participation or compliance; traceable to the resistance and trust–erosion themes in collaborative–governance scholarship (Ahn & Baldwin, 2024; Lopes & Farias, 2022).	I	— (future PB2, MB2 undermine d before deployme nt)	Board	High — plausible without adverse coincidence, since the decentralized regime’s siloed custody (T4) is the framework’s direct target.	Stewardship–over–ownership policy design: custodian protections codified in the Inter–Lab Policy Framework (loan limits, recall rights, liability principle); departmental representation on the Board; pilot–first gradualism to demonstrate benefit before scaling (Section 4.1.6 change–management structure; Dean et al., 2024).
RR–03	Incomplete or nonconforming data onboarding. Departmental inventories enter the registry partially, late,	I	EB2 (with PB1, PB2 downstream)	Unit	High — a registry that is visibly incomplete defeats PB2 in practice, because checks	Readiness gate G2 (data readiness) blocks pilot start until completeness and standard conformity are met; EB2 data–

Risk ID	Risk description	FIRM category	Associate d Bow– Tie barrier	Risk owner	Qualitative priority	Specific mitigation strategy
	or off–standard, so the shared–visibility premise of the eligibility check is false from the start; traceable to the implementation–fidelity theme in educational change (Sung & Kim, 2021).				return false absences.	quality indicators (completeness, currency, consistency) operationalized from day one; Unit’s negative procedural power to decline certifying a check when data–quality rules are unmet (Section 4.1.4).
RR–04	Competence gaps in operational execution. Technicians and departmental staff lack trained familiarity with FEFO discipline, custody–transfer documentation, and registry standards at go–live, so correctly designed workflows are executed incorrectly.	MB1, EB3 (execution layer)	Custodian Department		Moderate — degrades barrier execution but is correctable through the standards’ competence clauses before consequences propagate.	Role–based competence and awareness programme per ISO 14001:2015 clauses 7.2–7.3 and ISO 22301:2019 clause 7.2 (ISO, 2015; ISO, 2019): onboarding plus periodic refreshers administered by custodian departments with Unit support materials; training scheduled within the

Risk ID	Risk description	FIRM category	Associate d Bow– Tie barrier	Risk owner	Qualitative priority	Specific mitigation strategy
						G2 phase of the roadmap.
RR– 05	Compliance fatigue and procedural decay. Procedural burden (checks, logs, rotation discipline) comes to be perceived as disproportionate to benefit; staff revert to informal practice, hollowing out enforcement from within; traceable to the nominal–compliance theme (Sung & Kim, 2021; Vlachopoulos, 2021).	I	EB1 (with EF1 activated against PB2, MB1)	Board	Moderate — a slow–burn degradation caught by audit cadence rather than a discrete event.	Proportionate–procedure design (auditability embedded in workflows, not appended as reporting burden — Section 4.1.1, Principle 4); duties attached to existing roles; Board termly review of procedural burden; benefit communication through Unit reporting so that displaced purchases and redistributions are visible to participants (Dean et al., 2024).
RR– 06	Custody disputes during the pilot. Early loans in the Biology Department pilot produce contested damage or responsibility claims	I	EB3 (trial under load)	Custodi an Departm ent	Low — contained by the custody–transfer protocol’s evidentiary artifacts and bounded pilot scope; resolution	EB3 custody–transfer protocol applied from the first loan (condition record, custody acknowledgment, chain–of–custody log); defined escalation

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Risk ID	Risk description	FIRM category	Associate d Bow– Tie barrier	Risk owner	Qualitative priority	Specific mitigation strategy
	before practice has settled.				path is protocolized.	ladder technician → Unit → custodian supervisor → Board; pilot exit criteria at G3 include demonstrated dispute–resolution integrity (Section 4 readiness gates).
RR–07	Eligibility–check bypass. Requisitions proceed without the mandatory registry check — through time pressure, habit, or deliberate circumvention — reactivating threat T1 and the duplicate–purchasing pathway.	F	PB2 (degraded by EF1)	Custodi an Departm ent	High — plausible under normal operations in a compliance–driven culture; defeats the framework’s primary fiscal barrier.	Barrier reinforcement: Unit verification of the documented check as a requisition precondition; EB1 audit cadence tests a sample of requisitions each term for check evidence; repeated violations escalate to the Board under Section 4.1.2 decision rights; operating criteria discipline per ISO 14001:2015 clause 8.1 analogue (ISO, 2015).

Risk ID	Risk description	FIRM category	Associate d Bow– Tie barrier	Risk owner	Qualitative priority	Specific mitigation strategy
RR–08	FEFO drift. Date–ordered rotation erodes into convenience picking, so earliest–expiring stock remains on shelves and the expiry pathway (T2 → TE1) reopens despite the standard’s existence.	F	MB1 (degraded by EF1)	Technicians (executive on–level owner; account ability rests with the custodian supervisor)	High — the barrier lives or fails at the shelf; drift is silent until expiry surfaces.	Committee FEFO standard with labeling, date–marking, and expiry–flagging thresholds; technician escalation duty at defined thresholds; custodian supervisor accountability with EB1 audit of rotation practice; competence maintenance per ISO 14001:2015 clause 7.2 (ISO, 2015; Durgan et al., 2023).
RR–09	Registry data decay. Entries lag events, records go stale, and the registry’s picture of holdings diverges from physical stock, blinding PB1, PB2, and MB2 simultaneously (EF2).	I	EB2 (degrading PB1, PB2, MB2)	Unit	High — data decay is the single escalation factor that degrades three barriers at once.	EB2 data–quality indicators monitored continuously by the Unit; technician entry discipline as barrier work (Section 4.1.5); Unit reporting of data–quality trends to the Board’s termly review; nonconformity–and–corrective–action loop per the ISO clause 10

Risk ID	Risk description	FIRM category	Associate d Bow– Tie barrier	Risk owner	Qualitative priority	Specific mitigation strategy
						analogue (ISO, 2015; ISO, 2019).
RR– 10	Loan integrity failure — damage, loss, or overdue return. Loaned items return damaged, are lost in transit, or are held beyond term, imposing remediation burdens and deterring future lending; traceable to the free–riding and responsibility–ambiguity failure modes of sharing arrangements (Wang & Qu, 2025).	F	MB2 (with EB3 as evidentiary control)	Custodian Department (technicians execute records and flag exceptions)	Moderate — individual events are bounded, but recurrence would erode the trust on which MB2 depends.	Inter–Lab Policy Framework risk controls: damage/loss liability principle with chain–of–custody log as evidence; loan limits; recall rights; returned–damaged exception state triggering escalation rather than informal settlement; aggregate damage and overdue records to the Board’s termly review (Section 4.1.6 (e); Wang & Qu, 2025).
RR– 11	Custodian recall conflicts. A custodian exercises its recall right while a borrower’s scheduled teaching depends on the loaned item, transferring disruption	M*	MB2 (recall–right control)	Board (adjudication of cross–departmental conflicts)	Moderate — infrequent by design but consequential for C3 when it occurs, since teaching is semester–locked.	Policy sequencing: custodian recall rights are absolute for scheduled teaching (ISO 22301:2019 priority of prioritized activities; ISO, 2019, clause 8.3); loan

Risk ID	Risk description	FIRM category	Associate d Bow– Tie barrier	Risk owner	Qualitative priority	Specific mitigation strategy
	rather than relieving it.					durations set against published teaching calendars at approval; conflicts escalate to the Board, whose adjudication precedent is logged to refine loan–term rules.
RR– 12	Expiry clusters. Multiple chemical stocks approach expiry simultaneously — for example after a bulk purchase or semester–end course completions — exceeding the redistribution mechanism’s absorptive capacity and forcing disposal of usable stock.	F	MB2 (capacity exceeded; MB3 as fallback)	Custodi an Departm ent	Moderate — partially self–inflicted through procurement timing, hence controllable, but consequential for C1/C2 when realized.	Technician expiry–flagging at threshold (early–warning duty); Unit expiry–flag summaries give the Board forward visibility; MB2 redistribution prioritized for cluster items; PB3 joint/circular procurement rules reduce incoming volume bunching at source (Sönnichsen & Clement, 2020; Freese et al., 2024).
RR– 13	Disposal nonconformity. Expired or surplus	I	MB3	Committ ee (with the	Moderate — standing protocols exist, but disposal	MB3 governed disposal protocols with documented disposal

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Risk ID	Risk description	FIRM category	Associate d Bow– Tie barrier	Risk owner	Qualitative priority	Specific mitigation strategy
	chemicals enter disposal pathways outside the governed protocols — undocumented, mistimed, or routed through noncompliant channels — generating HSE exposure and compliance–obligation breach.			college safety and compliance officer)	is episodic and easily bypassed under storage pressure.	records; redistribution–before–disposal rule (PB2 in its disposal–direction mode) checks live demand before any disposal; emergency–preparedness interface per ISO 14001:2015 clause 8.2 for degraded–stock discovery; evaluation of compliance obligations per clause 9.1.2 (ISO, 2015).
RR– 14	Audit–finding recurrence. The same nonconformities reappear across successive audit cycles because corrective actions are assigned but not closed, converting EB1 from a control into a ritual.	I	EB1 (self–referential failure of the meta–control)	Board	Moderate — indicates EF1 has colonized the enforcement layer itself; recoverable through the improvement loop if acted on.	Corrective–action tracking with named owners and closure evidence at each Board termly review, per the Annex SL clause 10 improvement logic (ISO, 2015; ISO, 2019); recurring findings escalated to the annual management review

Risk ID	Risk description	FIRM category	Associate d Bow– Tie barrier	Risk owner	Qualitative priority	Specific mitigation strategy
						(clause 9.3 analogue); audit cadence adjusted toward repeat-finding domains.
RR– 15	Premature digital platform investment. Pressure to acquire a smart-inventory platform (barcode/RFID) before process standardization and role clarity are established, digitizing fragmentation and consuming budget without capability gain; traceable to the organization-before-technology finding of the digital-transformation literature (Rodríguez–Abitia & Bribiesca–Correa, 2021; Bellantuono et al., 2021).	F	— (would bypass the Perform–band precondition for platform value)	Board (gate authority); Unit (readiness reporting)	Moderate — high fiscal consequence if realized, but structurally preventable by holding the gate.	Readiness gate G4 (digital platform readiness) as a binding precondition: no platform procurement before standardized processes, defined workflows, and role clarity are demonstrated; Unit maintains the requirements baseline so that when the gate opens, procurement targets organizational needs rather than vendor features (Carpitella & Izquierdo, 2025).

The register's two strata differ in one respect that governs their treatment. Transition risks (RR-01–RR-06) are *time-bound*: they are live only while the corresponding adoption phase is live, and each is discharged — not merely mitigated — when its readiness gate closes. Ratification delay ceases to threaten once G1 closes with policies ratified; data-onboarding risk is discharged at G2; pilot custody disputes at G3. Their mitigation logic is therefore gate logic: hold the checkpoint until the preconditions it names are demonstrably met. Operational risks (RR-07–RR-15), by contrast, are *standing*: they persist as long as the framework operates, because the threats they register are permanent properties of laboratory inventory work rather than of the transition to it. Their mitigation logic is barrier logic: continuous enforcement, monitored by the escalation-factor meta-controls and reviewed on the Board's termly cadence. The register thus encodes the thesis's sequencing claim in risk form — adoption risks are front-loaded and closable, while operational risks are perpetual and governable — and the Board's termly review must be able to retire discharged transition entries without disturbing the standing operational core (Dean et al., 2024; 31000 ISO/IEC, 2018).

Three features of [Table 4.6](#) warrant emphasis. First, **traceability is complete in both directions**: every operational risk names a threatened barrier, and every barrier of Section 2 appears in at least one register row, so the register covers the entire Bow-Tie architecture rather than a selection of convenient entries; every transition risk, correspondingly, cites the change-literature theme that predicts it. Second, **technician assignments are execution-level only**: RR-08 and RR-10 place technicians at the operational surface of barriers whose failure is enacted at the shelf and the bench, but accountability for both rests with the custodian supervisor and the Unit, and no register row assigns a technician decision authority of any kind — the register is, in this respect, the risk-domain restatement of [Section 4.1.5](#)'s non-authority clause. Third, **no row contains a number**: priority is expressed in the verbally defined bands of [Section 4.3.1.3](#), each

with a stated rationale, preserving the register’s character as a qualitative governance instrument (Hopkin, 2018; 31000 ISO/IEC, 2018).

4.3.4 Mitigation Architecture and Residual–Risk Logic

4.3.4.1 How the mitigation set reinforces the barrier architecture

Read as a whole, the register’s mitigation column is not a list of fifteen independent responses but a reinforcement scheme for the barrier architecture of [Section 2.9.3](#), organized in three layers. The **first layer** consists of direct barrier reinforcement: where a risk targets a specific barrier, its mitigation strengthens that barrier’s specification or enforcement — the FEFO standard’s labeling and flagging thresholds against RR–08, the Unit’s verification power against RR–07, the custody–transfer artifacts against RR–06 and RR–10. The **second layer** consists of the escalation–factor barriers operating as *meta–controls*: EB1 (audit cadence) is the control that catches enforcement failures across PB2, MB1, and the workflow rules generally, which is why RR–05, RR–07, RR–08, and RR–14 all terminate in the audit–and–review loop; EB2 (data–quality indicators) is the meta–control for the entire registry–dependent risk family (RR–03, RR–09), converting data integrity from an assumption into a monitored property; EB3 (custody–transfer protocol) is the meta–control for the loan–integrity family (RR–06, RR–10, RR–11), ensuring that when the sharing mechanism is stressed, the evidentiary basis for resolution already exists (Johnson et al., 2018). The **third layer** consists of governance mechanisms that sit above individual barriers: the readiness gates G1–G4 defined in Section 4 hold RR–01, RR–03, RR–06, and RR–15 respectively, functioning as policy–controlled checkpoints that prevent a phase from beginning before its preconditions are demonstrably in place; and the Board’s termly review and annual management review supply the Plan–Do–Check–Act closure that converts one–off mitigations into a self–correcting system ((14001 ISO/IEC, 2015), clauses 9.3, 10;(22301 ISO/IEC, 2019), clauses 9.3, 10).

This layered structure embodies the section’s central design claim: **mitigation in a governance framework is the enforcement of architecture, not the accumulation of precautions**. Each registered risk was generated by asking how a named barrier could fail; each mitigation answers by naming who reinforces that barrier, through which control, monitored by which meta-control. Nothing in the mitigation set is free-floating, and — by the same token — the mitigation set exposes the architecture’s load-bearing members: EB1 and EB2 carry the largest share of the register, and their failure (registered as RR-14 and RR-09 respectively) would degrade multiple barriers at once. These two meta-controls therefore warrant the most intensive standing attention, a conclusion the [Section 4.1.7](#) KPI dashboard operationalizes by assigning dedicated indicators to audit cadence adherence and registry data quality.

4.3.4.2 Residual-risk statements

Mitigation reduces but never abolishes risk; the register’s intellectual honesty requires stating what remains after the mitigation set is applied, and why the residue is acceptable or monitorable. Residual-risk statements are qualitative, in keeping with the register’s method (31000 ISO/IEC, 2018).

- **Residual enforcement risk (from RR-05, RR-07, RR-08).** Even with audit cadence, some degree of informal practice will persist in any large decentralized institution; the residue is acceptable because it is *detectable* — EB1 surfaces it at termly intervals before it compounds into barrier failure — and because the framework’s design minimizes the burden that drives informality. The Board accepts this residue as a standing condition to be monitored, not a defect to be eliminated once.
- **Residual data risk (from RR-03, RR-09).** Perfect registry currency is unattainable in an operational environment; the residue is monitorable because EB2 makes divergence between records and stock a measured property with defined thresholds,

and the Unit's certification power prevents decisions from being taken on visibly degraded data.

- **Residual sharing risk (from RR-06, RR-10, RR-11).** Some loan events will still produce damage, delay, or conflict; the residue is acceptable because each event is bounded by the liability principle, resolvable through the escalation ladder, and informative — aggregate records refine loan limits and terms at Board review. The alternative residue, zero sharing, is precisely the underutilization pathology (TE2) the framework exists to cure, so a monitored non-zero loan-incident rate is the rational acceptance position (X. Wang & Qu, 2025; Zhu & Liu, 2021).
- **Residual external risk (R and M* categories).** Reputational and service-environment exposure cannot be controlled directly; the residue is managed through the internal controls that prevent waste incidents and teaching disruption, through the monitoring and evaluation-of-compliance functions of ISO 14001:2015 clause 9.1.2, and through USR practice that keeps public sustainability claims anchored to audited operations (Ali et al., 2021; Ceulemans et al., 2015; Lakhno, 2024).

4.3.4.3 Standards alignment of the register and its maintenance

The register's construction and maintenance align explicitly with the two anchor standards' planning clauses. ISO 14001:2015 clause 6.1 requires the management system to determine risks and opportunities related to its environmental aspects, compliance obligations, and context, and to plan actions to address them: the register's I- and R-classified entries — expiry clusters, disposal nonconformity, audit-finding recurrence — are exactly such risk determinations for the framework's significant environmental aspects, and their mitigations are the planned actions clause 6.1 contemplates (14001 ISO/IEC, 2015). ISO 22301:2019 clause 8.2.3 requires risk assessment to analyse, evaluate, and prioritize risks of disruption to prioritized activities: the register's M-classified entries and the continuity-relevant families (RR-09, RR-11) perform this function in qualitative form,

*assessing disruption risks to scheduled practical teaching and time-sensitive research against the qualitative MTPD/RTO reasoning of [Section 2.9.4](#) — the framework adopts the clause’s analogue**, not a certification claim (22301 ISO/IEC, 2019). In both alignments, the register substitutes qualitative barrier-relative judgment for the quantitative scoring the study’s methodology excludes, without surrendering the standards’ procedural discipline of identification, analysis, evaluation, treatment, and review.

Finally, the register is specified as a **living artifact**, not a deliverable completed at design time. Ownership rests with the Board under its risk-register mandate ([Section 4.1.2](#)); review occurs each academic term as standing Board business, at which band assignments are contested, mitigations are assessed for closure, and new entries are admitted through the same traceability rule (Bow-Tie pathway or documented change-literature theme) that governed construction. Two forward linkages are designed in. The register **feeds the [Section 4.1.7](#) KPI dashboard**: the escalation-factor meta-controls EB1 and EB2, identified here as load-bearing, appear there as audit-cadence-adherence and data-quality-conformity indicators, and every operational risk’s mitigation names the workflow evidence the dashboard monitors. The register also **feeds the [Section 4.1.6](#) readiness gates**: G1 discharges RR-01, G2 discharges RR-03 and the competence component of RR-04, G3 tests RR-06 under controlled pilot conditions, and G4 holds RR-15 until organizational readiness is demonstrated. The risk register, the KPI dashboard, and the readiness gates thereby constitute a single governance loop — risks registered, mitigations enforced, performance monitored, phases gated — through which the framework’s maturity trajectory from Inform/Conform toward Perform is made auditable at every step (Hillson, D. A., 1997; 31000 ISO/IEC, 2018).

4.4 Key Performance Indicators & Governance Dashboard

Section 4 concluded that the participatory inventory framework is conditionally feasible, its conditions consolidated into the readiness gates G1–G4; [Section 2.9.2](#) registered the risks

that could defeat those conditions and the barriers they protect, identifying the escalation-factor barriers EB1 (audit cadence) and EB2 (data-quality indicators) as the load-bearing meta-controls of the architecture. What neither section provides is the instrument that makes barrier performance continuously visible: a defined set of key performance indicators (KPIs) and the governance dashboard through which they are reported, reviewed, and acted upon. The present section supplies that instrument. Consistent with the study's binding methodology, every indicator is *defined* — measurement method, data source, owner, frequency, and directional target fully specified — while no numeric baseline, numeric target, or empirical result is asserted. The KPI set is a design artifact: it specifies what the science faculty within the host higher education institution will observe once the framework operates, so that the transition from the Managed/Normalized maturity band toward Perform is evidenced rather than assumed (Hillson, D. A., 1997; 14001 ISO/IEC, 2015; 22301 ISO/IEC, 2019).

4.4.1 Measurement Philosophy for a Qualitative Framework

4.4.1.1 Indicators as policy instruments

In an operating management system, indicators report on a past that has already occurred. In a design-phase framework, their function is different and prior: a KPI is a *policy instrument* that makes barrier performance observable and auditable before any data exists. Defining an indicator commits the governance architecture — at design time, while commitments are cheap — to observing a named property, through a named method, by a named owner, on a named cadence. This commitment has three governance effects. First, it closes the escape route of unenforced policy (escalation factor EF1): a barrier whose performance no one must observe can decay silently — precisely the failure mode the escalation-factor layer exists to catch (Johnson et al., 2018). Second, it disciplines the framework's claims: because the cost-avoidance and waste-reduction mechanisms of Sections [4.2](#) and [4.3](#) are structural rather than measured, credibility depends on specifying

how the institution would know whether each mechanism works once adopted. Third, it converts the audit cadence (EB1) from a calendar of meetings into an evidence-driven review, since the dashboard gives the Board's termly sessions determinate content ((14001 ISO/IEC, 2015), clause 9.3;(22301 ISO/IEC, 2019), clause 9.3).

This philosophy aligns with both anchor standards' performance-evaluation clauses, adopted here by analogue. ISO 22301:2019 clause 9.1 requires the organization to determine what needs to be monitored and measured, the methods, the timing of analysis, and who is responsible; ISO 14001:2015 clause 9.1.1 imposes the parallel requirement, and clause 9.1.2 adds a distinct, periodic evaluation of compliance with the organization's compliance obligations (14001 ISO/IEC, 2015; 22301 ISO/IEC, 2019). The framework adopts this structure exactly: the KPI families of [Section 4.1.2](#)–[Section 4.1.4](#) are the determined objects, the methods below the determined methods, and the [Section 4.1.5](#) cadence the determined timing. Consistent with the thesis's terminology discipline, indicators concerning the management system itself are framed in the language of *conformity* — ISO 14001:2015 being a voluntary standard — while *evaluation of compliance* is reserved for obligations under applicable hazardous-substance and waste regulation ((14001 ISO/IEC, 2015), clauses 9.1.1, 9.1.2).

4.4.1.2 The definition-before-data principle

The section's governing methodological rule is the **definition-before-data principle**: a KPI is fully specified at design time, while its baseline is established only after onboarding in the implementation roadmap of [Section 4.1.6](#). Full specification comprises six elements, applied uniformly below: (1) a *definition* of the property observed; (2) a *measurement method* — a formula or structured observation protocol expressed qualitatively; (3) a *data source* within the framework's documented information, in the sense of clause 7.5 of both anchor standards (14001 ISO/IEC, 2015; 22301 ISO/IEC, 2019); (4) an *owner* from the [Section 4.1](#) governance architecture; (5) a *frequency* aligned to the academic term and

review cadence; and (6) a *directional target*. Targets are directional only: *increase*, *decrease*, or *establish-then-improve* (establish the baseline in the first operating periods, then pursue improvement against it). No numeric target is set, because no numeric evidence exists from which a defensible target could be derived; an invented target would be the fabricated precision the methodology excludes, and would preempt the management review's proper role of setting quantitative objectives once operating data accumulates ((14001 ISO/IEC, 2015), clause 6.2;(22301 ISO/IEC, 2019), clause 6.2).

The principle has a further, maturity-specific justification. The framework's trajectory — Inform/Conform toward Managed/Normalized toward Perform, the thesis's adapted labels anchored to Hillson's (1997) levels and the CMMI/ISO capability scale — defines Perform as measured, anticipatory, integrated practice (Hillson, D. A., 1997; Paulk et al., 1993). That band cannot be claimed by assertion; it is claimed by producing an evidence base of monitored performance, reviewed findings, and closed corrective actions. The readiness literature confirms that such an evidence base, not technology acquisition, distinguishes institutions ready for advanced practice from those that merely aspire to it (Bravo-Jaico et al., 2025; Rodríguez-Abitia & Bribiesca-Correa, 2021). The KPI set is therefore the framework's *maturity instrument*: the dashboard is what the Managed/Normalized-to-Perform transition looks like when made observable.

4.4.2 Operational Efficiency KPIs

The operational family monitors the framework's productive mechanisms — sharing, lending, rotation, and purchase displacement — that is, the pathways by which the design converts policy into avoided waste. Each indicator is specified below and mapped to the barrier it monitors and to the risk register entries of [Section 2.9.2 \(Table 4.6\)](#) it informs.

KPI-O1 — Shared asset utilization indicator. *Definition:* the extent to which loanable assets held in custodian holdings realize use across laboratories, as evidenced by executed

inter-lab loans recorded against those holdings. *Measurement method*: a structured comparison of the loan registry's record of cross-laboratory usage events against the custodian holdings declared in the shared registry — a qualitative utilization reading expressed as the pattern and breadth of sharing activity across item classes and departments, not a computed ratio. *Data source*: the Digital Supply Chain Unit's shared registry, in which every approved loan produces a registry-logged audit trail under the Inter-Lab Policy Framework ([Section 4.1.6](#)). *Owner*: the Unit (compilation); the Board (interpretation at termly review). *Frequency*: termly. *Directional target*: establish-then-improve — the first operating terms establish the utilization pattern; thereafter the Board seeks broadening utilization across item classes. *Linked barrier*: MB2 (inter-lab sharing/redistribution), whose effectiveness this indicator directly observes. *Linked risks*: RR-10 (loan integrity failure) and RR-11 (custodian recall conflicts), since a utilization pattern collapsing toward zero signals that sharing frictions, not absent demand, are suppressing MB2 (Strom et al., 2020; X. Wang & Qu, 2025).

KPI-O2 — Inter-lab loan cycle-time indicator. *Definition*: the elapsed duration of the loan workflow, read in two segments — request-to-approval and handover-to-return — as recorded in workflow timestamps. *Measurement method*: qualitative reading of the registry's timestamped workflow states (request lodged; custodian decision; custody acknowledgment; return-condition check; closure), identifying where durations concentrate and whether any segment lengthens across successive terms. No numeric thresholds are set; the method detects *trend and friction location* — a lengthening request-to-approval segment indicates decision friction at custodian level, a lengthening handover-to-return segment custody friction in execution. *Data source*: registry workflow logs generated by technician execution of the custody-transfer protocol. *Owner*: the Unit (compilation); custodian departments (response where their segment lengthens). *Frequency*: termly. *Directional target*: decrease — cycle times should shorten as workflows routinize. *Linked barrier*: EB3 (custody-transfer protocol). *Linked risks*: RR-06 (custody disputes during the

pilot) and RR-10 (overdue returns), both of which manifest first as segment lengthening before they manifest as incidents ([Section 4.3](#)).

KPI-O3 — FEFO conformity rate. *Definition:* the degree to which physical stock arrangement and issue practice conform to the Committee’s First-Expired-First-Out standard — earliest-expiring items positioned and issued first, expiry labels and date-marking present, expiry flags raised at the ratified thresholds. *Measurement method:* structured shelf-audit observation against the FEFO standard’s checklist, executed within the EB1 audit cadence: auditors record conformities and nonconformities by category (arrangement, labeling, flagging), producing a conformity profile rather than a count. *Data source:* shelf-audit records; technician expiry-flag entries in the registry. *Owner:* custodian departments (execution-level conformity); the Board (review through EB1); technicians generate the underlying records through rotation and flagging but hold no ownership of the indicator. *Frequency:* each audit cycle. *Directional target:* increase. *Linked barrier:* MB1 (FEFO rotation rules). *Linked risks:* RR-08 (FEFO drift) directly, and RR-12 (expiry clusters) informatively, since drift at the shelf is the upstream condition of cluster formation (Durgan et al., 2023; Wilke et al., 2023).

KPI-O4 — Duplicate-purchase displacement rate. *Definition:* the extent to which requisitions for loanable item classes are redirected to existing stock by the mandatory registry check — purchases that would have duplicated serviceable holdings and did not proceed because prevention barrier PB2 made the duplication visible. *Measurement method:* review of documented eligibility checks and their outcomes: each Unit-certified check closes as *proceed* (no serviceable stock found) or *displaced* (requisition redirected to existing stock or converted to a loan/redistribution request); the indicator is the qualitative pattern of displacement outcomes across terms. *Data source:* the eligibility-check records that PB2 requires as requisition preconditions ([Section 4.1.3](#)). *Owner:* the Unit (certification and compilation); the Board (review). *Frequency:* termly. *Directional target:* establish-

then-improve — early terms establish the displacement pattern; a persistent zero-displacement pattern is treated not as success but as a *signal to investigate*, since it may indicate check bypass rather than genuinely lean purchasing. *Linked barrier*: PB2 (eligibility clauses). *Linked risk*: RR-07 (eligibility-check bypass), which this indicator and KPI-G5 triangulate from opposite directions (Sönnichsen & Clement, 2020).

4.4.3 Environmental & Safety KPIs

The environmental family monitors the framework's significant environmental aspects — expired-chemical stocks destined for hazardous-waste streams and redundant acquisition — identified under the clause 6.1.2 analysis of [Section 4.5](#), and operationalizes the standard's monitoring and evaluation-of-compliance requirements at laboratory level ((14001 ISO/IEC, 2015), clauses 6.1.2, 9.1.1, 9.1.2). Each indicator is grounded in documented green-laboratory practice, where date-ordered rotation, pre-expiry redistribution, and governed disposal constitute the standard control chain against chemical waste (Durgan et al., 2023; Freese et al., 2024; Gutierrez et al., 2020).

KPI-E1 — Hazardous waste reduction rate. *Definition*: the directional trend of hazardous-waste volumes leaving the college's laboratories through governed disposal channels. *Measurement method*: qualitative trend reading of the disposal manifests required by mitigation barrier MB3 across successive terms, read as a trend line (rising, stable, falling) with commentary on composition shifts, never as a computed percentage. *Data source*: governed disposal manifests maintained under MB3. *Owner*: the Committee, through its safety and compliance interface (compilation); the Board (review). *Frequency*: termly, consolidated annually for the management review. *Directional target*: decrease. *Linked barriers*: MB1, MB2, and MB3 jointly — the indicator reads the *output* of the whole mitigation chain, since stock consumed in place (MB1) or redistributed before expiry (MB2) never reaches the manifest. *Linked risks*: RR-12 (expiry clusters) and RR-13 (disposal nonconformity); a falling manifest trend accompanied by rising expired-stock incidence

(KPI-E3) is a warning configuration, suggesting disposal leakage outside governed channels rather than genuine prevention ((14001 ISO/IEC, 2015), clause 9.1.2).

KPI-E2 — Pre-expiry chemical redistribution rate. *Definition:* the extent to which chemical stocks approaching expiry are redistributed to live demand before lapse, relative to stocks that proceed to expiry write-off. *Measurement method:* structured comparison of two MB2 record classes — executed pre-expiry redistributions (consumption transfers under the joint FEFO-custody protocol) against expiry write-offs in the same period — expressed as the qualitative balance between salvage and loss. *Data source:* MB2 redistribution records (chain-of-custody logs for consumption transfers) and registry expiry-flag histories. *Owner:* the Unit (compilation); custodian departments (response). *Frequency:* termly. *Directional target:* increase — the salvage share should grow as flagging thresholds and redistribution routing mature. *Linked barrier:* MB2 in its redistribution mode. *Linked risks:* RR-12 (expiry clusters exceeding redistribution capacity) and RR-09 (registry data decay), the latter because redistribution is blind where records of live demand are stale (Freese et al., 2024).

KPI-E3 — Expired-stock incidence. *Definition:* the occurrence of items reaching expiry in storage, as surfaced by expiry flags and audit observations per audit cycle. *Measurement method:* qualitative incidence reading from two convergent sources — technician-raised expiry flags logged at the Committee's thresholds, and expired-stock observations recorded in shelf audits under EB1 — read jointly so that audit findings corroborate or correct flag-based reporting. *Data source:* registry expiry-flag entries; shelf-audit records. *Owner:* custodian departments (execution-level); the Committee (interpretation against the FEFO standard). *Frequency:* each audit cycle, summarized termly. *Directional target:* decrease. *Linked barrier:* MB1, whose failure this indicator measures at the consequence end. *Linked risks:* RR-08 (FEFO drift) and RR-12 (expiry clusters). KPI-E3 and KPI-O3

are deliberately paired: O3 reads the barrier's *practice*, E3 its *result*, and divergence between them triggers the corrective-action loop ((14001 ISO/IEC, 2015), clause 10).

KPI-E4 — Disposal-protocol conformity. *Definition:* the degree to which disposal events conform to the governed protocols of MB3 — documented routing through compliant channels, redistribution-before-disposal checks completed, and records complete at the time of disposal. *Measurement method:* conformity assessment of disposal documentation against the MB3 protocol checklist within the EB1 cadence — the laboratory-level operationalization of ISO 14001:2015 clause 9.1.2's evaluation of compliance, since hazardous-waste handling is where external compliance obligations bind most directly ((14001 ISO/IEC, 2015), clause 9.1.2). The same audit cycle records completion of the emergency-preparedness exercises adopted by analogue from clause 8.2 — planned responses to chemical incidents, periodically tested and reviewed — as a preparedness note accompanying the indicator ((14001 ISO/IEC, 2015), clause 8.2). *Data source:* MB3 disposal records; clause 9.1.2 evaluation records; exercise documentation. *Owner:* the Committee with the college safety and compliance officer. *Frequency:* each audit cycle; annual consolidation at management review. *Directional target:* increase toward, and then hold at, full documented conformity. *Linked barrier:* MB3. *Linked risks:* RR-13 (disposal nonconformity) directly; RR-14 (audit-finding recurrence) where repeat disposal findings appear across cycles.

4.4.4 Governance & Digital Readiness KPIs

The governance family monitors the meta-controls and preconditions on which the two operational families depend: the integrity of the shared record, the honesty of the enforcement layer, and the institution's readiness for the digital platform the framework deliberately defers. These indicators operationalize the escalation-factor barriers directly — EB1 and EB2, identified in [Section 4.3.4](#) as the architecture's load-bearing members, each receive a dedicated standing indicator.

KPI-G1 — Catalog standardization coverage. *Definition:* the extent of the college's holdings onboarded to the Committee's unified catalog standard (PB1), read against remaining legacy records not yet conforming. *Measurement method:* structured census of registry records by conformity status — records carrying the full minimum attribute set versus legacy records pending migration — expressed as a coverage profile by department and item class. *Data source:* the shared registry, using the Unit's onboarding records. *Owner:* the Unit. *Frequency:* termly during onboarding phases; thereafter on change. *Directional target:* increase toward full coverage of the pilot scope as the precondition of readiness gate G2. *Linked barrier:* PB1. *Linked risk:* RR-03 (incomplete or nonconforming data onboarding). Coverage is the gate criterion made continuous: G2 certifies it once; KPI-G1 keeps it visible thereafter, since new acquisitions and new custodians continually generate fresh onboarding demand ([Section 4.6](#)).

KPI-G2 — Registry data-quality conformity. *Definition:* the conformity of registry records to the Unit's data-quality rules — completeness (required fields populated), currency (records reflecting events within the expected entry lag), and consistency (records agreeing across linked workflows). *Measurement method:* the field-completeness and currency checks defined under escalation-factor barrier EB2, executed by the Unit as standing data stewardship and reported as a conformity profile by department and item class — operationalizing EB2 as [Section 4.1.4](#) specifies, converting data integrity from an assumption into a monitored property. *Data source:* the registry itself, audited against physical-stock spot checks within the EB1 cadence. *Owner:* the Unit. *Frequency:* continuous monitoring with termly reporting. *Directional target:* increase, then hold. *Linked barrier:* EB2, with PB1, PB2, and MB2 as the barriers its degradation would blind. *Linked risks:* RR-09 (registry data decay) and RR-03 (onboarding quality). Because data decay can degrade three barriers at once ([Section 4.3](#)), this indicator carries the framework's highest monitoring intensity.

KPI-G3 — Audit cadence adherence. *Definition:* the degree to which the planned audit calendar is actually executed — shelf audits, eligibility-check tests, and disposal-conformity assessments occurring as scheduled, with documented outputs. *Measurement method:* comparison of planned against executed and documented audits per term; deviations are recorded with causes, since a skipped audit is itself a finding about EF1 (unenforced policy). *Data source:* the EB1 audit programme and its outputs. *Owner:* the Board (owner of the audit cadence); execution by the audit function with Unit and Committee support. *Frequency:* termly self-assessment; annual confirmation at management review. *Directional target:* establish-then-improve toward full adherence. *Linked barrier:* EB1. *Linked risks:* RR-05 (compliance fatigue) and RR-14 (audit-finding recurrence). The indicator is reflexive by design: it monitors the monitor, addressing the failure mode in which the enforcement layer itself decays into ritual (Johnson et al., 2018).

KPI-G4 — Audit-findings resolution rate. *Definition:* the extent to which audit findings are closed — corrective actions completed with documented evidence — by the next review cycle. *Measurement method:* tracking of findings from opening to closure across successive cycles, reported as open, carried-over, and closed findings with named owners, following the nonconformity-and-corrective-action logic of clause 10 of both anchor standards adopted by analogue ((14001 ISO/IEC, 2015), clause 10;(22301 ISO/IEC, 2019), clause 10). Recurring findings are flagged as a distinct category, since recurrence rather than volume is the diagnostic of systemic failure. *Data source:* corrective-action records maintained through Board review. *Owner:* the Board. *Frequency:* termly, with annual consolidation. *Directional target:* increase (closure); decrease (recurrence). *Linked barrier:* EB1 in its improvement mode. *Linked risk:* RR-14 (audit-finding recurrence), which this indicator exists to detect before corrective action becomes ritual.

KPI-G5 — Eligibility-check execution rate. *Definition:* the extent to which requisitions for loanable item classes are accompanied by the documented registry check that

prevention barrier PB2 mandates. *Measurement method*: the EB1 audit cycle's test of requisition files for check evidence, reported as a conformity profile of requisitions with and without certified checks, corroborated against the Unit's certification records. *Data source*: requisition documentation sampled within the audit cadence; Unit certification logs. *Owner*: custodian departments (execution-level conformity); the Board (review and escalation of repeated violations under its [Section 4.1.2](#) decision rights). *Frequency*: each audit cycle. *Directional target*: increase toward universal execution. *Linked barrier*: PB2. *Linked risk*: RR-07 (eligibility-check bypass). With KPI-O4 this indicator forms a triangulation pair: G5 observes whether the check *happens*, O4 what the check *displaces*, and their joint reading distinguishes a healthy control from a bypassed one (Sönnichsen & Clement, 2020).

KPI-G6 — Digital readiness gate status. *Definition*: the institution's checklist-based maturity toward readiness gate G4 — the state of data standards, process stability, and role competence that the digital-transformation literature identifies as the precondition for smart-inventory platform value (Carpitella & Izquierdo, 2025; Rodríguez-Abitia & Bribiesca-Correa, 2021; Wilke et al., 2023). *Measurement method*: a structured readiness checklist maintained by the Unit as its requirements baseline, with items described, not scored: (a) catalog standard ratified and coverage sustained (reads KPI-G1); (b) data-quality conformity sustained across consecutive terms (reads KPI-G2); (c) loan, custody, and FEFO workflows demonstrated as stable under pilot and scaled operation (reads KPI-O2, KPI-O3, and the G3 gate evidence); (d) role competence current under the clause 7.2 competence programme ((14001 ISO/IEC, 2015), clause 7.2; (22301 ISO/IEC, 2019), clause 7.2); and (e) audit and corrective-action loops functioning (reads KPI-G3, KPI-G4). Each item is assessed as *met* / *partially met* / *not met* by inspection of the underlying dashboard evidence; the indicator aggregates the dashboard itself rather than measuring independently. *Data source*: the Unit's requirements baseline and the dashboard record. *Owner*: the Unit (maintenance); the Board (gate authority). *Frequency*: termly assessment; the gate decision itself is singular. *Directional target*: establish-then-improve toward all-

items–met. *Linked barrier*: the Perform–band precondition as a whole; formally, the G4 gate of [Section 4.6](#). *Linked risk*: RR–15 (premature digital platform investment), which this indicator holds closed by making readiness a demonstrated condition rather than a procurement impulse.

4.4.5 The Governance Dashboard

The fourteen indicators consolidate into a single governance dashboard — one instrument through which the Board, the Committee, and the Unit observe the barrier architecture’s performance as a whole. [Table 12.4](#) presents the consolidated specification: every KPI with its domain, measurement method, data source, owner, frequency, directional target, linked barrier, and linked entries from [Section 2.9.3](#)’s FIRM–classified register (Hopkin, 2018). The consolidation is itself a design claim: because every row names a barrier and a risk, the dashboard covers the Bow–Tie architecture and the register’s standing operational core without remainder, and a Board reviewing the dashboard is, by construction, reviewing the whole framework.

Table 4.7. Consolidated governance dashboard for the participatory inventory framework (directional targets: ↑ increase; ↓ decrease; E→I establish-then-improve; risk IDs per [Table 4.6](#))

KPI ID	Domain	Indicator	Measurement method	Data source	Owner	Frequency	Directional target	Linked barrier	Linked risk IDs
KPI–O1	Operational	Shared asset utilization	Qualitative reading of cross–lab loan events against custodian holdings	Unit shared registry (loan audit trail)	Unit (compiles); Board (reviews)	Termly	E→I	MB2	RR–10, RR–11

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KPI ID	Domain	Indicator	Measurement method	Data source	Owner	Frequency	Directional target	Linked barrier	Linked risk IDs
KPI-O2	Operational	Inter-lab loan cycle time	Trend reading of workflow timestamps (request-to-approval; handover-to-return)	Registry workflow logs	Unit (compiles); Custodian Dept (responds)	Termly	↓	EB3	RR-06, RR-10
KPI-O3	Operational	FEFO conformity rate	Structured shelf-audit observation against the FEFO standard checklist	Shelf-audit records; expiry-flag entries	Custodian Dept; Board via EB1	Each audit cycle	↑	MB1	RR-08, RR-12
KPI-O4	Operational	Duplicate-purchase displacement	Review of eligibility-check outcomes (proceed vs. displaced)	PB2 eligibility-check records	Unit (certifies/compiles); Board	Termly	E→I	PB2	RR-07
KPI-E1	Environmental	Hazardous waste reduction	Qualitative trend of governed disposal manifests with composition commentary	MB3 disposal manifests	Committee (safety interface); Board	Termly; annual consolidation	↓	MB1, MB2, MB3	RR-12, RR-13
KPI-E2	Environmental	Pre-expiry redistribution rate	Balance of executed pre-expiry redistribution	MB2 custody logs; expiry-flag histories	Unit (compiles);	Termly	↑	MB2	RR-09, RR-12

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KPI ID	Domain	Indicator	Measurement method	Data source	Owner	Frequency	Directional target	Linked barrier	Linked risk IDs
			s vs. expiry write-offs		Custodian Dept				
KPI-E3	Environmental	Expired-stock incidence	Joint reading of expiry flags and audit expiry observations per cycle	Registry expiry flags; shelf-audit records	Custodian Dept; Committee	Each audit cycle; termly summary	↓	MB1	RR-08, RR-12
KPI-E4	Environmental	Disposal-protocol conformity	Conformity assessment of disposal documentation; cl. 9.1.2 evaluation analogue; cl. 8.2 exercise note	MB3 disposal records; evaluation and exercise documentation	Committee with safety and compliance officer	Each audit cycle; annual consolidation	↑ (then hold)	MB3	RR-13, RR-14
KPI-G1	Governance	Catalog standardization coverage	Census of records conforming to the catalog standard vs. legacy records	Registry onboarding records	Unit	Termly during onboarding; on change thereafter	↑ (toward G2 criterion)	PB1	RR-03
KPI-G2	Governance	Registry data-quality conformity	EB2 completeness, currency, and consistency checks; spot checks	Registry; EB1 spot checks	Unit	Continuous; termly reporting	↑ (then hold)	EB2	RR-03, RR-09

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KPI ID	Domain	Indicator	Measurement method	Data source	Owner	Frequency	Directional target	Linked barrier	Linked risk IDs
			vs. physical stock						
KPI-G3	Governance	Audit cadence adherence	Planned vs. executed audits, with deviation causes recorded	EB1 audit programme and outputs	Board	Termly; annual confirmation	E→I	EB1	RR-05, RR-14
KPI-G4	Governance	Audit-findings resolution	Findings tracked open / carried-over / closed; recurrence flagged (cl. 10 analogue)	Corrective-action records	Board	Termly; annual consolidation	↑ closure; ↓ recurrence	EB1	RR-14
KPI-G5	Governance	Eligibility-check execution	Audit test of requisition files for certified check evidence	Requisition files; Unit certification logs	Custodian Dept; Board	Each audit cycle	↑	PB2	RR-07
KPI-G6	Governance	Digital readiness gate status	Checklist assessment (met / partially met / not met) across data standards, process stability, role competence	Unit requirements baseline; dashboard evidence	Unit (maintains); Board (gate authority)	Termly; singular gate decision	E→I	G4 gate (Perform precondition)	RR-15

4.4.5.1 Reporting architecture

The dashboard's reporting architecture follows the [Section 4.1](#) allocation of roles without exception, and its record flow is deliberately bottom-up. **Laboratory technicians generate the records** through execution alone: FEFO rotation and expiry flagging produce the entries behind KPI-O3 and KPI-E3; loan workflow execution produces the timestamps and custody artifacts behind KPI-O1, KPI-O2, and KPI-E2; catalog and registry entries produce the data that KPI-G1 and KPI-G2 assess. Technicians hold no ownership, compilation, or interpretation role for any indicator — their contribution is evidentiary, consistent with the non-authority clause of [Section 4.1.5](#), with accountability for record quality resting with custodian supervisors and the Unit. **The Digital Supply Chain Unit compiles the dashboard termly**, drawing together registry-derived indicators, audit outputs, and disposal documentation, and certifying data quality before the dashboard reaches the Board — the negative procedural power [Section 4.1.4](#) grants it. **The Governance Board reviews the dashboard termly** as standing business and receives its consolidated form at the annual management review, adopted by analogue from clause 9.3 of both anchor standards, at which directional performance is assessed, corrective actions are confirmed or escalated, and — once operating history permits — quantitative objectives may be set under the clause 6.2 analogues ((14001 ISO/IEC, 2015), clauses 6.2, 9.3;(22301 ISO/IEC, 2019), clauses 6.2, 9.3). **The audit function verifies cadence and data quality**: EB1 tests the evidence behind the indicators, and EB2's standing checks keep the registry substrate honest, so that the dashboard is itself audited rather than self-attesting.

4.4.5.2 The dashboard as maturity evidence and gate instrument

The dashboard closes the thesis's governance loop in two directions. **Upward, it operationalizes the Perform maturity band**. The adapted trajectory defines Perform as measured, anticipatory, integrated practice (Hillson, D. A., 1997; Paulk et al., 1993); the

dashboard is what “measured” concretely means here — barrier performance observed on cadence, findings closed with evidence, readiness assessed against a maintained checklist. The readiness literature’s finding that institutions advance only on demonstrated organizational evidence, not aspiration, is given institutional form: the Perform claim, when the college eventually makes it, will be substantiated by the dashboard record and by nothing else (Bellantuono et al., 2021; Bravo–Jaico et al., 2025; Rodríguez–Abitia & Bribiesca–Correa, 2021). **Forward, the dashboard feeds [Section 4.1.6](#)’s readiness gates.** Gate G2 (data readiness) consumes the governance family’s data indicators: KPI–G1 coverage and KPI–G2 data–quality conformity are the gate’s certifying evidence, monitored continuously thereafter. Gate G3 (pilot workflow integrity) consumes the operational family: KPI–O1 through KPI–O4 and the E–family’s redistribution (KPI–E2) and incidence (KPI–E3) indicators are the standing form of the workflow evidence the pilot must first demonstrate qualitatively. Gate G4 (digital platform readiness) is, by construction, KPI–G6: the checklist indicator *is* the gate instrument, and its all–items–met state is the gate’s opening condition (Carpitella & Izquierdo, 2025; Wilke et al., 2023). [Section 4.1.6](#) sequences these consumptions along the implementation phases; what the present section has fixed is the indicator vocabulary — KPI–O1 through KPI–G6, with methods, owners, and directional targets — that makes the roadmap’s gates verifiable and the framework’s maturity trajectory auditable from its first operating term.

4.5 Phased Implementation Roadmap and Change Management

The preceding sections of [Phase 2](#) established that the participatory inventory framework is feasible — conditionally strong, gated by the readiness gates G1–G4 (Section 4) — and that the risks threatening its adoption and operation are registered, classified, and owned ([Section 2.9.2](#)), with a governance dashboard monitoring the same conditions continuously ([Section 4.1.7](#)). What remains is the question of order: in what sequence should the science faculty within the host higher education institution adopt the framework, through

which checkpoints, and under what change–management discipline? The present section answers that question and, in doing so, completes Research Objective O4. The roadmap is specified as a governed initiative: phases are progressively elaborated, each terminates at one of the analytical readiness gates defined in [Section 4.6](#), and every activity is owned by a named body within the [Section 4.1](#) governance architecture (Project Management Institute (PMI, 2021); (Takagi et al., 2024)). Consistent with the study’s binding methodology, the roadmap contains no empirical content: phase timeframes are schedule designations fixed by the study’s terms of reference, gate criteria are structural conditions verified by inspection of documented information, and no metrics, targets, or pilot results are asserted anywhere in the section.

4.5.1 Sequencing Logic

The roadmap’s sequence is not an administrative convenience but a reasoned derivation from three analytical commitments of the earlier sections: the maturity–band trajectory of [Section 2.9.2](#), the organization–before–technology ordering claim, and the gate logic of Section 4. Each is restated here in its sequencing consequence.

Maturity–band progression. [Section 2.9.2](#) diagnosed the decentralized regime as sitting in the *Inform/Conform* band and specified the trajectory toward *Managed/Normalized* and then *Perform* as the framework’s declared, adapted terminology anchored to Hillson’s Naive–to–Natural progression and the CMM/ISO capability scale (Hillson, D. A., 1997; Paulk et al., 1993). The roadmap’s phases are [Section 2.9.2](#)’s three transition mechanisms made schedulable: [Phase 1](#) performs the governance transition’s institutional half (constituting bodies, ratifying policy); [Phase 2](#) the standardization transition (catalog rollout, data onboarding); [Phase 3](#) demonstrates the standardized processes operating under load; and [Phase 4](#) institutionalizes the measurement–and–review transition — audit cadence, management review, continual improvement — that opens the path to Perform (14001 ISO/IEC, 2015; 22301 ISO/IEC, 2019). The sequence is irreversible by design:

measurement without standardized processes audits nothing, and governance without ratified policy enforces nothing.

Organization before technology. The roadmap holds digitalization to the position [Section 2.9.2](#) assigned it: a Perform-band capability unlocked by, never substituted for, organizational reform. The higher-education digital-transformation literature is consistent that technology layered onto unstandardized processes and unclear roles reproduces fragmentation in digital form, and that organizational readiness — process definition, governance clarity, data discipline — is the binding constraint (Bellantuono et al., 2021; Bravo-Jaico et al., 2025; Rodríguez-Abitia & Bribiesca-Correa, 2021). Smart-inventory research confirms the claim in the inventory domain: automated tracking delivers value only where processes and data semantics are already standardized (Carpitella & Izquierdo, 2025), and documented RFID-assisted stock control presupposes exactly the rotation discipline and record conformity the framework installs first (Wilke et al., 2023). The platform therefore appears only as the object of gate G4 in the continuous [Phase 4](#) — never as a [Phase 1](#) acquisition.

Pilot-first gradualism in a large public institution. The Biology Department pilot precedes college-wide scaling for three reasons. First, the change-management evidence indicates that staged, capability-building transitions succeed where big-bang adoptions stall: early, bounded demonstration converts abstract policy into visible practice and gives resisters a falsifiable claim rather than a *fait accompli* (Dean et al., 2024; Vlachopoulos, 2021). Second, the Biology Department is the thesis's embedded unit of analysis and presents the college's full inventory complexity, so workflow integrity demonstrated there transfers with the fewest caveats (Section 1). Third, pilot-first sequencing is the risk treatment [Section 2.9.2](#) specified for transition risks RR-02 and RR-06: resistance and early custody disputes are absorbed inside a bounded scope with a protocolized resolution

path before the regime is exposed college-wide. In project-management terms, this is progressive elaboration tailored to institutional context (PMI, 2021; Takagi et al., 2024).

Gates as phase terminators. Every phase terminates at one of the analytical readiness gates of [Section 4.6](#) — G1 policy ratification, G2 data readiness, G3 pilot workflow integrity, G4 digital platform readiness — and no successor phase begins until its gate closes. The gate discipline is the roadmap’s load-bearing control, because [Section 4.3.4.3](#) established that transition risks are discharged by gates, not by elapsed time: G1 discharges RR-01, G2 discharges RR-03 and the competence component of RR-04, G3 tests RR-06 under controlled conditions, and G4 holds RR-15 until organizational readiness is demonstrated. A phase that overruns its schedule designation is a scheduling matter for the Board’s termly review; a phase whose gate has not closed is a stop. The roadmap is, in this sense, PMBOK tailoring logic applied to a policy reform: scope fixed by the framework, sequence by the maturity trajectory, progress by gate evidence rather than calendar (31000 ISO/IEC, 2018; PMI, 2021).

4.5.2 Phase 1: Institutional Foundation and Policy Ratification (Months 1–2)

Phase 1 converts the framework from design artifact into ratified institutional policy. Its activities are:

1. **Constitute the Academic Inventory Governance Board.** College leadership delegates the Board’s five mandates ([Section 4.1.2](#)) and appoints its composition of roles. Constitution comes first deliberately: every subsequent ratification requires a ratifying authority, and the collaborative-governance literature identifies legitimate, visibly mandated authority as the precondition for participatory arrangements that do not decay into nominal compliance (Ahn & Baldwin, 2024; Lopes & Farias, 2022).
2. **Charter the Technical Standardization Committee and the Digital Supply Chain Unit.** The Committee receives its standard-drafting mandate; the Unit its data-

stewardship mandate, including its negative procedural power to decline certifying an eligibility check when data-quality rules are unmet (Sections [3.3–3.4](#)).

3. **Ratify the policy core.** In a single ratification cycle, the Board adopts the unified catalog and records standard (PB1); the eligibility clauses requiring a documented shared-registry check before requisition (PB2); the FEFO policy standard (MB1); and the Inter-Lab Policy Framework with its eligibility classification, loan workflow, custody-transfer protocol, and risk controls — loan limits, recall rights, and the damage/loss liability principle ([Section 4.1.6](#)).
4. **Appoint roles and confirm the technician operational mandate.** Custodian supervisors, executing technicians, and escalation contacts are named in each department, with the technician role confirmed exactly as [Section 4.1.5](#) specifies it: execution of FEFO rotation, loan workflows, custody documentation, and catalog entries, with a bounded escalation duty — and no administrative decision-making authority, procurement approval, financial authority, or policy-setting role. Confirming the non-authority clause at ratification prevents the authority inflation the governance literature identifies as a failure mode of participatory arrangements (Gestel & Grotenbreg, 2021; Lopes & Farias, 2022).
5. **Initiate change communication.** The Board opens the communication structure specified in [Section 4.1.6](#) — a standing channel carrying the framework’s rationale, the eligibility rules, and the pilot plan to departments — following the awareness and communication provisions both anchor standards assign to a management system’s support function ((14001 ISO/IEC, 2015), clauses 7.3–7.4;(22301 ISO/IEC, 2019), clauses 7.3–7.4).

Governance and gate. The Board leads [Phase 1](#); the Committee drafts; departments comment within time-boxed windows. The phase terminates at **gate G1 — policy ratification**, whose criteria per [Section 4.6](#) are: the Board constituted; the policy core

ratified; roles appointed and communicated per the clause 5.3 analogue of both standards; and the [Section 2.9.2](#) risk register adopted as a standing Board instrument ((14001 ISO/IEC, 2015), clause 5.3;(22301 ISO/IEC, 2019), clause 5.3). The linked transition risks are **RR-01 (policy ratification delay)** — High priority because the entire barrier architecture depends on this gate — and **RR-02 (departmental resistance to shared visibility and custody rules)**, which [Phase 1](#) begins treating through departmental Board representation and the custodian protections ratified within the Inter-Lab Policy Framework. Gate G1 also activates the audit-cadence adherence indicator (KPI-G3), since the Board's termly review cycle begins with ratification.

4.5.3 Phase 2: Catalog Standardization and Data Onboarding (Months 3–4)

Phase 2 performs the standardization transition out of the Inform/Conform band: it deploys prevention barrier PB1 and populates the shared registry on which every downstream mechanism — the eligibility check, redistribution, the dashboard — depends. Its activities are:

1. **Roll out the PB1 catalog standard, Biology Department first.** The Committee's standard — naming conventions, classification hierarchies, units of measure, hazard annotations, the minimum attribute set — is applied to the embedded unit's inventory before any other department, so that the standard is stress-tested against the college's most chemically diverse stock while the onboarding team is still small and correctable ([Section 2.2.2](#)).
2. **Onboard departmental inventories to the shared registry.** Biology Department holdings are entered into the Unit-operated registry in full conformity with the ratified standard; remaining departments begin preparatory classification so that [Phase 4](#) scaling starts from documented groundwork rather than a cold start. Registry entries are executed by technicians as catalog work under [Section 4.1.5](#), with the Unit stewarding conformity and custodian supervisors accountable for completeness.

3. **Establish the data-quality baseline per EB2.** The Unit records the first measurement of its data-quality indicators — completeness, currency, and consistency of registry records against the standard. This baseline is, by design, *the first recorded measurement*: a starting condition to be documented so that subsequent measurements are interpretable, not a value asserted in advance. The baseline operationalizes escalation-factor barrier EB2 and instantiates the catalog standardization coverage (KPI-G1) and data-quality conformity (KPI-G2) indicators as live instruments ([Section 4.1.7](#)).
4. **Build technician and departmental competence.** Role-based onboarding is delivered for executing technicians and custodian staff — FEFO discipline, custody-transfer documentation, registry data standards, chemical-handling safety — with periodic refreshers scheduled from the outset, applying directly the competence and awareness provisions of both anchor standards ((14001 ISO/IEC, 2015), clauses 7.2–7.3;(22301 ISO/IEC, 2019), clauses 7.2–7.3). Competence building in this phase treats transition risk RR-04 before it can degrade the pilot.

Governance and gate. The Unit leads [Phase 2](#); the Committee supports with standard interpretation and defect correction; custodian departments are accountable for completeness. The phase terminates at **gate G2 — data readiness**, whose criteria per [Section 4.6](#) are: onboarding complete for the pilot scope, and registry records conforming to the Committee’s standard as verified through the data-quality indicator (KPI-G2) and the catalog-coverage indicator (KPI-G1) against their [Section 4.1.7](#) definitions — by inspection of documented information, not sampled statistics. G2 discharges **RR-03 (incomplete or nonconforming data onboarding)**, because a visibly incomplete registry defeats the eligibility check in practice by returning false absences ([Section 4.3](#)), and the competence component of **RR-04**. The Unit’s certification power is the gate’s enforcement edge: the pilot does not begin on data the Unit cannot certify.

4.5.4 Phase 3: Biology Department Pilot and Workflow Testing (Months 5–6)

Phase 3 places the ratified regime into live operation within the embedded unit — the framework’s exercise phase, in which documented workflows must demonstrate that they work under the ordinary pressures of a teaching department before the college is asked to scale them. Its activities are:

1. **Operate inter-lab loan workflows live.** Requests, eligibility checks, custodian approvals, and returns are executed within and around the Biology Department under the Inter-Lab Policy Framework’s full workflow ([Section 4.1.6 \(b\)](#)), with technicians executing transfers and records and custodian supervisors approving within ratified rules.
2. **Exercise the custody-transfer protocol (EB3).** Every pilot loan produces the protocol’s evidentiary artifacts — condition record, custody acknowledgment, chain-of-custody log across the four custody states — so that the escalation-factor barrier against custody ambiguity (EF3) is tested under real transactions rather than assumed ([Section 4.1.6 \(c\)–\(d\)](#)).
3. **Execute FEFO (MB1) and the expiry escalation ladder.** Technicians perform date-ordered rotation, labeling, and expiry flagging per the Committee’s standard; flagged items trigger the escalation ladder — technician flags, the Unit routes and documents, the custodian supervisor decides, the Board adjudicates — including pre-expiry redistribution offers under MB2 where live demand exists elsewhere ([Section 4.1.5](#); [Section 4.1.6](#)).
4. **Conduct a structured walkthrough of continuity procedures.** Following by analogue the exercise-programme logic of ISO 22301:2019 clause 8.5, the Unit and custodian departments rehearse the framework’s continuity function: a simulated supply interruption in which the shared registry and inter-lab loans

substitute for external supply to protect prioritized teaching activities ((22301 ISO/IEC, 2019), clause 8.5; [Section 2.9.4](#)). The walkthrough is documented and its findings assigned, mirroring the standard's exercise–evaluation requirement.

5. **Hold a qualitative pilot review.** The Board convenes a structured review of pilot documented information: workflow logs, custody records, escalation records, and the exercise report.

Governance and gate. Custodian departments and the Unit execute; technicians operate the workflows within their bounded mandate; the Board reviews. The phase terminates at **gate G3 — pilot workflow integrity**, whose exit criteria are expressed as *demonstrated workflow integrity*, explicitly **not** as metric thresholds: all workflow steps executed as designed in documented cases; every exception escalated through the ladder and resolved within policy; custody records complete for every loan event; FEFO rotation and expiry flagging operating as routine; the continuity walkthrough conducted with findings assigned. G3 discharges **RR-06 (custody disputes during the pilot)** by demonstrating dispute–resolution integrity, and it provides the first operational evidence for **RR-08, RR-10, and RR-11** — operational risks the pilot surfaces under controlled scope so that their standing mitigations are calibrated before scaling. During the pilot, the operational–efficiency KPI family (utilization, KPI-O1; loan cycle–time, KPI-O2; FEFO conformity, KPI-O3; duplicate–purchase displacement, KPI-O4) and the relevant environmental and safety indicators (pre–expiry redistribution, KPI-E2; expired–stock incidence, KPI-E3) record their first measurements — establishing [Section 4.1.7](#) baselines without any threshold being imposed on pilot exit.

4.5.5 Phase 4: College–Wide Scaling and Digital Platform Readiness Gate (Continuous)

Phase 4 differs in kind from its predecessors: it has no closing month, because it is the framework’s steady state — scaling, enforcement, and improvement as standing business, with the digital platform question held permanently behind its gate. Its activities are:

- 1. Scale ratified policy and onboarding across the College of Science.**
Departments onboard to the shared registry in a rolling sequence set by the Board, reusing the pilot’s corrected practice; the eligibility clauses, FEFO standard, and Inter–Lab Policy Framework apply college–wide as each department’s onboarding is certified by the Unit. Scaling reuses rather than redesigns demonstrated workflows — the point of pilot–first gradualism (Dean et al., 2024; Vlachopoulos, 2021).
- 2. Institutionalize the audit cadence (EB1) and management review.** The Board’s termly review and annual management review operate as the framework’s Check function, analogous to clauses 9.2 and 9.3 of both anchor standards: audit of eligibility–check evidence, rotation practice, and custody records; review of barrier performance, data–quality indicators, and continuity readiness, with corrective actions assigned and tracked to closure ((14001 ISO/IEC, 2015), clauses 9.2–9.3;(22301 ISO/IEC, 2019), clauses 9.2–9.3).
- 3. Operate continual improvement.** The clause 10 analogue of both standards converts audit findings and dashboard signals into policy and standard revisions through the Committee and Board ((14001 ISO/IEC, 2015), clause 10;(22301 ISO/IEC, 2019), clause 10) — the measurement–and–review transition of [Section 2.9.2](#) in standing operation, and the mechanism by which the framework approaches the Perform band.
- 4. Hold the digital platform readiness gate (G4).** Only after data standards, process stability, and role competence are demonstrably mature — evidenced through the governance and digital–readiness KPI family, including the digital readiness gate

status indicator (KPI-G6) — does the college *commission consideration* of a smart inventory platform (barcode- or RFID-assisted tracking and related instrumentation), against the requirements baseline the Unit has maintained throughout (Carpitella & Izquierdo, 2025; Wilke et al., 2023). G4 releases procurement consideration, not procurement itself, because platform provision remains Contingent on university-level information technology outside the framework's control ([Section 4.4](#)).

The risk this gate exists to prevent is explicit in the register: **RR-15, premature digital platform investment** — pressure to acquire a platform before process standardization and role clarity are established, digitizing fragmentation without capability gain (Bellantuono et al., 2021; Rodríguez-Abitia & Bribiesca-Correa, 2021). G4 is RR-15's named mitigation, and the Board holds gate authority exactly so that the failure mode is structurally impossible rather than merely discouraged. [Phase 4](#) is also where the register's standing operational risks are governed as permanent business: **RR-05, RR-07, RR-09, RR-12, RR-13, and RR-14** are monitored through the full dashboard — the operational-efficiency family (KPI-O1-O4), the environmental and safety family (KPI-E1-E4), and the governance and digital-readiness family (KPI-G1-G6) — with the Unit compiling, the Board reviewing termly, and the annual management review closing the loop ([Section 4.1.7](#)).

4.5.6 Consolidated Roadmap Table

[Table 13.4](#) consolidates the four phases into a single governance view, linking each phase to its timeframe, objectives, key activities, responsible bodies, readiness gate with exit criteria, the risk-register entries it treats or discharges ([Section 2.9.2](#)), and the dashboard indicators it activates or feeds ([Section 4.1.7](#)). The table is the roadmap's audit surface: the Board can read, phase by phase, what must be true before the next phase begins, and which risks and indicators evidence it.

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Table 4.8. Consolidated phased implementation roadmap for the participatory inventory framework (gates per [Section 4.6](#); risks per [Table 4.6](#); KPIs per [Section 4.1.7](#))

Phase	Timeframe	Objectives	Key activities	Responsible bodies	Readiness gate + exit criteria	Linked risks (RR IDs)	Linked KPIs (KPI IDs)
1 — Institutional foundation and policy ratification	Months 1–2	Convert the framework into ratified policy; constitute governance; confirm bounded roles	Constitute Board; charter Committee and Unit; ratify catalog standard (PB1), eligibility clauses (PB2), FEFO standard (MB1), Inter-Lab Policy Framework; appoint roles incl. technician operational mandate; initiate change communication	Board (leads); Committee (drafts); departments (comment)	G1 — policy ratification: Board constituted; policy core ratified; roles appointed and communicated (cl. 5.3 analogue); risk register adopted	RR-01 (discharged); RR-02 (treatment opened); RR-05 (pre-emptive design)	KPI-G3 (audit cadence adherence activated)
2 — Catalog standardization and data onboarding	Months 3–4	Standardize records (PB1); populate shared registry; build competence	PB1 rollout in Biology Department; registry onboarding; EB2 data-quality baseline as first recorded measurement; role-based competence and awareness programme (cl. 7.2–7.3 analogues)	Unit (leads); Committee (supports); custodian departments (accountable); technicians (execute entries)	G2 — data readiness: onboarding complete for pilot scope; data-quality conformity per KPI-G2 and catalog coverage per KPI-G1 definitions	RR-03 (discharged); RR-04 (competence component discharged); RR-09 (baseline monitoring opened)	KPI-G1, KPI-G2
3 — Biology Department pilot and workflow testing	Months 5–6	Demonstrate workflow integrity under live operation in the embedded unit	Live loan workflows; custody-transfer protocol (EB3); FEFO execution (MB1) and expiry escalation ladder; continuity walkthrough (ISO 22301 cl. 8.5 analogue); qualitative pilot review	Custodian departments + Unit (execute); technicians (operate workflows); Board (reviews)	G3 — pilot workflow integrity: all workflow steps executed as designed; exceptions escalated and resolved; custody records complete; walkthrough conducted — qualitative criteria, no metric thresholds	RR-06 (discharged); RR-08, RR-10, RR-11 (first operational evidence)	KPI-O1–O4, KPI-E2, KPI-E3 (first measurements recorded)
4 — College-wide scaling	Continuous	Scale to all College of	Rolling departmental onboarding; audit	Board (gate authority,	G4 — digital platform readiness:	RR-15 (held); RR–	KPI-O1–O4; KPI–

Phase	Timeframe	Objectives	Key activities	Responsible bodies	Readiness gate + exit criteria	Linked risks (RR IDs)	Linked KPIs (KPI IDs)
and digital platform readiness gate		Science departments; institutionalize enforcement and improvement; hold the platform gate	cadence (EB1) and management review (cl. 9.2–9.3 analogues); continual improvement (cl. 10 analogues); G4 assessment against Unit requirements baseline	review); Unit (scaling certification, requirements baseline); Committee (standard revision); all departments	standardized processes, conformant data, demonstrated workflow stability and role competence per KPI–G6; releases platform procurement <i>consideration</i> only	05, RR–07, RR–09, RR–12, RR–13, RR–14 (standing governance)	E1–E4; KPI–G1–G6 (full dashboard)

Three features of the table warrant interpretation. First, **the gate column is the roadmap’s control column**: timeframes may flex under Board review, but gate criteria are structural conditions that may not, because acceleration cannot substitute for evidence (PMI, 2021). Second, **the risk column shows the two strata of [Section 2.9.2](#) behaving differently across phases**: transition risks (RR–01, RR–03, RR–06) appear once and are discharged by their gates, while operational risks (RR–05 through RR–15) reappear in [Phase 4](#) as standing entries — adoption risks are front-loaded and closable, operational risks perpetual and governable ([Section 4.3](#)). Third, **the KPI column shows measurement following capability, never preceding it**: indicators activate only when the activity they measure exists, so the dashboard grows with the framework — the measurement-and-review transition expressed as instrumentation rather than assumption ((Hillson, D. A., 1997; 14001 ISO/IEC, 2015), clause 9.1;(22301 ISO/IEC, 2019), clause 9.1).

4.5.7 Change Management and Barrier Mitigation

A roadmap that specifies activities and gates but ignores the human institution that must enact them would repeat the error the framework exists to correct: the diagnosis of Section 1 is, at root, a governance failure, not a logistics failure. The change-management and collaborative-governance literature identifies three institutional failure modes for reforms of

this kind, and this section matches each to its mitigation within the framework's own instruments — nothing here adds a new mechanism; change management is the deliberate operation of mechanisms already specified, read through the evidence on how such reforms fail (Dean et al., 2024; Sung & Kim, 2021; Vlachopoulos, 2021).

(a) Institutional inertia. Large public institutions absorb reform through routine: policies are acknowledged, then displaced by the prior default. The framework's first counter is **leadership sponsorship through the Board**, whose leadership chair, termly cadence, and risk-register ownership institutionalize sponsorship as a standing function rather than a personality-dependent enthusiasm — the condition the collaborative-governance literature identifies as decisive for cross-unit arrangements (Ahn & Baldwin, 2024; Lopes & Farias, 2022). The second counter is **Vision 2030 alignment as a legitimating frame**: fiscal efficiency, sustainability, and digital transformation are national priorities to which the host institution is explicitly committed, so the framework is legible to leadership as a contribution to commitments already made (Alamoudi et al., 2023; Alshammari, 2025). The third counter is **quick, visible wins through PB2 displacement**: the eligibility check's first effect — a duplicate purchase displaced because the registry showed serviceable stock elsewhere — is visible to exactly the departments asked to change their behavior, converting benefit from abstraction into a recorded event the Unit reports back to departments (Dean et al., 2024; Sönnichsen & Clement, 2020).

(b) Departmental silos. The decentralized regime's deepest habit is possession: departments experience shared visibility and lending as loss of control over "their" stock, and the sharing literature confirms that pooled-resource arrangements erode through free-riding, ambiguous responsibility, and perceived inequity when platform rules are weak (X. Wang & Qu, 2025; Zhu & Liu, 2021). The counter is the **stewardship-over-ownership design** ratified in [Phase 1](#), operated as an incentive structure rather than a slogan: loan limits protect the custodian's own teaching base; recall rights are absolute for scheduled

teaching, reflecting the ISO 22301:2019 priority of prioritized activities ((22301 ISO/IEC, 2019), clause 8.3); and the damage/loss liability principle with its chain-of-custody evidence ensures that lending does not transfer risk to the lender ([Section 4.1.6 \(e\)](#)). Benefit distribution is kept equitable by design — every department is simultaneously a potential borrower and a protected custodian, and the dashboard makes flows visible so that a disproportionate lending load can be remedied at Board review. These are the design cautions the sharing literature itself prescribes: participation survives where decision rights are renegotiated explicitly, protections are enforceable, and benefits are demonstrably reciprocal (Ahn & Baldwin, 2024; Gestel & Grotenbreg, 2021; X. Wang & Qu, 2025; Zhu & Liu, 2021).

(c) Compliance fatigue. The third failure mode is the slowest: procedural burden comes to be perceived as disproportionate to benefit, staff revert to informal practice, and the framework hollows out from within — the register’s RR-05 and the nominal-compliance theme of the higher-education change literature (Sung & Kim, 2021; Vlachopoulos, 2021). The counter has four components. First, **proportionate procedures integrated into existing roles**: auditability is embedded in workflows as automatic logging at the moment of action ([Section 4.1.1, Principle 4](#)), duties attach to roles staff already hold, and no new bureaucratic layer is created at the bench — technicians execute rotation, records, and escalation within their technical capacity and never carry administrative authority. Second, **competence and awareness building** as continuing practice rather than one-off training, per the clause 7.2–7.3 analogues of both standards (14001 ISO/IEC, 2015; 22301 ISO/IEC, 2019); the green-laboratory literature confirms that sustained awareness work, not rule density, changes laboratory routine (Fareed El-Tony & Choo, 2024). Third, a **communication structure** per the clause 7.4 analogues: the Unit’s reporting makes displaced purchases, redistributions, and loan activity visible to participants, so the benefit side of the burden-benefit perception is continuously evidenced ((14001 ISO/IEC, 2015), clause 7.4;(22301 ISO/IEC, 2019), clause 7.4;(Dean et al., 2024)). Fourth, **participation**

as resistance management: the evidence indicates that staff resist less when they hold genuine, bounded voice in a reform's operation — precisely what the escalation duty gives the operational level, a formal channel into governance without decision rights (Gestel & Grotenbreg, 2021; Lopes & Farias, 2022; Sung & Kim, 2021; Vlachopoulos, 2021).

The three failure modes share one property the framework exploits: each is **detectable before it is fatal**. Inertia appears as ratification delay (RR-01 against gate G1); silo behavior as withheld onboarding (RR-02 and RR-03 against gates G1–G2); fatigue as audit findings, data decay, and bypassed checks (RR-05, RR-07, RR-09 under standing surveillance by EB1 and EB2). Change management is therefore not a parallel program bolted onto the roadmap but the roadmap's risk register read from the human side — and the Board's termly review is where the two readings meet (Hopkin, 2018; 31000 ISO/IEC, 2018).

Phase 2 synthesis. [Phase 2](#) set out to subject the [Phase 1](#) design to evaluation before recommending adoption, and it closes with an interlocked answer. The feasibility assessment (Section 4) delivered a conditionally strong verdict whose conditions were named as the readiness gates G1–G4, answering research sub-question 2. The classified risk register ([Section 2.9.2](#)) derived fifteen traceable risks from the Bow-Tie architecture and the change literature, classified them under the FIRM taxonomy, and assigned each an owner and a barrier-reinforcing mitigation, completing the risk-classification component of research sub-question 2. The KPI dashboard ([Section 4.1.7](#)) converted the framework's load-bearing controls into defined indicators, completing the performance-indicator component of research sub-question 3 and operationalizing measurement-and-review without fabricating data. The present section has sequenced adoption as the ordered passage of the gates along the maturity trajectory, discharged and held the register's risks at their proper checkpoints, and specified the change-management operation of sponsorship, custodian protection, and proportionate procedure — answering research

sub-question 4's implementation component and completing Objective O4. Together, the framework, the feasibility verdict, the register, the dashboard, and the roadmap constitute a single governance loop — design, evaluation, risk control, monitoring, staged adoption — through which the College of Science can move its laboratory inventory regime from Inform/Conform toward Perform under evidence rather than assertion. The thesis is thereby positioned for its subsequent phases: institutional deliberation on ratification, and, should the gates be passed, the digital platform consideration that gate G4 deliberately reserves for a mature organization (Hillson, D. A., 1997; PMI, 2021; Rodríguez-Abitia & Bribiesca-Correa, 2021).

4.6 Executive Research Recommendations and Conclusion

This thesis moved from diagnosis to design, from design to evaluation, and from evaluation to sequencing: the decentralized laboratory inventory regime of a large public science faculty within a Saudi higher education institution was characterized as a Risk Maturity Gap (Section 1); an integrated framework was constructed to close it ([Section 2.9](#)); a three-tier governance architecture was specified to operate it ([Section 4.1](#)); feasibility was assessed as conditionally strong, gated by readiness gates G1–G4 (Section 4); transition and operational risks were registered, classified, and owned ([Section 2.9.2](#)); the barrier architecture was made observable through a defined dashboard ([Section 4.1.7](#)); and adoption was sequenced as the ordered passage of the gates ([Section 4.1.6](#)). The present section converts that cumulative argument into executive guidance addressed to three named audiences, each recommendation anchored to a specific framework element — a gate, a barrier, a risk-register entry, or an indicator family. Consistent with the study's binding methodology, no recommendation rests on empirical findings; each is a reasoned consequence of structural analysis, standards alignment, and verified literature (Hillson, D. A., 1997; PMI, 2021).

4.6.1 Synthesis of the Study's Argument

The thesis opened with a reframing: laboratory inventory failure is a governance problem with an inventory attached. Section 1 characterized the prevailing decentralized regime — each department keeping its own records, requisitions, and stock, with no shared visibility, no inter-laboratory coordination policy, and no standardized data structure — and derived its structural consequences: duplicate purchasing by default, depressed asset utilization, expired-chemical accumulation, and the absence of any organizational baseline for digitalization (Rodríguez-Abitia & Bribiesca-Correa, 2021; Strom et al., 2020; Tu & Greever-Wilson, 2025). Read against the adapted three-band maturity trajectory — *Inform/Conform* → *Managed/Normalized* → *Perform*, declared as adapted terminology anchored to (Hillson, D. A., 1997) levels and the CMMI/ISO capability scale (Paulk et al., 1993) — the regime sits in the Inform/Conform band while the institution's Vision 2030 and ISO-aligned ambitions presuppose Perform. That distance is the Risk Maturity Gap (Alamoudi et al., 2023; Bellantuono et al., 2021).

[Section 2.9.1](#) converted the diagnosis into an integrated framework of five analytical lenses: the adapted maturity model diagnosing capability; Bow-Tie analysis structuring threat-barrier-consequence pathways around two adapted Top Events — chemical expiration (TE1) and chronic asset underutilization (TE2) — with prevention barriers PB1–PB3, mitigation barriers MB1–MB3, and escalation-factor barriers EB1–EB3 (31010 ISO/IEC, 2019; Johnson et al., 2018); ISO 22301:2019 framing shared visibility and inter-lab loans as continuity strategies protecting prioritized activities through business impact analysis (BIA) and minimum acceptable capacity reasoning (22301 ISO/IEC, 2019); ISO 14001:2015, read with the university social responsibility (USR) literature, framing environmental and reputational outcomes (Ali et al., 2021; 14001 ISO/IEC, 2015); and the FIRM Scorecard used strictly as a classification taxonomy (Hopkin, 2018). [Section 4.1](#) answered the question the Bow-Tie method itself poses — who owns each barrier, and

with what authority — by specifying the Academic Inventory Governance Board, the Technical Standardization Committee, and the Digital Supply Chain Unit, with laboratory technicians executing bounded operational workflows under an explicit non-authority clause, the whole bound together by the Inter-Lab Policy Framework governing temporary asset loans and First-Expired-First-Out (FEFO) chemical redistribution ((Ahn & Baldwin, 2024; Gestel & Grotenbreg, 2021);(14001 ISO/IEC, 2015), clause 5.3;(22301 ISO/IEC, 2019), clause 5.3).

Section 4 assessed the design across organizational, financial, technical, and environmental dimensions and delivered the verdict of **conditionally strong** feasibility: no sub-criterion infeasible, every Conditional rating naming a condition within the college's own authority, and the single Contingent element — the smart-inventory platform — deliberately peripheral (Carpitella & Izquierdo, 2025; PMI, 2021). The conditions consolidated into four gates: G1 policy ratification, G2 data readiness, G3 pilot workflow integrity, and G4 digital platform readiness. [Section 2.9.2](#) registered fifteen risks (RR-01–RR-15) — six transition and nine standing operational — classified under FIRM, prioritized in verbal bands, and each assigned an owner and a barrier-reinforcing mitigation (Hopkin, 2018; 31000 ISO/IEC, 2018). [Section 4.1.7](#) defined a fourteen-indicator dashboard — operational KPIs O1–O4, environmental KPIs E1–E4, governance KPIs G1–G6 — under the definition-before-data principle: fully specified, with no baseline, numeric target, or result asserted ((14001 ISO/IEC, 2015), clause 9.1;(22301 ISO/IEC, 2019), clause 9.1). [Section 4.1.6](#) sequenced adoption in four phases — policy ratification (months 1–2, G1); catalog standardization and data onboarding (months 3–4, G2); the Biology Department pilot (months 5–6, G3); and college-wide scaling with the platform gate held on demonstrated maturity (continuous, G4) — discharging transition risks at their gates and governing operational risks through the standing dashboard (PMI, 2021; Takagi et al., 2024).

Read against the research questions and objectives of Section [1.4–1.5](#), the argument resolves as follows:

- **RQ1 / O1:** The decentralized regime can be characterized structurally as an Inform/Conform–band governance failure whose waste consequences and absent digitalization baseline are predictable outcomes of organizational design, not individual failure ((Hillson, D. A., 1997); Section 1).
- **RQ2 / O2:** Feasibility can be assessed qualitatively across four dimensions through structural analysis, standards conformity, and documented practice, yielding a conditionally strong verdict gated by G1–G4, and risks can be classified and prioritized without numeric scoring through Bow–Tie derivation, FIRM classification, and barrier–relative verbal bands ((Hopkin, 2018; 31010 ISO/IEC, 2019); Sections [4.2 – 4.3](#)).
- **RQ3 / O3:** The framework should specify the Board–Committee–Unit architecture with proportionate authority, the Inter–Lab Policy Framework with custodian protections, a strictly bounded technician operational mandate, and the fourteen–KPI dashboard as the measurement instrument ((14001 ISO/IEC, 2015), clause 5.3;(22301 ISO/IEC, 2019), clause 5.3; [Section 4.1](#), [Section 4.1.7](#)).
- **RQ4 / O4:** The roadmap should sequence the three maturity transitions — standardization, governance, measurement–and–review — as four gate–terminated phases, with digitalization released only after gate G4 confirms organizational readiness ((Rodríguez–Abitia & Bribiesca–Correa, 2021); [Section 4.1.6](#)).

4.6.2 Strategic Recommendations for University Leadership

Recommendation 1 — Ratify and sponsor the Academic Inventory Governance Board as a standing institutional organ. Organizational feasibility was rated Conditional on two decisions only leadership can take: constitution of the Board and ratification of the policy core (gate G1). The collaborative–governance literature is consistent that cross–unit

pooling arrangements succeed where decision rights are explicit and sponsorship is sustained, and decay where either lapses (Ahn & Baldwin, 2024; Lopes & Farias, 2022; X. Wang & Qu, 2025). Sponsorship is institutionalized in the framework as a standing function — the leadership chair, the termly cadence, and risk-register ownership (RR-01, RR-02, RR-05) — precisely so that it does not depend on individual enthusiasm (Dean et al., 2024).

Recommendation 2 — Hold gate G4: no smart-platform procurement precedes organizational maturity (RR-15). The digital-transformation and smart-inventory literatures converge on the finding that technology layered onto unstandardized processes and unclear roles reproduces fragmentation in digital form, and that automated tracking delivers value only where inventory processes and data semantics are already standardized (Bellantuono et al., 2021; Carpitella & Izquierdo, 2025; Rodríguez-Abitia & Bribiesca-Correa, 2021; Wilke et al., 2023). Leadership should treat any platform proposal arriving before the G4 readiness evidence — catalog coverage (KPI-G1), data-quality conformity (KPI-G2), functioning audit loops (KPI-G3-G4), and the consolidated readiness checklist (KPI-G6) — as a governance signal to decline, not a procurement opportunity to negotiate. G4 releases procurement *consideration*, not procurement itself, and provision remains Contingent on university-level information technology ([Section 4.4](#)).

Recommendation 3 — Align the framework with Vision 2030 and USR/sustainability reporting so that practice precedes disclosure. The framework is legible to leadership as a direct operational contribution to Vision 2030's expectation domains — fiscal efficiency (PB2), environmental sustainability (the MB1→MB2→MB3 control chain), and digital transformation readiness (the G4 discipline)(Alamoudi et al., 2023; Alshammari, 2025). The USR literature adds a reputational discipline: sustainability reporting in higher education is exposed to greenwashing critique wherever public claims outrun audited operations (Ali et al., 2021; Ceulemans et al., 2015; Lakhno, 2024). Sustainability

communication should therefore draw every claim from the registry, the disposal manifests, and the corrective-action record, keeping Reputational-category risks derivative of — and controlled through — the internal Financial and Infrastructure controls ([Section 4.2](#)).

Recommendation 4 — Fund coordination capacity rather than new bureaucracy. The framework was designed for fiscal neutrality: duties attach to existing roles, the registry runs on existing infrastructure, and technician duties are re-specifications of existing technical work ([Section 4.3](#)). What leadership must genuinely supply is transitional coordination capacity — drafting cycles, onboarding effort, competence delivery, audit execution — not new administrative headcount; bureaucratic accretion is a documented driver of compliance fatigue (Sung & Kim, 2021; Vlachopoulos, 2021).

Recommendation 5 — Institutionalize the audit cadence (EB1) and the annual management review. [Section 2.9.2](#) identified EB1 and EB2 as the architecture's load-bearing meta-controls, and RR-14 registers their failure mode: findings recurring without closure, converting enforcement into ritual. Both anchor standards supply the machinery — internal audit and management review (ISO 14001:2015 clauses 9.2–9.3; ISO 22301:2019 clauses 9.2–9.3, adopted by analogue) — operationalized as the Board's termly review and annual management review, monitored reflexively by KPI-G3 and KPI-G4. The cadence should be ratified as standing business with protected agenda time; an audit calendar that yields no review time re-creates escalation factor EF1 at the highest level (Johnson et al., 2018).

4.6.3 Recommendations for College Management (College of Science Deanship)

Recommendation 1 — Charter the Committee and the Unit promptly, in the same cycle as the Board's constitution (gate G1). Sequencing the charters together prevents the ratification bottleneck registered as RR-01, the highest-priority transition risk, and reflects the change literature's finding that reforms stall in the interval between announced

intent and constituted machinery (Dean et al., 2024; Vlachopoulos, 2021). Drafting cycles should be time-boxed with departmental comment windows, so that departmental voice is institutionalized inside the drafting process rather than expressed as resistance outside it ([Section 4.1.6](#)).

Recommendation 2 — Enforce the eligibility clauses (PB2) as non-negotiable from the first requisition cycle. PB2 is the framework’s primary fiscal barrier; RR-07 registers its bypass as a High-priority Financial-category risk plausible under normal operations. The sustainable-procurement literature documents visibility-and-eligibility discipline at the requisition point as the operative mechanism of redundant-acquisition displacement (Sönnichsen & Clement, 2020; Q. Wang et al., 2020). Enforcement is structural: the Unit’s certification power exercised without exception, repeated violations escalated to the Board, and KPI-G5 and KPI-O4 read jointly to confirm both that the check happens and what it displaces.

Recommendation 3 — Protect custodian rights as the design answer to silo resistance ([Section 4.1.6](#)). The counter to departmental silos is stewardship-over-ownership operated as an incentive structure: loan limits protecting the custodian’s teaching base, recall rights absolute for scheduled teaching — reflecting the ISO 22301:2019 priority of prioritized activities ((22301 ISO/IEC, 2019), clause 8.3) — and the damage/loss liability principle with chain-of-custody evidence ([Section 4.1.6 \(e\)](#)). Because pooled-resource arrangements erode through free-riding, ambiguous responsibility, and perceived inequity when rules are weak (X. Wang & Qu, 2025; Zhu & Liu, 2021), the deanship should defend these protections publicly and consistently; they are the instrument through which RR-02 is treated.

Recommendation 4 — Resource registry onboarding and technician competence building as first-order deliverables of [Phase 1](#)– [Phase 2](#). Gate G2 is the framework’s hardest early test: onboarding complete for the pilot scope and records conformant to the

catalog standard, verified through KPI-G1 and KPI-G2 — a visibly incomplete registry defeats the eligibility check by returning false absences (RR-03). Competence building follows the role-based onboarding and refreshers adopted from both standards (ISO 14001:2015 clauses 7.2–7.3; ISO 22301:2019 clauses 7.2–7.3), treating RR-04 before it can degrade the pilot.

Recommendation 5 — Respect pilot discipline: hold gate G3 on qualitative workflow integrity, not metric thresholds. G3’s exit criteria are deliberately qualitative — workflows executed as designed, exceptions escalated and resolved, custody records complete, the continuity walkthrough conducted — because imposing numeric thresholds on a pilot would manufacture the fabricated precision the methodology excludes and would corrupt the dashboard’s definition-before-data discipline ([Section 4.1.1](#)). The deanship should certify the documented workflow evidence, discharging RR-06 through demonstrated dispute-resolution integrity before any scaling decision ([Section 4.1.6](#)).

4.6.4 Recommendations for Laboratory Supervisory Personnel

Recommendation 1 — Operationalize FEFO rotation and custody-transfer protocols at the bench as routine, not as campaign. Mitigation barrier MB1 and escalation-factor barrier EB3 are enacted physically: date-checking, rotation, expiry labeling and flagging, condition records, and chain-of-custody logs (Durgan et al., 2023; Wilke et al., 2023). RR-08 registers FEFO drift as a High-priority risk whose failure is silent until expiry surfaces; the supervisory counter is accountability for rotation practice as standing business, audited under EB1 through KPI-O3 and KPI-E3, whose divergence triggers corrective action ((14001 ISO/IEC, 2015), clause 10).

Recommendation 2 — Develop technician competence strictly within the bounded operational mandate ([Section 4.1.5](#)). Supervisors should neither burden technicians with decisions beyond their technical capacity — no administrative decision-making,

procurement approval, financial authority, or policy-setting — nor strip them of the escalation voice the framework grants: responsibility-without-rights is a documented failure mode of participatory arrangements (Ahn & Baldwin, 2024; Lopes & Farias, 2022), while the bounded escalation duty is participation that is real but bounded (Gestel & Grotenbreg, 2021). Competence maintenance follows the clause 7.2–7.3 analogues of both standards (14001 ISO/IEC, 2015; 22301 ISO/IEC, 2019).

Recommendation 3 — Maintain escalation discipline through the ladder. The ladder — technician flags, the Unit routes and documents, the custodian supervisor decides, the Board adjudicates — mirrors the warning-and-communication logic of ISO 22301:2019 clause 8.4 (22301 ISO/IEC, 2019). Supervisors hold its decisive rung: an escalation absorbed informally destroys the documented information on which custody integrity and the loan-integrity risk family (RR-06, RR-10, RR-11) depend, enacting escalation factor EF3 in miniature.

Recommendation 4 — Own data quality at the point of entry: EB2 starts at the shelf. Registry data decay (RR-09) is the register's most dangerous operational risk because it degrades three barriers simultaneously (PB1, PB2, MB2). Records originate in technician entries at receipt, issue, transfer, and disposal; supervisory accountability for entry timeliness and standard conformity is therefore barrier work, not clerical supervision, and KPI-G2 carries the framework's highest monitoring intensity accordingly ([Section 4.1.7](#)).

4.6.5 Theoretical and Practical Contributions

The study's contributions can be stated in five bounded claims. First, it delivers an **integrated qualitative governance model for participatory laboratory inventory**: five analytical lenses — risk maturity (Hillson, D. A., 1997; Paulk et al., 1993), Bow-Tie analysis (31010 ISO/IEC, 2019), business continuity (22301 ISO/IEC, 2019), environmental management and USR (Ali et al., 2021; 14001 ISO/IEC, 2015), and the

FIRM taxonomy (Hopkin, 2018) — integrated so that each answers a question the others cannot. The four relevant literature streams — circular economy, green laboratories, equipment sharing, and digital readiness — rarely meet in one framework, almost never converge on educational rather than research laboratories, and are virtually absent from the Saudi and Gulf context; the model occupies that intersection (Alamoudi et al., 2023; Durgan et al., 2023; Kirchherr et al., 2017; Strom et al., 2020).

Second, the thesis contributes the **adapted three-band maturity trajectory as an assessment vocabulary**, explicitly declared as adapted terminology anchored to (Hillson, D. A., 1997) and the CMMI/ISO capability scale (Paulk et al., 1993); its practical value is that it converts reform sequencing into a maturity argument, naming standardization, governance, and measurement-and-review as the three transitions no procurement can replace. Third, it contributes the **bow-tie-to-governance ownership method**: the conversion of a barrier architecture into an organizational chart of accountability, with every barrier assigned a named owner and the register, dashboard, and gates traceable back to the same Bow-Tie structure — operationalizing the method's documented management value (Cormier et al., 2019; de Ruijter & Guldenmund, 2016).

Fourth, the thesis offers a **transferable template for Saudi and Gulf higher education**: written for a large public science faculty within a Saudi higher education institution, with a life sciences department as the embedded unit of analysis, its constructs transfer by reasoned analogy, consistent with analytic rather than statistical generalization (Knott et al., 2022; Takagi et al., 2024). Fifth, it contributes the **definition-before-data KPI philosophy as a design-phase measurement contribution**: fourteen indicators fully specified with no baseline, numeric target, or result asserted, so that measurement follows capability and never precedes it, and a future Perform-band claim would be substantiated by evidence rather than aspiration ((14001 ISO/IEC, 2015), clause 9.1;(22301 ISO/IEC, 2019), clause 9.1;(Rodríguez-Abitia & Bribiesca-Correa, 2021)).

4.6.6 Limitations and Future Research

The study's limitations follow from its deliberate design choices, and each defines a research direction. **Empirical validation after gate-governed implementation:** the framework is a design artifact; once the College passes gates G1–G3, the dashboard's established baselines and pilot workflow evidence become the record against which its structural claims can be tested, and [Section 2.9.2](#)'s verbal priority bands can be revisited with operating history (31000 ISO/IEC, 2018). **Cross-institutional comparative designs:** the single embedded case claims analytic generalization only; comparative qualitative designs across other faculties within the host institution, as well as other Saudi and Gulf institutions, would test the transferability claim (Knott et al., 2022; Takagi et al., 2024). **Digital platform evaluation once G4 opens:** once readiness is demonstrated, evaluation of barcode- and RFID-assisted tracking against the Unit's requirements baseline becomes both possible and necessary (Carpitella & Izquierdo, 2025; Maulana et al., 2023; Wilke et al., 2023). **Extension to research core facilities:** shared-instrumentation governance presents a cognate but distinct problem for which the core-facility literature provides a comparative base (Adami et al., 2021; Strom et al., 2020; X. Wang & Qu, 2025). **Longitudinal maturity assessment:** repeated assessment against the adapted bands across successive review cycles would convert the trajectory from a sequencing device into a validated construct and test whether the three named transitions are in fact the mechanisms of band movement (Hillson, D. A., 1997; Paulk et al., 1993).

4.6.7 Concluding Statement

This thesis set out to answer how an organizational framework for participatory inventory management in educational laboratories within a large public higher education institution in Saudi Arabia should be designed, assessed for feasibility and risk, and sequenced for implementation, so as to close the maturity gap between the prevailing decentralized regime and the institution's ISO-aligned, Vision 2030 ambitions. Its answer compresses into three propositions. First, participatory inventory management is a governance problem with an inventory attached: the duplicate purchases, idle instruments, and expiring chemicals of the decentralized regime are the predictable output of an organization that lacks shared visibility, standardized records, and allocated decision rights — and they will persist under any technology or exhortation that leaves that structure intact (Ahn & Baldwin, 2024; Hillson, D. A., 1997). Second, a qualitatively evaluated, gate-governed framework can be designed, risk-classified, and sequenced without fabricated evidence: the conditionally strong feasibility verdict, the fifteen-risk FIRM-classified register, the fourteen-indicator dashboard, and the four-phase roadmap demonstrate that design-phase rigor is achievable through structural analysis, standards alignment, and documented practice (Hopkin, 2018; PMI, 2021). Third, the institution's path from Inform/Conform to Perform runs through policy, standardization, and stewardship before technology: the readiness gates G1–G4 encode that ordering as enforceable checkpoints, and gate G4 stands as the framework's institutional memory of why it must hold (Carpitella & Izquierdo, 2025; Rodríguez-Abitia & Bribiesca-Correa, 2021). What the University is asked to adopt is not a system but a sequence — ratify, standardize, pilot, scale, and only then digitize — and what this thesis has supplied is the architecture, the evaluation, the risk map, the instruments, and the order in which that sequence can be walked under evidence rather than assertion.

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APPENDICES

Appendix A

The Inter–Lab Policy Framework

The **Inter–Lab Policy Framework** is the operative instrument of participatory inventory: the Board–ratified policy governing temporary inter–laboratory asset loans and FEFO–based chemical redistribution. It is the organizational form of mitigation barrier MB2 and escalation–factor barrier EB3, and the element that most directly engages the sharing–governance caution that pooled assets fail through ambiguous responsibility: every loan must therefore carry an explicit, documented allocation of custody at every state (Strom et al., 2020; X. Wang & Qu, 2025). The policy is specified in five components.

Eligibility and scope

The policy distinguishes *loanable* from *excluded* item classes. Loanable classes comprise durable instruments and equipment, glassware, and consumables whose transfer does not compromise their function, together with chemical stocks eligible for redistribution under the FEFO rules. Excluded are: controlled and regulated substances, whose movement is governed by external regulation and institutional hazardous–substance rules rather than by this policy; calibrated–critical instruments, whose relocation would invalidate calibration, unless the Committee has approved a specific transfer protocol for the instrument class; and items under active booking by the custodian’s own scheduled teaching, against which the custodian’s recall right applies ([Section 4.1.6](#) (Inter–Lab Policy Framework)). The classification is drafted by the Committee, ratified by the Board, and encoded in the registry by the Unit, so that eligibility is checkable at the moment of request rather than negotiable after it ((14001 ISO/IEC, 2015), clause 8.1;(Johnson et al., 2018)).

Loan request–approval workflow

The workflow is specified as numbered steps, each producing documented information at the moment of execution ((14001 ISO/IEC, 2015), clause 7.5):

1. **Registry availability check.** The borrowing laboratory’s designated staff query the shared registry for the required item class; the registry response — holdings, location, custody — is logged automatically. This is the eligibility clause (PB2) operating in its loan–direction mode.
2. **Borrower request.** The borrower submits a request stating item, quantity, purpose (course or protocol), requested duration, and collection arrangements; requests are routed to the custodian department, with the Unit copied for logging.
3. **Custodian approval.** The custodian department approves or declines under Board–ratified rules, weighing its own scheduled demand, item–class eligibility, and outstanding loan load. Approval authority rests with the custodian supervisor; technicians do not approve. Declined requests state the ratified rule applied.
4. **Loan terms.** An approved loan is issued with duration, a condition baseline (from [Section 4.1.6](#) (Scope & Eligibility)), and return criteria, logged in the registry by the executing technician.
5. **Execution and logging.** Technicians prepare, hand over, and log the loan per the custody–transfer protocol; the registry loan state moves to *on–loan* with custodian and borrower recorded.
6. **Return and closure.** On return, technicians perform the return–condition check and log closure or escalate damage; the loan state closes.

Custody transfer protocol

Custody transfer is the policy's evidentiary core, designed against escalation factor EF3 (custody ambiguity). Every handover is documented through three artifacts: a *condition record* (the item's state at transfer, constituting the condition baseline), a *custody acknowledgment* (the receiving party's signed or system-logged acceptance), and a *chain-of-custody log* (the time-ordered record of custody states from dispatch to return). The governing principle is that **custody is responsibility for care, not transfer of ownership**: the lending department retains ownership and stewardship, while the borrower holds custodial responsibility for the loan's duration ([Section 4.1.1](#), [Principle 2](#); (Zhu & Liu, 2021)). For chemical redistribution, the custody protocol operates jointly with FEFO: near-expiry stock moves first, so that a transfer is, where possible, a consumption transfer — the receiving laboratory consumes stock that would otherwise expire in the custodian's store (Durgan et al., 2023; Freese et al., 2024). Consumption transfers close without return; returnable transfers follow the full chain-of-custody cycle.

Responsibility tracking

The policy defines four custody states and assigns accountability in each: *in-custody* (custodian department accountable; technicians maintain records), *in-transit* (accountability assigned per the custody acknowledgment, defaulting to the borrower once logged), *on-loan* (borrower accountable for care, return, and damage reporting), and *returned-damaged* (an exception state triggering escalation, not informal settlement). Exceptions follow a defined escalation ladder — **technician** → **Digital Supply Chain Unit** → **custodian supervisor** → **Board** — with each rung activated when the lower rung cannot resolve within its authority: technicians' flag, the Unit routes and documents, the custodian supervisor decides within policy, and the Board adjudicates cross-departmental disputes ((22301 ISO/IEC, 2019), clause 8.4 analogue).

Risk controls

Five controls protect the lending regime. **First**, the *damage/loss liability principle*: the party holding custody when damage or loss occurs bears responsibility for remediation through departmental channels, with the chain-of-custody log as the evidentiary basis — a design response to the free-riding and responsibility-ambiguity failure modes of sharing arrangements (X. Wang & Qu, 2025). **Second**, *loan limits*: per-item-class caps on simultaneous outward loans protect the custodian's own teaching base. **Third**, *recall rights*: the custodian may recall loaned items when its own scheduled teaching requires them — the ISO 22301:2019 priority of prioritized activities over sharing convenience, since continuity solutions exist to protect prioritized activities, not to redistribute their dependencies away ((22301 ISO/IEC, 2019), clause 8.3). **Fourth**, the *audit trail*: every workflow step produces registry-logged documented information, so loans are reconstructible at audit without reliance on memory or email. **Fifth**, *review*: aggregate loan-flow and damage records feed the Board's termly review, closing the PDCA loop on the policy itself ((14001 ISO/IEC, 2015), clauses 9.3, 10). [Figure 3.4](#) renders the workflow and its escalation ladder.

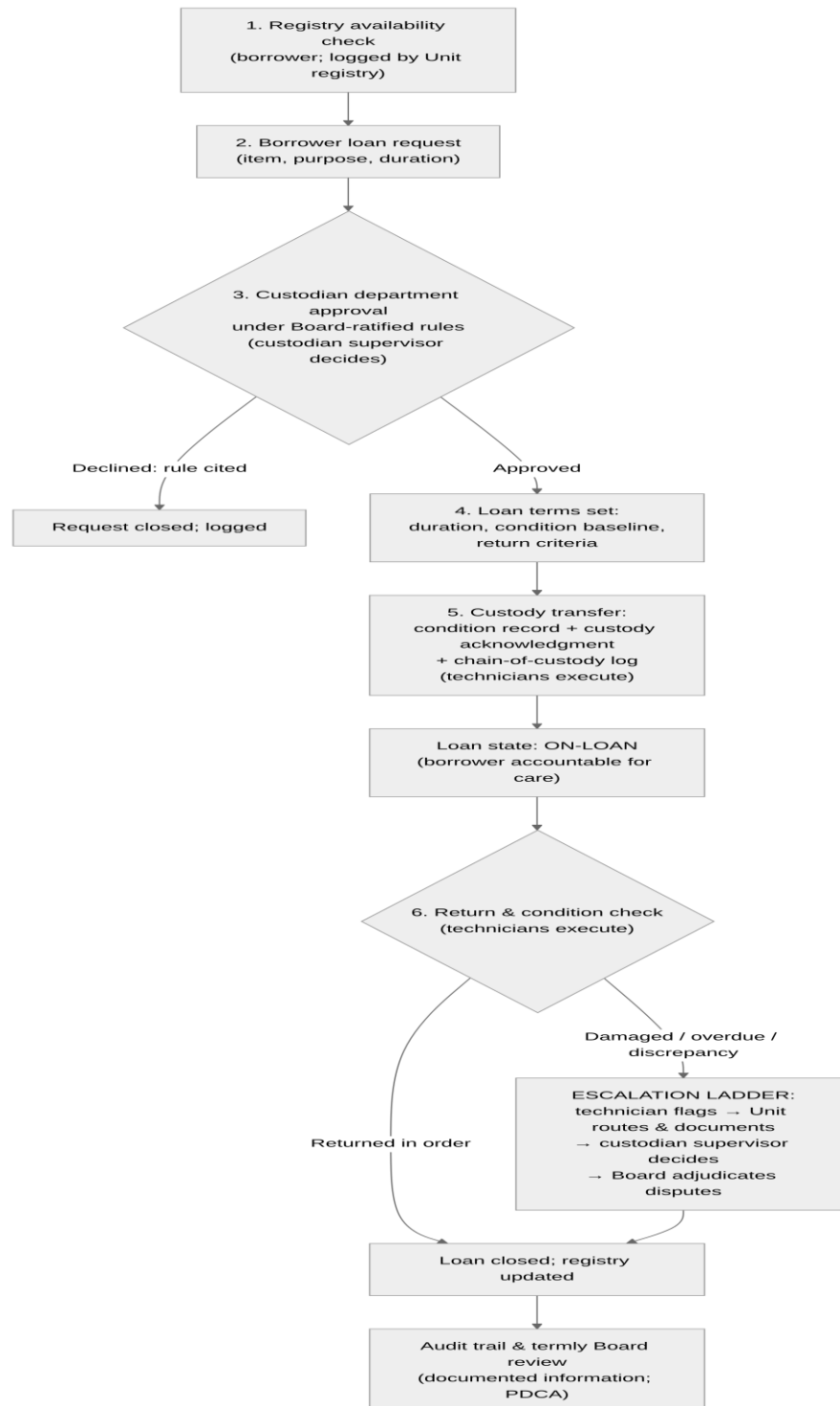


Figure 3.4. Inter-lab loan workflow and escalation ladder under the Inter-Lab Policy Framework (design specification; custody states and controls per [Section 4.1.6](#)).

Appendix B

Table 4.6. *Classified risk register for the participatory inventory framework (transition risks RR-01–RR-06; operational risks RR-07–RR-15)*

Risk ID	Risk description	FIRM category	Associate d Bow– Tie barrier	Risk owner	Qualitative priority	Specific mitigation strategy
RR-01	Policy ratification delay. The catalog standard, eligibility clauses, FEFO standard, and Inter-Lab Policy Framework stall in drafting or ratification, leaving the framework without enforceable content; traceable to the ratification–bottleneck theme in university change management (Vlachopoulos, 2021; Dean et al., 2024).	I	— (future PB1, PB2, MB1, EB3 left unratified)	Board	High — the entire barrier architecture depends on ratification; delay leaves every threat pathway open.	Readiness gate G1 (policy ratification) held as a hard checkpoint in the Section 4.1.6 roadmap; Board constitution scheduled first; drafting cycles time-boxed with departmental comment windows; Vision 2030 sponsorship framing to sustain leadership attention (Vlachopoulos, 2021).
RR-02	Departmental resistance to shared visibility and custody rules. Departments perceive the shared registry	I	— (future PB2, MB2 undermine d before deployme nt)	Board	High — plausible without adverse coincidence, since the decentralized regime’s siloed custody (T4) is the	Stewardship-over-ownership policy design: custodian protections codified in the Inter-Lab Policy Framework (loan limits,

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Risk ID	Risk description	FIRM category	Associate d Bow– Tie barrier	Risk owner	Qualitative priority	Specific mitigation strategy
	and loan regime as a loss of control over “their” stock and withhold participation or compliance; traceable to the resistance and trust–erosion themes in collaborative–governance scholarship (Ahn & Baldwin, 2024; Lopes & Farias, 2022).				framework’s direct target.	recall rights, liability principle); departmental representation on the Board; pilot–first gradualism to demonstrate benefit before scaling (Section 4.1.6 change–management structure; Dean et al., 2024).
RR–03	Incomplete or nonconforming data onboarding. Departmental inventories enter the registry partially, late, or off–standard, so the shared–visibility premise of the eligibility check is false from the start; traceable to the implementation–fidelity theme in	I	EB2 (with PB1, PB2 downstream)	Unit	High — a registry that is visibly incomplete defeats PB2 in practice, because checks return false absences.	Readiness gate G2 (data readiness) blocks pilot start until completeness and standard conformity are met; EB2 data–quality indicators (completeness, currency, consistency) operationalized from day one; Unit’s negative procedural power to decline certifying a check

Risk ID	Risk description	FIRM category	Associate d Bow– Tie barrier	Risk owner	Qualitative priority	Specific mitigation strategy
	educational change (Sung & Kim, 2021).					when data–quality rules are unmet (Section 4.1.4).
RR–04	Competence gaps in operational execution. Technicians and departmental staff lack trained familiarity with FEFO discipline, custody–transfer documentation, and registry standards at go–live, so correctly designed workflows are executed incorrectly.	I	MB1, EB3 (execution layer)	Custodian Department	Moderate — degrades execution but is correctable through the standards’ competence clauses before consequences propagate.	Role–based competence and awareness programme per ISO 14001:2015 clauses 7.2–7.3 and ISO 22301:2019 clause 7.2 (ISO, 2015; ISO, 2019): onboarding plus periodic refreshers administered by custodian departments with Unit support materials; training scheduled within the G2 phase of the roadmap.
RR–05	Compliance fatigue and procedural decay. Procedural burden (checks, logs, rotation discipline) comes to be perceived as	I	EB1 (with EF1 activated against PB2, MB1)	Board	Moderate — a slow–burn degradation caught by audit cadence rather than a discrete event.	Proportionate–procedure design (auditability embedded in workflows, not appended as reporting burden — Section 4.1.1 , Principle 4);

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Risk ID	Risk description	FIRM category	Associate d Bow– Tie barrier	Risk owner	Qualitative priority	Specific mitigation strategy
	disproportionate to benefit; staff revert to informal practice, hollowing out enforcement from within; traceable to the nominal–compliance theme (Sung & Kim, 2021; Vlachopoulos, 2021).					duties attached to existing roles; Board termly review of procedural burden; benefit communication through Unit reporting so that displaced purchases and redistributions are visible to participants (Dean et al., 2024).
RR–06	Custody disputes during the pilot. Early loans in the Biology Department pilot produce contested damage or responsibility claims before practice has settled.	I	EB3 (trial under load)	Custodian Department	Low — contained by the custody–transfer protocol’s evidentiary artifacts and bounded pilot scope; resolution path is protocolized.	EB3 custody–transfer protocol applied from the first loan (condition record, custody acknowledgment, chain–of–custody log); defined escalation ladder technician → Unit → custodian supervisor → Board; pilot exit criteria at G3 include demonstrated dispute–resolution integrity (Section 4 readiness gates).

Risk ID	Risk description	FIRM category	Associate d Bow– Tie barrier	Risk owner	Qualitative priority	Specific mitigation strategy
RR– 07	Eligibility–check bypass. Requisitions proceed without the mandatory registry check — through time pressure, habit, or deliberate circumvention — reactivating threat T1 and the duplicate–purchasing pathway.	F	PB2 (degraded by EF1)	Custodian Department	High — plausible under normal operations in a compliance–driven culture; defeats the framework’s primary fiscal barrier.	Barrier reinforcement: Unit verification of the documented check as a requisition precondition; EB1 audit cadence tests a sample of requisitions each term for check evidence; repeated violations escalate to the Board under Section 4.1.2 decision rights; operating criteria discipline per ISO 14001:2015 clause 8.1 analogue (ISO, 2015).
RR– 08	FEFO drift. Date–ordered rotation erodes into convenience picking, so earliest–expiring stock remains on shelves and the expiry pathway (T2 → TE1) reopens	F	MB1 (degraded by EF1)	Technicians (executive on–level owner; account ability rests with the custodian	High — the barrier lives or fails at the shelf; drift is silent until expiry surfaces.	Committee FEFO standard with labeling, date–marking, and expiry–flagging thresholds; technician escalation duty at defined thresholds; custodian supervisor accountability with EB1 audit of rotation

Risk ID	Risk description	FIRM category	Associate d Bow– Tie barrier	Risk owner	Qualitative priority	Specific mitigation strategy
	despite the standard’s existence.			n supervis or)		practice; competence maintenance per ISO 14001:2015 clause 7.2 (ISO, 2015; Durgan et al., 2023).
RR– 09	Registry data decay. I Entries lag events, records go stale, and the registry’s picture of holdings diverges from physical stock, blinding PB1, PB2, and MB2 simultaneously (EF2).		EB2 (degrading PB1, PB2, MB2)	Unit	High — data decay is the single escalation factor that degrades three barriers at once.	EB2 data–quality indicators monitored continuously by the Unit; technician entry discipline as barrier work (Section 4.1.5); Unit reporting of data–quality trends to the Board’s termly review; nonconformity–and–corrective–action loop per the ISO clause 10 analogue (ISO, 2015; ISO, 2019).
RR– 10	Loan integrity failure — damage, loss, or overdue return. Loaned items return damaged, are lost in transit, or are held beyond term, imposing remediation	F	MB2 (with EB3 as evidentiary control)	Custodi an Departm ent (technici ans execute records	Moderate — individual events are bounded, but recurrence would erode the trust on which MB2 depends.	Inter–Lab Policy Framework risk controls: damage/loss liability principle with chain–of–custody log as evidence; loan limits; recall rights; returned–damaged

Risk ID	Risk description	FIRM category	Associate d Bow– Tie barrier	Risk owner	Qualitative priority	Specific mitigation strategy
	burdens and deterring future lending; traceable to the free–riding and responsibility–ambiguity failure modes of sharing arrangements (Wang & Qu, 2025).			and flag exception ns)		exception state triggering escalation rather than informal settlement; aggregate damage and overdue records to the Board’s termly review (Section 4.1.6 (e); Wang & Qu, 2025).
RR– 11	Custodian recall conflicts. A custodian exercises its recall right while a borrower’s scheduled teaching depends on the loaned item, transferring disruption rather than relieving it.	M*	MB2 (recall–right control)	Board (adjudication of cross–departmental conflicts)	Moderate — infrequent by design but consequential for C3 when it occurs, since teaching is semester–locked.	Policy sequencing: custodian recall rights are absolute for scheduled teaching (ISO 22301:2019 priority of prioritized activities; ISO, 2019, clause 8.3); loan durations set against published teaching calendars at approval; conflicts escalate to the Board, whose adjudication precedent is logged to refine loan–term rules.
RR– 12	Expiry clusters. Multiple chemical	F	MB2 (capacity	Custodi an	Moderate — partially self–	Technician expiry–flagging at threshold

Risk ID	Risk description	FIRM category	Associate d Bow– Tie barrier	Risk owner	Qualitative priority	Specific mitigation strategy
	stocks approach expiry simultaneously — for example after a bulk purchase or semester–end course completions — exceeding the redistribution mechanism’s absorptive capacity and forcing disposal of usable stock.		exceeded; MB3 as fallback)	Departm ent	inflicted through procurement timing, hence controllable, but consequential for C1/C2 when realized.	(early–warning duty); Unit expiry–flag summaries give the Board forward visibility; MB2 redistribution prioritized for cluster items; PB3 joint/circular procurement rules reduce incoming volume bunching at source (Sönnichsen & Clement, 2020; Freese et al., 2024).
RR– 13	Disposal nonconformity. Expired or surplus chemicals enter disposal pathways outside the governed protocols — undocumented, mistimed, or routed through noncompliant channels — generating HSE exposure and	I	MB3	Committ ee (with the college safety and compliance officer)	Moderate — standing protocols exist, but disposal is episodic and easily bypassed under storage pressure.	MB3 governed disposal protocols with documented disposal records; redistribution–before–disposal rule (PB2 in its disposal–direction mode) checks live demand before any disposal; emergency–preparedness interface per ISO 14001:2015 clause 8.2 for

Risk ID	Risk description	FIRM category	Associate d Bow– Tie barrier	Risk owner	Qualitative priority	Specific mitigation strategy
	compliance–obligation breach.					degraded–stock discovery; evaluation of compliance obligations per clause 9.1.2 (ISO, 2015).
RR– 14	Audit–finding recurrence. The same nonconformities reappear across successive audit cycles because corrective actions are assigned but not closed, converting EB1 from a control into a ritual.	I	EB1 (self–referential failure of the meta–control)	Board	Moderate — indicates EF1 has colonized the enforcement layer itself; recoverable through the improvement loop if acted on.	Corrective–action tracking with named owners and closure evidence at each Board termly review, per the Annex SL clause 10 improvement logic (ISO, 2015; ISO, 2019); recurring findings escalated to the annual management review (clause 9.3 analogue); audit cadence adjusted toward repeat–finding domains.
RR– 15	Premature digital platform investment. Pressure to acquire a smart–inventory platform (barcode/RFID)	F	— (would bypass the Perform–band precondition)	Board (gate authority); Unit (readiness)	Moderate — high fiscal consequence if realized, but structurally preventable by holding the gate.	Readiness gate G4 (digital platform readiness) as a binding precondition: no platform procurement before

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Risk ID	Risk description	FIRM category	Associate d Bow– Tie barrier	Risk owner	Qualitative priority	Specific mitigation strategy
	before process standardization and role clarity are established, digitizing fragmentation and consuming budget without capability gain; traceable to the organization–before–technology finding of the digital–transformation literature (Rodríguez–Abitia & Bribiesca–Correa, 2021; Bellantuono et al., 2021).		on for platform value)	reportin g)		standardized processes, defined workflows, and role clarity are demonstrated; Unit maintains the requirements baseline so that when the gate opens, procurement targets organizational needs rather than vendor features (Carpitella & Izquierdo, 2025).

Appendix C

Table 12.4. Consolidated governance dashboard for the participatory inventory framework (directional targets: ↑ increase; ↓ decrease; E→I establish-then-improve; risk IDs per [Table 11.4](#))

KPI ID	Domain	Indicator	Measurement method	Data source	Owner	Frequency	Directional target	Linked barrier	Linked risk IDs
KPI-O1	Operational	Shared asset utilization	Qualitative reading of cross-lab loan events against custodian holdings	Unit shared registry (loan audit trail)	Unit (compiles); Board (reviews)	Termly	E→I	MB2	RR-10, RR-11
KPI-O2	Operational	Inter-lab loan cycle time	Trend reading of workflow timestamps (request-to-approval; handover-to-return)	Registry workflow logs	Unit (compiles); Custodian Dept (responds)	Termly	↓	EB3	RR-06, RR-10
KPI-O3	Operational	FEFO conformity rate	Structured shelf-audit observation against the FEFO standard checklist	Shelf-audit records; expiry-flag entries	Custodian Dept; Board via EB1	Each audit cycle	↑	MB1	RR-08, RR-12
KPI-O4	Operational	Duplicate-purchase displacement	Review of eligibility-check outcomes (proceed vs. displaced)	PB2 eligibility-check records	Unit (certifies/compiles); Board	Termly	E→I	PB2	RR-07

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KPI ID	Domain	Indicator	Measurement method	Data source	Owner	Frequency	Directional target	Linked barrier	Linked risk IDs
KPI-E1	Environmental	Hazardous waste reduction	Qualitative trend of governed disposal manifests with composition commentary	MB3 disposal manifests	Committee (safety interface); Board	Termly; annual consolidation	↓	MB1, MB2, MB3	RR-12, RR-13
KPI-E2	Environmental	Pre-expiry redistribution rate	Balance of executed pre-expiry redistribution s vs. expiry write-offs	MB2 custody logs; expiry-flag histories	Unit (compiles); Custodian Dept	Termly	↑	MB2	RR-09, RR-12
KPI-E3	Environmental	Expired-stock incidence	Joint reading of expiry flags and audit expiry observations per cycle	Registry expiry flags; shelf-audit records	Custodian Dept; Committee	Each audit cycle; termly summary	↓	MB1	RR-08, RR-12
KPI-E4	Environmental	Disposal-protocol conformity	Conformity assessment of disposal documentation; cl. 9.1.2 evaluation analogue; cl. 8.2 exercise note	MB3 disposal records; evaluation and exercise documentation	Committee with safety and compliance officer	Each audit cycle; annual consolidation	↑ (then hold)	MB3	RR-13, RR-14
KPI-G1	Governance	Catalog standardization coverage	Census of records conforming to the catalog	Registry onboarding records	Unit	Termly during onboarding; on	↑ (toward G2 criterion)	PB1	RR-03

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KPI ID	Domain	Indicator	Measurement method	Data source	Owner	Frequency	Directional target	Linked barrier	Linked risk IDs
			standard vs. legacy records			change thereafter			
KPI-G2	Governance	Registry data-quality conformity	EB2 completeness, currency, and consistency checks; spot checks vs. physical stock	Registry; EB1 spot checks	Unit	Continuous; termly reporting	↑ (then hold)	EB2	RR-03, RR-09
KPI-G3	Governance	Audit cadence adherence	Planned vs. executed audits, with deviation causes recorded	EB1 audit programme and outputs	Board	Termly; annual confirmation	E→I	EB1	RR-05, RR-14
KPI-G4	Governance	Audit-findings resolution	Findings tracked open / carried-over / closed; recurrence flagged (cl. 10 analogue)	Corrective-action records	Board	Termly; annual consolidation	↑ closure; ↓ recurrence	EB1	RR-14
KPI-G5	Governance	Eligibility-check execution	Audit test of requisition files for certified check evidence	Requisition files; Unit certification logs	Custodian Dept; Board	Each audit cycle	↑	PB2	RR-07

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KPI ID	Domain	Indicator	Measurement method	Data source	Owner	Frequency	Directional target	Linked barrier	Linked risk IDs
KPI-G6	Governance	Digital readiness gate status	Checklist assessment (met / partially met / not met) across data standards, process stability, role competence	Unit requirements baseline; dashboard evidence	Unit (maintains); Board (gate authority)	Termly; singular gate decision	E→I	G4 gate (Performance precondition)	RR-15

Appendix D

Table 7.4. *RACI-style accountability matrix for key framework processes*

Process	Governance Board	Technical Standardization Committee	Digital Supply Chain Unit	Custodian Department	Laboratory Technicians
Catalog standard– setting	A (ratifies)	R (drafts, maintains)	C (registry feasibility)	C (departmental comment)	I
Eligibility check before requisition	I	A (clause owner)	R (operates/verifies check)	C (must comply)	C (data accuracy)
Loan approval	I	I	C (logs; data support)	A/R (custodian supervisor approves)	I (no approval role)
FEFO execution	I	C (standard owner)	I (flag reports)	A (supervisor accountable)	R (rotation, flagging)
Custody transfer	I	I	C (chain-of– custody log)	A	R (records, handover)
Registry upkeep	I	C (data standard)	A (stewardship)	C	R (entries)
Expiry escalation	I	I	A (routes, coordinates)	C (decides redistribution)	R (flags, escalates)
Audit & management review	A/R (cadence, review)	C	R (reporting support)	C	I

Table 4.2. *Barrier–ownership mapping from the [Section 2.9.3](#) Bow–Tie architecture to [Section 4.1](#) bodies*

Barrier (Section 2.9.3)	Organizational owner	Execution level
PB1 Standardized catalog & records	Technical Standardization Committee	Technicians (entries); Unit (registry)
PB2 Eligibility clauses	Committee (drafts); Board (ratifies)	Unit (check operation); custodians (compliance)
PB3 Joint/circular procurement rules	Board (ratifies); Committee (drafts)	Departments, via Unit procurement liaison
MB1 FEFO rotation	Committee (standard); custodian supervisor (accountable)	Technicians (rotation, flagging)
MB2 Inter–lab sharing / redistribution	Board (Inter–Lab Policy Framework)	Custodians (approval); technicians (execution)
MB3 Governed disposal protocols	Committee, with safety & compliance officer	Departments under Unit reporting
EB1 Audit cadence	Governance Board	Unit (reporting support)
EB2 Data–quality indicators	Digital Supply Chain Unit	Technicians (entry discipline)
EB3 Custody–transfer protocol	Board (policy); Committee (protocol content)	Technicians (condition records, logs)