Industrializing electricity grid expansion through asset standardization

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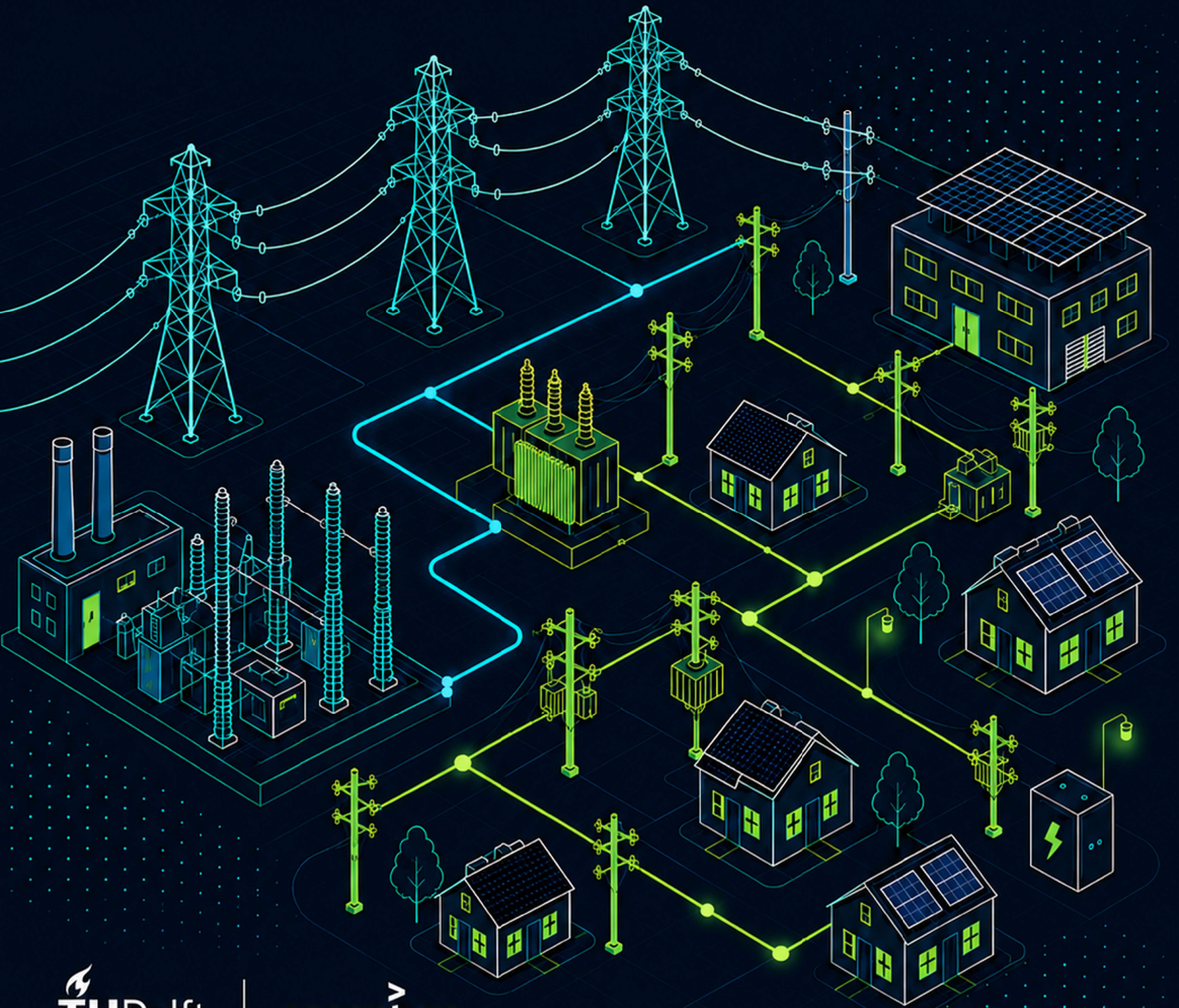

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Industrializing electricity grid expansion through asset standardization

An empirical study of governance and organizational conditions for implementing internal asset standards in Dutch LV-MV distribution networks

by

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Executive summary

The Dutch electricity distribution network is under severe and accelerating expansion pressure. Network-tariff regulator ACM projects a doubling of low- and medium-voltage (LV/MV) grid capacity over the next two decades, against a backdrop of grid-congestion queues, deferred connection requests, and acute workforce shortages in engineering and execution. Distribution system operators (DSOs) respond by industrializing the way they design, procure and construct grid assets, with internal asset standardization promoted as the central lever. Yet, despite a decade of programmatic effort, the depth and consistency with which standards are actually implemented varies substantially across DSOs and asset classes, and the conditions that explain this variation are poorly understood. This thesis treats standardization not as a self-evident solution but as a conditional practice whose outcomes depend on governance and organizational context. It asks: *How do organizational structure and governance design shape the implementation of internal asset standards in Dutch DSO LV/MV grid construction projects?*

A four-phase qualitative design addresses this question. Phase 1 establishes sensitizing concepts through a PRISMA-guided systematic literature review and five expert interviews with sector consultants. Phase 2 conducts a comparative case study of three Dutch DSOs, with two embedded standardization programs each, six cases in total, spanning low, semi- and very-high asset complexity. Phase 3 synthesizes the case material thematically and across dimensions of complexity and organizational structure, and Phase 4 validates the resulting propositions in a structured session with senior practitioners from the three DSOs. The three DSOs together cover approximately 90% of the Dutch distribution network, which supports analytic generalization to the Dutch sector while constraining statistical generalization beyond it. Because all six programs are ongoing rather than completed, findings are framed throughout as practitioner-perceived outcomes from operating programs rather than as verified causal effects.

The single variable that best explains differences in implementation depth across the six cases is not asset complexity, program size or engineering effort, but the completeness of the surrounding governance architecture. The case evidence suggests that the three tiers are individually necessary and jointly associated with high implementation depth within the observed portfolio. A normative tier establishes the standard as authoritative and assigns ownership. A procedural tier operationalizes that commitment through cross-functional pre-authorization, change management, and a formal deviation pathway. A structural tier converts compliance from a behavioral obligation into a system default, through IT-mediated ordering, supply-chain lead-time asymmetry, or procurement integration that makes the standard configuration easier to obtain than any alternative. Programs operating all three tiers achieve substantially deeper and more stable implementation than those relying on normative and procedural mechanisms alone. The matching logic this thesis labels *governance-as-fit*: the appropriate architecture is not universally fixed but is calibrated to the asset complexity profile and to the organization's baseline of fragmentation.

One additional structural context factor, next to asset complexity and organizational fragmentation, raises the governance demand that any given program must meet. Inherent variability arises from grid history, site conditions, municipal interface demands, regulatory and technological discontinuities, and project-type asymmetries. Inherent variability cannot be designed away; the appropriate response operates on two levels jointly designed at the specification stage. Foreseeable variation is internalized into the standard as a bounded variant menu; genuinely residual variation is governed through a standardized deviation pathway that places the burden of proof on the requester. The most successful programs operate both layers deliberately and govern them through the same three-tier architecture. Two further conditions shape how depth matures across procurement cycles. Measurement infrastructure for benefits and compliance is absent across the three DSOs, leaving the feedback channel between operational deployment and the next specification round dependent on qualitative deployment experience alone; this gap is uniform across cases and structurally consistent with construction-sector findings from a quarter-century earlier, suggesting it is a structural feature of internally developed standardization rather than a maturity-stage artifact. Sequencing, in turn, determines whether urgency is productive or corrosive: governance infrastructure built before volume scales converts urgency into accelerated adoption, while the reverse order produces the deviations and rework that govern much of current sector experience.

For DSO program managers, seven practical prescriptions follow. Establish the full three-tier governance architecture before volume-scale deployment, with senior organizational mandate sought before execution rather than retrospectively. Prefer institutional compliance mechanisms over behavioral mechanisms, because behavioral mechanisms degrade under turnover and peak workload in ways that institutional ones do not. Anchor the standard procurement-side by co-tendering with operations, supply-chain management and procurement, so that the implementation chain holds ownership at the moment of commitment rather than receiving it afterwards. Design the standard for change through interface-level specifications and verifiable test protocols, since specifications that bind only specific components or that lack proof-of-compliance procedures convert routine supplier and field variation into delivery-blocking deviations. Manage the implementation chain through fixed release cycles aligned to contractor planning rhythms, with a dedicated change-management interface. Sustain the program through paired investment in measurement infrastructure, knowledge management, and cross-program interface coverage. Design the architecture for cross-cycle adaptation rather than for permanence, with explicit reassessment points after every two to three procurement cycles. Academically, the thesis contributes to three pre-specified literature streams: it specifies the institutional architecture required for sustained implementation depth in construction industrialization and capital-project standardization; it disaggregates the implementation-climate construct from innovation diffusion and implementation theory into three structurally distinct compliance substrates that fail and recover independently; and it introduces a dual-moderator structure to contingency theory and organizational design in which asset complexity and organizational fragmentation jointly define governance demand, with organizational growth rate identified as a novel third contingency variable. Internal asset standardization can materially support the industrialization of grid construction, but only when governance architecture is designed to match the complexity of the assets and the fragmentation of the organizations that deploy them.

Preface

Writing these introductory words after writing the many pages that follow gives me the chance to reflect, express appreciation, and apologize for the lengthy piece you are about to read. I could, of course, spend pages contemplating, however, I will keep short via two main messages: thanking the people who supported the thesis process, and a short personal reflection.

This thesis was written as part of the Management of Technology program at TU Delft and during an internship at Accenture Industry X, in collaboration with Dutch distribution system operators. I am grateful to my TU Delft and Accenture supervisors: Toyah Rodhouse, Martijn Leijten, and Geerten van de Kaa, for their ideas, guidance, and occasional gentle pushback. Julia Vermaas and Yannick Baudet provided empathetic and personal daily supervision (and fun). I thank all interview participants and their organizations for their time, effort, and willingness to share insights, as well as my fellow Accenture colleagues for a good time at the office and a lot of free coffee.

On a personal note, although this was my second thesis and therefore often accompanied by a certain thesis déjà-vu, I still look back at the Management of Technology program as a valuable choice. It broadened my interests and set me up for the professional path I will start next. The energy sector can use all the help it can get, so I hope this thesis adds, in a small way, to that development. Finally, I want to thank my family, and my parents in particular, for their unconditional support, also during the sometimes shaky last year.

Happy reading.

Rutger Blijleven
June 2026

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List of Abbreviations

Abbreviation	Full term
ACM	Autoriteit Consument & Markt (Dutch Authority for Consumers and Markets, the regulator overseeing Dutch network tariffs)
AM	Asset Management (organizational function within a DSO)
BEDD	Basic Engineering Design Data
BIM	Building Information Modelling
BoD	Board of Directors
CAM	Compact Aansluit Module (Compact Connection Module; jointly adopted by the three large Dutch DSOs)
CENELEC	European Committee for Electrotechnical Standardization
CII	Construction Industry Institute (US-based industry research consortium)
CMT	Contract Management Team (DSO-C governance body)
CODP	Customer-Order Decoupling Point
CPO	Charge Point Operator
CSF	Critical Success Factor
D1BM	Design One, Build Many
DSO	Distribution System Operator (the regulated regional network operator)
ElaadNL	Dutch knowledge and innovation centre for charging infrastructure, host of the federated CAM specification authority
EPC	Engineering, Procurement and Construction (a delivery-contract form in capital projects)
ERP	Enterprise Resource Planning (system class)
ETO	Engineer-to-Order (production strategy along the CODP axis)
EU	European Union
FTE	Full-Time Equivalent (workforce-size metric)
HV	High-Voltage (transmission-level grid above approximately 50 kV)
HREC	Human Research Ethics Committee (TU Delft)
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
KPI	Key Performance Indicator
LV	Low-Voltage (distribution-level grid below 1 kV)
MDT	Multi-Disciplinary Team (DSO-A governance body)
MFT	Multi-Functional Team (DSO-B governance body)
MOT	Management of Technology (the MSc program at TU Delft within which this thesis was written)
MTO	Make-to-Order (production strategy along the CODP axis)
MTS	Make-to-Stock (production strategy along the CODP axis)
MV	Medium-Voltage (distribution-level grid between approximately 1 kV and 50 kV)
MV-LV	Medium-Voltage to Low-Voltage (typical scope of distribution stations)
MV-MV	Medium-Voltage to Medium-Voltage (typical scope of transport-distribution stations)
NEN	NEderlandse Norm (Dutch national standards body)
NPV	Net Present Value
OIV	Operationeel Installatieverantwoordelijke (DSO statutory role for safe network operation)
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses (protocol used for the SLR in this thesis)
QCA	Qualitative Comparative Analysis
R&D	Research and Development
RAL	Reichs-Ausschuß für Lieferbedingungen (international color-code system referenced in cable specifications)

Abbreviation	**Full term**
RMU	Ring Main Unit (medium-voltage switchgear component within a distribution station)
RT-UMM	Research Team UMM-01 of the CII, focused on facility standardization in capital projects
RTU	Remote Terminal Unit (substation telemetry component)
SCM	Supply Chain Management (organizational function within a DSO)
SF_6	Sulfur hexafluoride (insulating gas in legacy MV switchgear; phased out under EU F-Gas Regulation 2024/573)
SLR	Systematic Literature Review
SRM	Strategic Resource Management (DSO procurement-enforcement function)
TE	Technische Expertise (DSO technical-expertise function holding the OIV role)
XLPE	Cross-Linked Polyethylene (cable-insulation material)
Study-internal identifiers	
M1	Standardization mechanism 1: design reuse (see Chapter 3)
M2	Standardization mechanism 2: procurement scale economies
M3	Standardization mechanism 3: schedule control
M4	Standardization mechanism 4: quality consistency
M5	Standardization mechanism 5: learning and portfolio improvement
SQ1	Sub-question 1 (literature mechanisms and contextual factors)
SQ2	Sub-question 2 (standardization forms and perceived outcomes)
SQ3	Sub-question 3 (cross-DSO patterns of convergence and divergence)
SQ4	Sub-question 4 (organizational structure and governance design)
DSO-A/B/C	The three anonymized Dutch DSO cases studied in this thesis

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Introduction

This chapter establishes the scholarly and practical motivation for the thesis. It opens by contextualizing the urgency of electricity grid expansion in the Netherlands and the structural tensions that make project-level acceleration difficult. It then introduces the concept of internal asset standardization and delimits how that concept is used in this study, before reviewing the adjacent literatures, identifying the theoretical niche this research occupies, and naming the three literature streams to which it contributes. A problem statement, research objective, and central research question with sub-questions follow. The chapter concludes with a brief account of the company context in which the study was conducted and a roadmap of the chapters that follow.

1.1. Electricity grid expansion in the Netherlands

The acceleration of electricity grid expansion has become a critical bottleneck in the energy transition across Europe, and the Netherlands exemplifies this challenge (Butorac, 2025). Over 14,000 companies are currently waiting for new or expanded electricity connections (Hermans, 2025), while congestion persists despite billions in infrastructure investments (Bergshoef, 2025). Construction timelines for high-voltage substations average 10–12 years, yet only approximately 30% of this time involves actual construction; the remainder is consumed by permitting, planning, and coordination processes (Bergshoef, 2025). This pronounced gap between calendar time and productive work time points to structural inefficiencies in the organization and design of grid expansion projects, inefficiencies that regulatory reform alone is unlikely to resolve.

In the Netherlands, legislative efforts have targeted the procedural component of these delays. Electricity grid expansion is now classified as a matter of *zwaarwegend maatschappelijk belang* (overriding public interest), which shortens legal procedures by directing appeals to the Council of State rather than lower courts, reducing delays by up to 1.5 years (Netbeheer Nederland, 2025). A further legislative amendment introduces a standard tolerance obligation, enabling grid operators to conduct soil and ground studies without landowner consent and thereby eliminating procedural obstacles that previously caused delays of two to eighteen months (ANP, 2025). These interventions reduce friction in the permitting environment; they do not, however, address the project-internal sources of variation and inefficiency that govern the remaining 70% of construction timelines.

Less well studied is whether and how distribution system operators (DSOs) themselves can reduce project-to-project variability in their own design, procurement, and execution processes. This is a non-trivial question. DSOs operate within a multi-level technical system in which choices made upstream, by transmission system operators such as TenneT and by international normative bodies setting equipment standards, constrain the design space available at the distribution level. What a DSO can standardize is itself shaped by what the overlying system has already fixed: voltage levels, protection philosophies, interface specifications, and equipment qualification requirements all arrive as boundary conditions rather than free design variables. This hierarchical embeddedness means that internal standardization in DSOs is structurally more constrained than standardization in, for example, modular housing or industrial facilities, and that its feasibility and limits are partly determined by factors outside the DSO's direct control.

Within the space that remains, standardization of physical assets has emerged as one candidate mechanism for accelerating project delivery. Standardization is here understood as the deliberate reduction of design variety through the repeated use of common components, station configurations, and cable families. In sectors such as manufacturing and modular construction, standardization of components and processes has been associated with shorter lead times, improved scalability, and lower unit costs (Bacchiocchi et al., 2019). Analogous initiatives are visible in grid infrastructure: TenneT's modular substation program for high-voltage assets reports accelerated design, procurement, and construction delivery through standardized 380 kV substation modules, with 80% of engineering work targeted for completion via standard design modules by the end of 2024 (Tennet, n.d.). The programmatic stance behind such rollout efforts is documented in adjacent research: Steekelenburg (2024) confirms across the three large Dutch DSOs that a *neighborhood-oriented* approach and a *solo-tenzij* (solo-unless) operating principle are the dominant external-rollout postures, deliberately prioritizing speed and standardization over case-by-case adaptation. The internal organizational and governance conditions that make this posture deliverable in practice, however, remain understudied.

Standardization is not, however, an unambiguous solution. The same mechanisms that can reduce lead times and unit costs also create risks: rigidity when site conditions deviate from the standard design, lock-in when technologies or regulations change, supplier dependency when a limited product catalog concentrates procurement power in a small number of vendors, and cultural resistance when engineers perceive standardized designs as constraints on professional judgment (Aapaoja & Haapasalo, 2014; Choi et al., 2022). Whether standardization delivers net benefits in a given context depends on how it is governed and implemented, not on the quality of the standard design alone. This thesis therefore approaches standardization not as a solution to be optimized but as a practice whose outcomes are shaped by the organizational conditions in which it operates.

Industry actors increasingly point to internal asset standardization as a key lever for scalable grid expansion, yet the mechanisms through which it is expected to accelerate delivery, and the conditions under which those mechanisms actually operate in LV/MV distribution contexts, remain conceptually under-developed and empirically undocumented. This thesis addresses that gap.

1.2. Defining internal asset standardization

Standardization encompasses multiple interpretations and applications; it is therefore necessary to clarify how the concept is understood and applied within this thesis.

In general, standardization refers to the introduction of agreed-upon norms, designs, or processes intended to reduce variation and facilitate coordination among actors. This research focuses specifically on *internal asset standards*, which operate at the organizational or inter-organizational level and govern the design and realization of specific physical assets, such as standardized transformer station designs used by grid operators. These internal standards do not replace external industry standards such as NEN or IEC norms; rather, they build upon them by filling the gaps that external norms leave open. Individual components of a grid asset may each carry their own international equipment standards, yet no external norm governs how those components are combined, dimensioned, and configured into a complete, deployable asset. DSOs therefore layer their own specifications on top of existing component norms, prescribing configurations, interfaces, and performance requirements particular to their network and operational context, thereby transforming a collection of individually certified components into a repeatable, organization-specific asset standard.

In classical standardization literature, a commonly used classification adapted from Swann (2010) distinguishes five categories of standards: safety standards, compatibility (interface) standards, quality standards, information and measurement standards, and variety-reducing standards. Standardization in DSOs has historically focused on safety, quality, and compatibility to ensure reliable system operation and effective collaboration with manufacturers. The conceptualization adopted in this thesis incorporates a stronger emphasis on *variety reduction*: the objective is not only to maintain safe and well-functioning assets, but also to achieve economies of scale, reduce construction time, and lower labor requirements during asset realization.

Unlike the external, market-competing standards examined in classical standardization theory, such as the USB interface standard studied by Blind (2004), DSO asset standards are owner-created and organizationally maintained. They take the form of *living catalogs*: dynamic collections of approved components and design configurations that accommodate variation through controlled exceptions and evolve continuously in response to changes in regulation, supplier markets, and site conditions. This adaptive character distinguishes them from the fixed, committee-ratified norms of classical standardization theory and is consistent with construction industrialization's focus on repeatable project delivery rather than market adoption (Gibb & Isack, 2001). It also reflects a structural feature of infrastructure governance: DSOs operate in heterogeneous and changing environments, and their standards must remain responsive to that heterogeneity. This responsiveness is precisely what makes implementation, understood here as the organizational process of getting projects to use the standard consistently, analytically interesting and practically challenging.

1.2.1. Standards in construction and capital projects

Although literature specifically addressing asset standards in electricity grids is scarce, standardization in construction has been researched for several decades. A widely used definition in this domain describes standardization as "the wide use of components, parts, procedures, or processes in which there is regularity, repetition, and a successful practice and predictability" (Gibb, 2001). While technical standards form the main focus of this thesis, their effective implementation requires the adoption of standardized processes to support consistent design, execution, and replication (Gibb, 2001).

The construction industry often draws inspiration from manufacturing, gradually adopting a more product-oriented logic, a trend broadly referred to as industrialization. Within this context, standardization is typically divided into process and product dimensions, with product standardization ranging from using standard building modules to replicating entire housing designs. Standardization is widely considered an essential enabler of industrialization, and is often discussed alongside closely related concepts such as prefabrication, pre-assembly, and modularization.

Importantly, construction and capital-project literature consistently portrays standardization as a double-edged strategy. Mechanisms such as design reuse, scale economies in procurement, and schedule control can deliver substantial benefits, but they operate only when specific implementation conditions are in place: clear governance ownership, early stakeholder alignment, disciplined change management, and technical designs that accommodate the variation inherent in real sites (Choi, Shrestha, Kwak, & Shane, 2020a; Gibb, 2001). Where these conditions are absent, the same standardization programs that promised efficiency can generate rigidity, supplier dependency, and professional resistance (Aapaoja & Haapasalo, 2014; Choi et al., 2022). Empirical work in capital projects consistently reports that observed standardization levels fall short of program targets, with the shortfall attributed to weak planning, governance, and implementation support rather than to design quality (Choi, Shrestha, Kwak, & Shane, 2020a). This conditionality, namely the observation that standardization benefits are not fixed properties of a design but emerge from the interaction between a standard and its implementation context, is the central intellectual problem that this thesis examines in the DSO setting.

In construction and infrastructure, standardization is typically studied as an integrated managerial strategy, addressing drivers, barriers, and critical success factors that simultaneously capture motives for adopting standardization and conditions for implementing it effectively across projects (Choi, Shrestha, Kwak, & Shane, 2020a; Gibb, 2001). The literature rarely distinguishes explicitly between adoption decisions and subsequent implementation processes, particularly when standards are internally developed by client organizations (Gibb & Isack, 2001). This construction and capital-project literature provides the closest conceptual parallel to DSO asset standards, which are internally developed templates for repeat project delivery, though DSOs face unique regulatory, network-integration, and public-stakeholder constraints that construction studies have not examined.

1.2.2. Standards in this research

While the core idea of standardization is similar to that used in the construction sector, its application in electricity grid expansion differs in several important ways. Grid operators are not-for-profit organizations, operate under different production and procurement logics, and engage with clients (e.g. end users or municipalities) through largely regulatory rather than market relationships. These characteristics shape both the purpose and the governance of adopted standards.

Certain exclusions follow from this context. This research does not address external norms (e.g. ISO or NEN standards) developed by national or international standardization bodies. Instead, the focus is on organizational or company-specific standards, that is, internal strategies for reducing design variety across projects. Moreover, standards in this thesis are not primarily documented procedures or guidelines (as in quality or safety management systems) but physical components or configurations. The emphasis lies on *asset standards*: tangible products, parts, or assemblies that can be found in the physical electricity grid, rather than process or project-management methodologies. Process and organizational standardization are not treated as separate objects of study but as the implementation conditions through which asset standardization becomes binding; they appear throughout the empirical chapters as governance architecture, release cycles, deviation procedures, and cross-functional team structures.

Asset (product) standardization, process standardization (how projects use the standard), and organizational standardization (the governance arrangements that decide and maintain it) are analytically distinguishable but practically nested. Aapaoja and Haapasalo (2014) state that the benefits of standard products can only be realized through systematic process approaches, and Gibb (2001) bundles components, methods, and processes as co-constituents of standardization rather than as alternatives. This thesis takes the asset standard as the analytical primary while treating the surrounding process and organizational layers as the implementation conditions through which the asset standard becomes binding. The three-tier governance architecture developed in Chapter 3 operationalizes the organizational layer of this nested view.

This thesis also distinguishes between the *adoption* and the *implementation* of asset standards. Adoption refers to the strategic decision to introduce a standardization program: the organizational commitment to develop and use internal standard designs for defined asset categories, driven by perceived relative advantages such as cost reduction, delivery speed, and workforce efficiency (Van de Kaa et al., 2021). Implementation refers to the subsequent process of embedding that decision in daily project practice, specifically ensuring that projects actually use the standard consistently, managing deviations, maintaining the catalog, and realizing the expected benefits (Klein & Sorra, 1996). In the DSO context studied here, adoption is largely assumed as given: all three organizations have made a strategic commitment to internal asset standardization. The empirically interesting question, and the focus of this thesis, is therefore implementation: why, despite strategic commitment, the expected benefits are only partially realized in practice.

Accordingly, the working definition adopted in this research is as follows:

> **An asset standard** is a physical component, part, or product defined and applied within an organization for repeated use across multiple projects, with the aim of reducing variety and improving efficiency.

This definition is used operationally throughout this thesis. It governs the selection of cases, the coding of interview data, and the comparative logic applied in Chapters 4–7.

1.3. Theoretical positioning and research gap

Across adjacent fields there is considerable work on standards, but only limited and indirect evidence on how internal standards for LV/MV grid assets are actually designed and implemented by distribution system operators. This section first situates the thesis within three converging streams of literature, then identifies the empirical and theoretical gaps at their intersection that motivate the research.

1.3.1. Three converging literature streams

This thesis draws on three complementary literatures, each addressing a distinct dimension of the research problem. The streams are named here in descriptive form; Chapter 3 develops each as an analytical lens that structures the empirical phases, and Chapter 9 returns to each as a target for contribution.

The first is *construction industrialization and capital-project standardization*. This stream conceptualizes standardization as a combined product–process strategy for repeatable project delivery (Choi, Shrestha, Kwak, & Shane, 2020a; Gibb, 2001; Mehta, 2024). It examines drivers, mechanisms, success factors, and implementation challenges at program and project level, and provides the empirical vocabulary for the systematic literature review in Chapter 3. The construction literature is the closest available analog to the DSO setting, but it tends to bundle adoption motives and implementation conditions into a single integrated framework. That conflation is unavoidable in client–contractor settings where adoption and implementation occur within a single project lifecycle, but it obscures the distinction in network-operator settings where adoption is a strategic decision separable from project-level implementation.

The second is *innovation diffusion and implementation theory*, specifically the distinction between innovation *adoption* and innovation *implementation* formalized by Klein and Sorra (1996). Klein and Sorra define implementation as "the process of gaining targeted organizational members' appropriate and committed use of an innovation" and identify implementation policies, implementation climate, and innovation–values fit as the proximate determinants of effective use. Rogers (2003) provides complementary attention to perceived attributes of the innovation, including relative advantage, compatibility, complexity, trialability, and observability, that influence the rate and depth of within-organization uptake. This thesis adopts the conceptual distinction between adoption and implementation rather than the full path-model machinery of Klein and Sorra: the qualitative, small-N case design is not suited to testing the path model quantitatively, but the construct of implementation climate and the analytical separation of adoption from implementation are directly applicable and load-bearing in the empirical chapters.

The third is *contingency theory and organizational design*. Donaldson (2001) consolidates the contingency tradition with its central claim that effective organizational structure depends on fit between structure and environmental contingencies, including size, technology, environmental uncertainty, and strategy. The project-management contingency stream represented by Shenhar (2001) extends this to a dynamic-fit formulation in which the appropriate organizational arrangement evolves over time as contingencies change. This thesis applies contingency theory to a domain to which it has not been systematically applied, namely internal asset standardization governance in regulated network infrastructure. The contingency lens organizes the cross-case analysis in Chapter 7 and is the primary vehicle for the theoretical contribution claim in Chapter 9. Throughout the thesis, the term *contingency* is used in this organizational-design sense, denoting an organizational context factor that moderates the relationship between a design choice and its outcome, and not in the project-management sense in which the same English word denotes a schedule reserve or risk buffer.

Several adjacent bodies of literature bear upon the topic, though they do not constitute central components of the thesis's analytical framework. Classical standardization theory (Blind, 2004) concerns itself with the formation and diffusion of *external* standards, with dominance mechanisms, network effects, and market adoption, and offers no account of how internally developed asset standards function within project-based organizations. Multi-level transition theory (Markard, 2011; Verbong & Geels, 2007) addresses sector-level transformation pathways at a macro scale that does not engage directly with intra-organizational governance arrangements. These adjacent literatures appear at relevant points in the chapters that follow, but they do not constitute streams to which the thesis aims to contribute primary findings.

1.3.2. The research gap at the intersection

The combined picture from these three streams reveals two interrelated gaps at their intersection.

The first is an *empirical gap*: no systematic study examines how internal LV/MV asset standards are implemented in DSO project environments, what implementation barriers arise, and how organizational conditions shape the extent to which theoretical benefits are realized in practice. The construction literature documents implementation challenges but does so primarily in commercial settings without the regulatory architecture, procurement regime, public-accountability obligations, and network-integration requirements that characterize Dutch DSOs. Industry papers and DSO asset-management plans endorse equipment standardization and harmonized design specifications as ways to improve safety, interoperability, and cost efficiency, but typically assume these benefits without empirical support and offer prescriptive guidance rather than systematic analysis of implementation challenges, organizational trade-offs, or critical success factors (Canadian Electricity Association, 2015; CURRENT, 2025).

The second is a *theoretical gap*. Existing frameworks do not account for the governance of internal asset standardization in regulated network infrastructure. Construction-and-capital-project work identifies the mechanisms and the implementation challenges but conflates adoption and implementation. Innovation implementation theory provides the adoption–implementation distinction but has not been applied to internally-developed asset standards in infrastructure contexts. Contingency theory provides the analytical machinery for treating governance arrangements as context-conditional but has not been systematically applied to standardization implementation in regulated network infrastructure. No theoretical account combines these elements to explain why organizations facing structurally similar standardization challenges achieve substantially different implementation depths.

Together, these gaps define the niche this thesis occupies: at the intersection of construction-and-capital-project standardization, innovation implementation theory, and contingency theory, it provides a context-sensitive empirical account of how internal asset standards are implemented in a regulated network-infrastructure setting and generates theoretically grounded insights into the organizational conditions that enable or obstruct that implementation. It is important to note that the thesis approaches standardization as an open inquiry. The goal is not to demonstrate that standardization is beneficial and should be adopted more widely, but to examine under what organizational conditions its expected benefits materialize and where and why they do not.

1.4. Thesis scope

This research examines the implementation of internal technical product and design standards in low- and medium-voltage (LV/MV) grid expansion projects in the Netherlands. It focuses on tangible grid assets such as cables, transformer stations, and related civil works, and investigates how DSO-defined standards for these assets are implemented in projects and programs and which barriers are perceived upon implementation.

The thesis adopts an organizational and project-level perspective: it studies how DSOs design, govern, and apply internal standards across multiple projects, how these standards interact with existing processes, regulations, and local site conditions, and why their expected benefits are only partially realized in practice. The empirical focus is on implementation, understood as the process of embedding adopted standards in daily project practice, rather than on the strategic adoption decision itself, which is treated as a contextual given for all three organizations studied.

The research excludes the following dimensions:

- High-voltage transmission systems and associated cross-border infrastructure, which follow different regulatory and technical dynamics.
- Development of detailed process or project-management standards as a primary object of study; these are treated only as contextual elements where they interact with asset standards.
- Full-scale quantitative modeling of time or cost impacts, as the focus lies on explaining underlying mechanisms, perceptions, and contextual factors rather than on precise numerical estimation.
- International comparative analysis, except for brief conceptual references, since the empirical focus is on the Dutch institutional and organizational environment.

1.5. Problem statement

Despite the urgent need to accelerate electricity grid expansion, Dutch DSOs continue to experience long lead times, capacity bottlenecks, and rising costs in the rollout of new LV/MV assets. Project delivery is hampered by high project-to-project variation in designs, interfaces, and site-specific solutions, which limits opportunities for repetition, learning, and economies of scale.

Internal asset standardization, through modular station concepts, standard station types, and standardized cable families, is increasingly promoted as a lever to reduce this variation and industrialize grid expansion. Yet in LV/MV practice, it is poorly understood how these standards are implemented and why they do or do not deliver their theoretical potential. Existing literature and industry examples largely focus either on highly productized systems in manufacturing or on modular construction concepts, offering little guidance on how internal standards behave once they enter context-dependent DSO project environments.

Crucially, this is not simply a question of finding the right standard design. As the construction and capital-project literature shows, standardization benefits are not fixed properties of a design; they are produced by the interaction between a standard and the organizational, regulatory, and technical conditions in which it is used. A well-designed standard will deliver its expected benefits only if the governance infrastructure, project processes, stakeholder alignment, and supplier relationships are sufficiently developed to support consistent application. Where these conditions are weak or absent, the same standard that promised efficiency gains may instead generate rigidity, deviation spirals, and supplier dependency. The central empirical problem is therefore not whether standardization is beneficial in the abstract, but under which organizational conditions its benefits are actually realized in Dutch DSO practice and what prevents that realization where it fails.

For Dutch DSOs, two interrelated knowledge gaps are particularly acute. First, there is no clear empirical account of how standardization programs actually play out across LV/MV projects: what forms standardization currently takes, what implementation barriers consistently arise during deployment, what organizational and contextual conditions appear to shape those barriers, and what accounts for the variation in implementation depth observed across organizations and asset types. Second, the organizational and process conditions that enable or obstruct the activation of standardization's benefit mechanisms, including design reuse, scale economies, schedule control, and learning effects, remain insufficiently understood. As a result, DSOs face strategic uncertainty: they lack a robust basis for judging which implementation barriers are most consequential, when standardization becomes rigid or counterproductive, and how organizational and system-level conditions shape what is achievable in practice.

1.6. Research objective

The overall objective of this thesis is to develop a theoretically grounded and empirically informed understanding of how asset standardization is implemented in Dutch DSO LV/MV grid expansion programs: what forms it takes in current practice, how its implementation is experienced by practitioners, what challenges arise during that implementation, and what organizational and contextual conditions appear to shape those challenges. Within that broader arc, particular attention is paid to the role of organizational structure and governance processes, which the empirical analysis identifies as the most analytically productive lens for understanding why implementation experiences differ across organizations and asset categories.

To achieve this, the research will:

- Conceptualize internal asset standards for grid expansion by synthesizing and critically assessing insights from the three literature streams identified in Section 1.3.1, identifying what is known and what remains empirically open.
- Document how Dutch DSOs currently implement asset standards in LV/MV grid expansion: what forms standardization takes, how implementation is experienced across programs and projects, and what practitioners perceive as its benefits and limitations.
- Identify the implementation barriers that arise during deployment and examine the organizational, contextual, and asset-related conditions that appear to shape them.
- Examine specifically how a DSO's organizational structure and governance design influence its standardization implementation experiences and the barriers it encounters, generating propositions for future research with larger samples.

This study adopts an exploratory, contingency-informed perspective (Donaldson, 2001): it treats organizational structure and governance design not as universal best practices but as variables whose appropriate form depends on the organizational context and the complexity profile of the assets being standardized. Rather than testing pre-specified causal hypotheses, the study generates empirically grounded insights and preliminary propositions at the intersection of the three literature streams identified above. The intended contribution is twofold: first, advancing academic understanding at this intersection by providing a context-sensitive account of how asset standardization is implemented in regulated, technically hierarchical infrastructure settings, with organizational structure and governance processes identified empirically as the dimensions along which the most consequential variation occurs; and second, offering practitioners a structured view of the implementation barriers that recur across DSO programs and the organizational conditions that appear to shape them.

1.6.1. Link to the MOT master's program

This thesis is situated within the Management of Technology program at TU Delft because it examines how a technical innovation, specifically the internal asset standard as a systematic approach to variety reduction, is implemented and managed within a complex organizational setting. The challenge is not to develop the technology itself but to understand how an organization manages the transition from bespoke, project-specific engineering to repeatable, catalog-based asset deployment. This involves questions of organizational design, governance, change management, and the interaction between technical systems and organizational routines, all of which are central to the MOT field. Where construction research is predominantly case-study and practice-oriented, focused on understanding what happened on specific projects, this thesis adds a theoretically explicit, stage-informed perspective by distinguishing adoption from implementation and by asking what organizational conditions appear to shape whether an adopted standard produces its intended effects in practice. This combination of practice-grounded empirical analysis and theoretically structured interpretation is characteristic of MOT research at the intersection of technology management and organizational design. A backward-looking reflection on the MOT curriculum and on this specific research process is provided in Section 9.7.2.

1.7. Research question and sub-questions

The central research question guiding this thesis is:

> **How do organizational structure and governance design shape the implementation of asset standards by Dutch DSOs in LV/MV grid construction projects?**

To address this question, the following sub-questions are explored in sequence:

SQ1: How are asset standards and their expected roles in electricity grid projects conceptualized in the relevant literature streams?

SQ2: What forms of asset standardization are currently in use in Dutch LV/MV grid expansion, and how are these standards implemented across programs and projects?

SQ3: What patterns of convergence and divergence in implementation experiences and outcomes are observed across the three DSOs and six cases, and what conditions appear to shape those patterns?

SQ4: How does a DSO's organizational structure and governance design influence its standardization implementation experiences and the barriers it encounters?

The sub-questions follow a deliberate descriptive-to-explanatory progression. They operationalize the research objective by moving from conceptualization (SQ1) through descriptive and perceptual implementation analysis (SQ2 and SQ3) to an explanation of how organizational structure and governance design condition implementation outcomes (SQ4), reflecting the descriptive-to-explanatory progression characteristic of implementation-climate and contingency-informed research designs. The main research question integrates these analytical stages by examining how organizational structure and governance design shape the implementation of asset standards in Dutch LV/MV grid construction projects, drawing on the conceptual, empirical, and comparative insights generated through the sub-questions.

It is important to note what this research design does and does not support. Given the exploratory nature of the study and the small sample of three DSOs and six embedded cases, the findings will be framed as descriptive accounts, observed patterns, and preliminary propositions rather than as causal claims or statistically generalizable conclusions. The goal is analytical depth and theoretical insight rather than breadth of generalization. Findings from this study are intended to inform, and to be tested in, future research with larger and more varied samples.

1.8. Company context

This thesis was conducted during an internship at Accenture Industry X, within the Manufacturing & Operations department, in collaboration with the Strategy & Consulting Utilities department. Accenture Industry X specializes in applying digital and engineering expertise to industrial asset-intensive sectors, with an active practice in energy infrastructure and grid modernization. The Utilities practice maintains established working relationships with Dutch DSOs through advisory engagements in asset management, standardization strategy, and digitization programs, and provided the principal point of access for the DSO interviews and case documentation that form the empirical core of this study.

This internship context shaped the research in two important ways. First, it provided access to a network of practitioners with direct experience of active standardization programs, access that would have been difficult to obtain through academic channels alone. Second, it grounded the research questions in problems that DSOs and their advisors recognize as consequential, reducing the risk of studying phenomena that are theoretically interesting but organizationally marginal.

At the same time, the internship context creates a positionality that must be acknowledged. As an embedded researcher with Accenture access, there is a risk that the research framing, case selection, and interpretation of findings were influenced, even inadvertently, by the perspectives and interests of the host organization. To mitigate this risk, interview data were independently coded against theoretically derived categories rather than against Accenture's own analytical frameworks, and the research questions were deliberately formulated to include the conditions under which standardization does *not* work, not only the conditions that support it. A fuller account of researcher positionality and the measures taken to manage it is provided in Section 2.7.

1.9. Thesis structure

The remainder of this thesis is organized as follows.

Chapter 2 presents the research methodology: the overall research design, the rationale for a qualitative comparative case study approach, the data collection and analysis procedures, and the measures taken to ensure quality and rigor.

Chapter 3 develops the theoretical foundations of the study through a systematic literature review of the three streams identified above, supplemented by exploratory expert interviews with Accenture consultants. It concludes with the sensitizing concepts and preliminary propositions that guide the empirical analysis.

Chapters 4, 5, and 6 present the within-case analyses for DSO-A, DSO-B, and DSO-C respectively. Each chapter documents the organizational context, the standardization programs examined, their governance structures, the implementation challenges encountered, and the outcomes perceived by practitioners.

Chapter 7 presents the cross-case analysis, comparing implementation experiences and governance arrangements across the six cases and identifying the patterns that emerge from that comparison.

Chapter 8 presents the expert validation and synthesis session, in which the cross-case findings were shared with senior practitioners from all three DSOs and assessed for relevance, completeness, and practical recognizability.

Chapter 9 synthesizes the full study: it answers the research questions, develops the study's theoretical contributions to the three literature streams identified above, derives practical implications for DSO program managers, states the study's limitations explicitly, reflects on the MOT program and on the research process, and identifies directions for future research.

2
Methodology

This chapter presents the research design, explains each methodological choice, and describes the analytical procedures used to answer the research question and sub-questions. Section 2.1 outlines the overall design and its rationale. Sections 2.2 through 2.5 detail the four sequential phases. Section 2.6 describes how findings across phases are integrated. Section 2.7 addresses researcher positionality. Section 2.8 provides a summary overview.

2.1. Research design

The study adopted a qualitative, multi-method design centered on a comparative case study. This choice was driven directly by the nature of the research questions. SQ2 documents what forms asset standardization takes in current practice and how it is implemented; SQ3 identifies patterns of convergence and divergence across cases and the conditions that appear to shape them; SQ4 zooms in on how organizational structure and governance design influence implementation experiences and barriers. These are exploratory, descriptive questions about contemporary organizational phenomena in real-world settings where the boundaries between the phenomenon and its context are not sharply drawn (Yin, 2018). A quantitative design would require outcome variables measurable before and after a standardization intervention; because the cases studied here involve ongoing programs whose effects are not yet fully realized, such measurement was not feasible, and the more relevant question was why and how implementation unfolds rather than how much output it has produced.

The design was structured in four sequential phases. Phase 1 generated the theoretical vocabulary and sensitizing concepts used in the empirical phases. Phases 2 and 3 collected and analyzed empirical data through within-case narratives and cross-case comparison. Phase 4 assessed whether the patterns identified in Phases 2 and 3 were recognizable and meaningful to senior practitioners.

Quality was addressed through tactics targeted at the four Yin (2018) criteria: *construct validity* via multi-level informants, a documented chain of evidence, and Phase 4 informant review; *internal validity* via within-case narratives, pattern matching against Phase 1 sensitizing concepts, and rival-explanation checks; *external validity* via literal-and-theoretical replication across six cases in three DSOs covering roughly 90% of the Dutch LV/MV grid, with scope conditions stated in the limitations; and *reliability* via a documented case-study protocol, the codebooks reproduced in Appendices B.1.5–C.1.3, and a pre-specified PRISMA screening protocol with 10% intra-rater re-assessment. The limitations of this design, including the constraints on causal inference and statistical generalization, are addressed in Section 9.6.

2.1.1. Qualitative thematic analysis as the core analytical method

Within-case and cross-case data were analyzed using thematic content analysis, a method chosen for three reasons specific to this study. First, the data were primarily perceptual: practitioners' accounts of what they experience as barriers, enablers, and outcomes of standardization programs. Thematic analysis is designed precisely to identify, organize, and interpret patterns in such experience-based qualitative data (Braun & Clarke, 2006). Second, the analysis was deductive-inductive: it began with sensitizing concepts derived from the SLR and expert interviews in Phase 1 and supplemented these with inductively derived codes that captured DSO-specific phenomena not anticipated by the literature. This combination is a defining strength of thematic analysis in theory-building research (Boyatzis, 1998). Third, thematic analysis was preferred over the two principal alternatives: pattern matching (Yin, 2018) is best suited to confirmatory designs in which specific predicted patterns are tested against empirical data, whereas this study was exploratory rather than confirmatory; qualitative comparative analysis (QCA) is designed for configurational analysis of necessary and sufficient conditions across a medium number of cases, typically ten or more, and with six cases the conditions for meaningful QCA were not met (Rihoux & Ragin, 2009).

2.2. Phase 1: Theoretical development

Phase 1 answered SQ1 by building a theoretical foundation for the empirical study. It proceeded in two steps: a systematic literature review that identified what is known about asset standardization mechanisms and implementation conditions in adjacent fields, and a set of exploratory expert interviews that translated those findings to the DSO context. The combined output was a set of sensitizing concepts and preliminary propositions that structured the data collection instruments and coding schemes used in Phases 2 and 3.

2.2.1. Systematic literature review

A systematic review was conducted to answer SQ1: how asset standards and their expected roles in projects are conceptualized in literature, and what mechanisms and implementation conditions that literature identifies. A systematic approach was chosen, rather than a narrative review, because the domain straddles multiple fields (construction management, capital projects, standardization theory) and a transparent, replicable search procedure reduced the risk of selection bias in the evidence base used to construct the theoretical framework (Page et al., 2021). The review followed the PRISMA 2020 guidelines to ensure transparency and reproducibility (Page et al., 2021). It targeted academic work that (1) conceptualized asset or product standardization in engineering, construction, or infrastructure settings; (2) explained mechanisms through which standardization influences project or operational performance; and (3) described contextual factors and barriers that shape standardization outcomes.

Identification
The search was conducted in Scopus and Dimensions. Scopus is widely regarded as one of the most comprehensive abstract and citation databases for scientific and technical disciplines and is frequently used as the primary source for systematic reviews in construction and project management (Ghaleb et al., 2022; Sánchez-Garrido et al., 2023). Dimensions covers the great majority of Scopus-indexed journal articles and offers broader indexing of newer and less traditional venues (Stahlschmidt & Stephen, n.d.; Thelwall, 2018). Using both databases strengthened coverage without substantially increasing duplication.

The search strings combined two elements: the type of standard (Part 1) and the project sector in which it is situated (Part 2), as shown in Table 2.1. Mechanism and factor terms were excluded because initial trials returned very few results when they were included: such terms are not consistently used as keywords in this literature. The term *standardization* was included in its broad form because influential articles sometimes use only this term in titles and abstracts without specifying product or asset standardization. Terms such as modularization, prefabrication, and preassembly were tested but generated several thousand additional hits and were excluded on grounds of feasibility and focus. Exact search strings, applied filters, and database-specific settings are documented in Appendix B.1.1.

Table 2.1: Overview of search string composition used in the systematic review (combined with Boolean operators).

Term part 1: standard	Term part 2: project sector
Product standard*	Construction project*
Standard component*	Capital project*
Standardi*ed design	Infrastructure project*
Standardi*ation	Electricity grid
	Power distribution

Screening and eligibility
All retrieved records were exported to a reference manager and filtered against basic eligibility criteria: journal articles, conference papers, and review papers only; English and Chinese language (Chinese was included because of the strong grid industrialization orientation of the Chinese electricity

sector); published from 1990 onward, as standardization literature in project and construction contexts emerges from that decade; and subject areas covering Engineering, Energy, Business, Management and Accounting, Environmental Science, Social Sciences, Decision Sciences, and Materials Science. Duplicates were then removed, taking the corpus from 1,481 initial records to 1,165.

Title and abstract screening applied two criteria: studies had to address asset or product standardization in an engineering, construction, or infrastructure context, and had to make at least some reference to mechanisms or influencing factors. Studies were excluded if they addressed only process, quality, safety, or decision-making standardization; treated standardization as global, ISO, or international norm-setting; addressed contract or work-breakdown-structure standardization; or focused on standardization of bids or contractor selection. Given that this is an under-researched domain, the scope was kept deliberately broad at this stage to avoid prematurely excluding relevant contributions. Title and abstract screening reduced the corpus from 874 records to 106.

Full-text assessment applied stricter criteria aligned with SQ1. Studies had to provide an explicit or implicit conceptualization of standards or degrees of standardization, and had to discuss at least one mechanism or contextual factor linking standardization to project or operational performance. Studies that mentioned standards only superficially, without engaging with mechanisms or conditions, were excluded. All exclusion decisions at this stage were documented with reasons. The per-record full-text disposition log is reproduced in Appendix B.1.1.

Inclusion, extraction, and synthesis

The final corpus is reported using a PRISMA 2020 flow diagram (Figure 2.1). For each included study, key information was extracted into a structured table covering domain, type or degree of standardization, conceptual definitions, described mechanisms, performance outcomes, and contextual factors. Extraction and synthesis were conducted in ATLAS.ti, using a deductive-inductive coding approach: initial codes were drawn from three analytical categories (mechanisms, enabling conditions, implementation challenges), and additional inductive codes were added where findings did not fit existing categories. The synthesis followed the three-stage thematic synthesis approach articulated by Thomas and Harden (2008): line-by-line coding of the included studies' findings, organization of related codes into descriptive themes (the four code groups of effects, factors, and challenges reproduced in Appendix B.1.5), and development of analytical themes that move beyond the primary studies to generate interpretive constructs (the five mechanism families synthesized in Chapter 3). The synthesized output provided the sensitizing concepts and preliminary propositions that structured the Phase 2 interview guides and coding scheme.

Procedural transparency of the review

A detailed screening log was maintained throughout, documenting inclusion and exclusion decisions and reasons for each record assessed at full-text stage. A random sample of 10% of excluded full texts was re-assessed two weeks after initial screening to check for consistency; no substantive discrepancies were identified. Screening was conducted by a single reviewer following a pre-specified protocol, with all decisions documented to allow external audit of the selection logic.

2.2.2. Industry consultant interviews

Five exploratory expert interviews were conducted with industry consultants experienced in grid-related standardization projects to translate the SLR findings into the specific realities of LV/MV grid expansion. This was necessary as literature drew mostly from commercial construction; was considerably pro-standardization; was source-concentrated as a large share originated from one particular research team. The interviews served three purposes: to validate and refine the mechanisms and conditions identified in the literature; to identify DSO-specific contingencies that are underrepresented in academic literature; and to assess which construction-derived concepts transfer directly to the DSO context, which require adaptation, and which do not transfer. They also informed the design of the Phase 2 case study protocol by surfacing the organizational vocabulary, role distinctions, and program-level vocabulary that the case interviews would need to engage with. Semi-structured interviews were the appropriate format because the goal was to probe expert knowledge in a flexible, open-ended way while maintaining comparability across the five conversations (Bogner et al., 2009). The interview protocol is reproduced in Appendix B.1.4, and a consolidated overview of the five interviews appears in Appendix B.1.3.

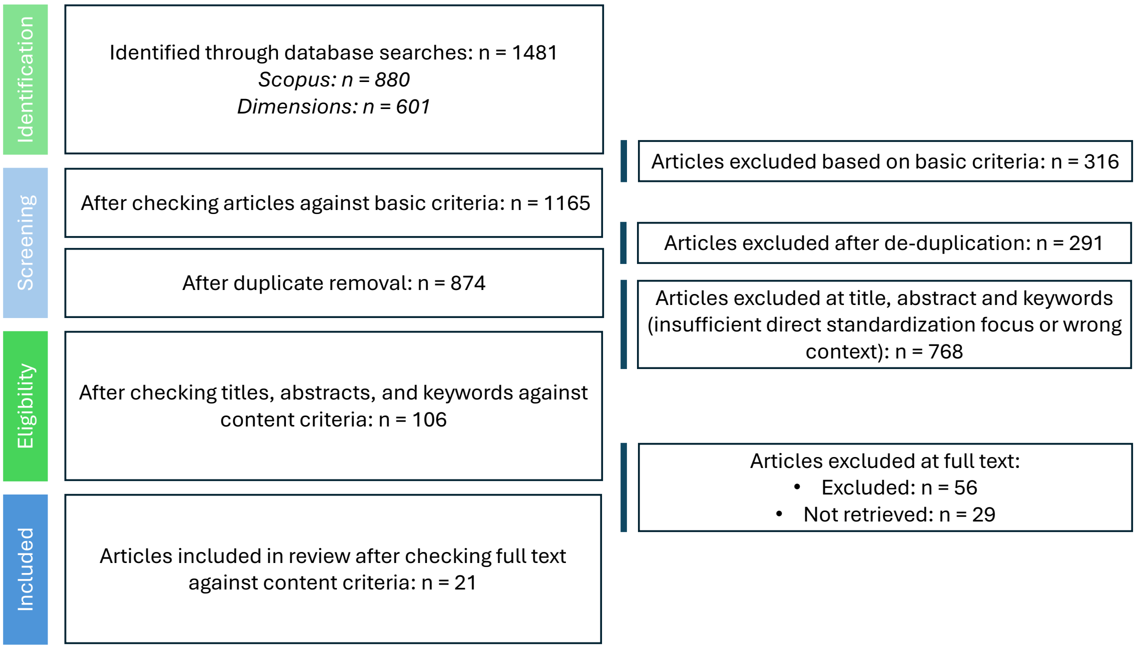


Figure 2.1: PRISMA 2020 flow diagram for the systematic literature review, showing the progression from database identification to screening, eligibility assessment, and final inclusion of the 21 studies used in the literature synthesis (adapted from Page et al. (2021)).

Interviews were recorded with consent, transcribed, and coded thematically in ATLAS.ti using the same deductive-inductive approach as the SLR synthesis; the resulting code additions are documented in Appendix B.1.6. The combined output of the SLR and these interviews formed the final set of sensitizing concepts and propositions used to design the Phase 2 case study protocol.

2.3. Phase 2: Within-case analysis

Phase 2 addressed SQ2 by documenting what forms asset standardization currently takes in Dutch LV/MV grid expansion and how these standards are implemented across programs and projects: what practitioners perceive as benefits and limitations, and where implementation barriers arise. It did this through a comparative multiple-case study of three Dutch DSOs, each examined through two embedded standardization programs.

2.3.1. Why a comparative case study

A comparative multiple-case design was chosen because the research questions called for in-depth, contextually sensitive accounts of organizational phenomena in real-world settings where the boundary between the phenomenon and its context is not clearly defined (Yin, 2018). The comparative case study occupies the appropriate middle ground for this study's exploratory purpose: it generates rich within-organization narratives while enabling structured comparison across organizations to identify convergent and divergent patterns (Eisenhardt, 1989). The goal was analytic generalization: the cases were selected to represent variation in organizationally and technically relevant dimensions, and the patterns identified across them were used to refine and extend theoretical propositions about implementation conditions (Flyvbjerg, 2006; Yin, 2018).

2.3.2. Case selection

Three leading Dutch DSOs were purposively selected because they collectively manage over 90% of LV/MV infrastructure in the Netherlands, making them collectively representative of the sector's operating conditions, regulatory environment, and organizational scale. Within each DSO, two embedded standardization programs were selected, giving six cases in total.

Case selection followed a combination of literal and theoretical replication logic (Yin, 2018). For the distribution station programs (Cases A.1, B.1, and C.1), literal replication was applied: all three involve the same asset type in comparable organizational contexts, so similar implementation patterns are expected if the same enabling conditions are present. Divergence in these cases is therefore informative about organizational differences rather than asset-type differences. For the secondary assets (A.2, B.2, C.2), theoretical replication was applied: asset type and complexity vary deliberately across cases to examine whether the patterns identified for complex assets hold for simpler ones. The resulting portfolio is:

- DSO-A: MV-LV distribution stations (semi-complex) and distribution cables (lower complexity)
- DSO-B: MV-LV distribution stations (semi-complex) and compact connection modules (lower complexity)
- DSO-C: MV-LV distribution stations (semi-complex) and MV-MV transportation stations (higher complexity)

This configuration enables cross-DSO comparison of a common asset type and within-DSO comparison of assets with different complexity profiles.

The selection criterion of ongoing programs, rather than completed ones, was a deliberate methodological choice aligned with the exploratory purpose. Completed programs would allow outcome evaluation; ongoing programs provide richer accounts of the implementation process as it is actually experienced. This choice also reflects a substantive characteristic of DSO asset standardization: unlike discrete construction projects, standardization programs in an asset management context are rarely considered finished. Asset Management functions continuously govern the asset catalog, update specifications in response to regulatory changes, supplier developments, and field experience, and manage deviation and exception processes on an ongoing basis. The boundary between "implementation" and "steady-state governance" is therefore inherently blurred, and treating a program as complete would misrepresent its nature.

2.3.3. Data collection

Each case was investigated primarily through semi-structured interviews, which provided the bulk of the empirical evidence. Triangulation operated principally at the level of *internal multi-level informants*: each case drew on respondents occupying distinct operational, tactical, and strategic positions, and convergence or divergence across those positions served as the within-case validity check that case-based theory-building research recommends (Eisenhardt, 1989). Document analysis and secondary materials supplemented the interview data where available and were used principally for contextualizing organizational background and corroborating specific factual claims about program history, suppliers, and timelines. Documentary access was structurally heterogeneous across DSOs, so documents and secondary materials functioned as contextualizing rather than as parallel sources for formal source triangulation; the perceptual, process-oriented research questions are also best addressed by interviews rather than by documents. A consolidated overview of all interviews across the three DSOs, showing case, anonymized role, and organizational level, is provided in Appendix C.1.1.

Semi-structured interviews

Semi-structured interviews were the primary data source because they provide detailed, experience-based accounts of implementation processes while maintaining sufficient structure for cross-case comparability (Rabionet, 2011). Approximately three interviews per case were conducted, each with a respondent occupying a distinct organizational role in relation to the standardization program: a project manager for the operational perspective, an asset engineer or technical specialist for the design and specification perspective, and a strategic program manager or asset management lead for the program governance perspective. This role-based selection was designed to capture both the strategic intent behind standardization decisions and the operational experience of implementing them, including the perceptual differences between those two levels. Multi-level informant designs of this kind are recommended in case-based theory-building research as a means of strengthening within-case validity through internal triangulation across organizational positions (Eisenhardt, 1989), an approach that is particularly valuable when multi-level organizational processes are the subject of study.

Three interviews per case represented a pragmatic starting point. Thematic saturation was assessed iteratively during data collection, and additional interviews were conducted where the emerging analysis suggested significant perspectives were underrepresented (Flyvbjerg, 2006).

Interview procedure. All interviews were conducted one-on-one via Microsoft Teams or in person, depending on participant availability. A semi-structured guide ensured coverage of core topics (standardization drivers, program history, governance structure, perceived benefits, experienced barriers, and contextual factors) while retaining the flexibility to probe emerging themes. The guide, reproduced in Appendix C.1.2, was adapted to the specific role of each participant so that operational respondents were asked about project-level experience and strategic respondents were asked about program governance and organizational design.

Interviews were audio-recorded with participants' consent, transcribed using Teams or equivalent transcription tools, and then manually checked and corrected for accuracy. Identifying details were removed or pseudonymized during this process. Cleaned transcripts formed the primary data for coding and within-case analysis.

Ethical conduct. The study followed the ethical code of conduct established by TU Delft for research involving human participants, including requirements for informed consent, participant anonymity, and secure data handling. All potential participants received written information about the study's purpose, the interview format, and their rights, including the right to decline questions or withdraw at any time without consequence. Informed consent was obtained before interviews were scheduled, and explicit permission was obtained for audio recording. The research proposal was submitted to the TU Delft Human Research Ethics Committee (HREC) for formal approval.

Documents and secondary materials

Documents served as a complementary source of evidence, used selectively to contextualize and corroborate interview accounts. Document use was modest in this study: approximately ten internal DSO documents were reviewed where access was granted; publicly available DSO annual reports and investment plans were consulted for all three case organizations; and approximately ten supplier announcements, regulatory communications, and trade-press articles were used selectively for triangulation of specific factual claims. Document analysis followed the qualitative approach of Bowen (2009), with attention to discrepancies between formal organizational narratives and the implementation experiences described by practitioners. Given the heterogeneous availability of documentation across DSOs, documents are treated throughout this thesis as contextualizing evidence rather than as a primary analytical basis. The consolidated source register is reproduced in Appendix C.1.4.

Secondary materials such as timelines and performance indicators were available only sparingly. Only one quantitative performance indicator was provided directly by an interviewee. No equivalent quantitative outcome data were available at DSO-B or DSO-C. Secondary materials therefore did not function as a meaningful third data source in the formal triangulation sense; where mentioned in the empirical chapters, they are used illustratively rather than analytically.

2.3.4. Data analysis

Within-case analysis used a hybrid approach combining thematic content analysis with narrative synthesis (Braun & Clarke, 2006; Miles & Huberman, 1994). Thematic analysis provided the systematic coding structure; narrative synthesis ensured that the resulting case description retained the chronological and organizational coherence needed to make the implementation story intelligible as a whole rather than as a collection of disconnected coded segments (Yin, 2018).

Coding was conducted in ATLAS.ti and proceeded in three cycles. In the first cycle, all transcripts were read holistically to build familiarity with each case, and then coded line-by-line with descriptive codes capturing standardization processes, outcomes, and barriers. The coding strategy was deductive-inductive: a priori codes drawn from the SLR and industry consultant interview findings (Phase 1) provided the initial framework, and inductive codes were added as new phenomena emerged from the data that were not captured by existing categories. In the second cycle, axial coding refined these initial codes into hierarchical categories covering organizational context and structure, program timeline and governance, perceived benefits and mechanisms, experienced challenges and barriers, and enabling and constraining contextual factors. In the third cycle, selective coding consolidated higher-order themes across these categories, with analytic memos documenting the reasoning behind coding decisions and the linkages between themes and Phase 1 propositions. This three-cycle approach followed the guidance of Saldaña (2013) and Miles and Huberman (1994) on progressive analytical refinement in qualitative case research.

Coded data were organized into conceptually clustered matrices for each case, with rows representing themes and columns representing data sources and respondents. These matrices provided the analytical backbone for within-case narrative construction while enabling cross-case pattern identification in Phase 3. The full codebook, with the Phase 1 SLR baseline, the consultant additions, and the within-case extensions reported as sequential layers, is reproduced in Appendices B.1.5–C.1.3. The audit trail from raw transcripts through coded segments in ATLAS.ti, to the conceptually clustered within-case matrices, to the cross-case comparison reported in Chapter 7, constitutes the chain of evidence required for case study reliability and construct validity (Yin, 2018).

2.4. Phase 3: Cross-case analysis

Phase 3 addressed SQ3 by comparing the within-case findings from Phase 2 systematically across the six cases to identify convergent and divergent patterns. The cross-case analysis followed the three tactics that Eisenhardt (1989) recommends for theory-building from comparative cases, applied as three sequential analytical movements. First, the asset complexity profile of each case is established, providing the structural variable along which the case portfolio is partitioned (Chapter 7, Section 7.2). Second, the three distribution station programs (A.1, B.1, C.1) are compared systematically across five dimensions, since these three cases share the same asset type and thus provide a basis for isolating organizational differences as the primary explanatory variable; this is the *category-based comparison* tactic. Third, the lower-complexity cases (A.2, B.2) and the higher-complexity transportation station case (C.2) are examined in turn to assess whether the patterns identified for semi-complex stations extend to other asset categories, and where they diverge; this applies the *pair-wise comparison* tactic. These three movements feed into the three overarching themes (Section 7.5) and the categorized challenge inventory (Section 7.6).

Cross-case patterns were identified through the third Eisenhardt tactic, *comparison matrices* (Eisenhardt, 1989; Miles & Huberman, 1994), that systematically display governance, timeline, supplier, and outcome dimensions across the relevant case sets. The matrices supported the analytical construction reported in Chapter 7 and are summarized at key points in that chapter, with the three-axis positioning of cases on the standardization sub-dimensions reproduced as Table D.1 in the Appendix. Where a pattern appeared consistently across multiple cases, it was treated as a convergent finding. Where cases diverged on the same dimension, the divergence itself became the object of analysis: what organizational or asset-related difference accounts for it? A two-source triangulation standard was applied throughout: a finding was treated as a cross-case pattern only when independently corroborated by evidence from at least two cases or two interviewees in different organizational positions; single-source observations were retained but explicitly labeled as case-specific. The final output of Phase 3 is a set of analytically elaborated patterns, each supported by evidence from multiple cases, and a set of preliminary propositions about the organizational, contextual, and asset-related conditions that appear to shape those patterns. These propositions are not tested in the statistical sense; they are descriptive summaries of observed regularities that provide the basis for the Phase 4 relevance check and for future research with larger samples.

2.5. Phase 4: Expert validation

Phase 4 addressed SQ4 by sharing the cross-case findings with senior practitioners from all three DSOs and assessing whether those findings, particularly the role attributed to organizational structure and governance design in shaping implementation experiences and barriers, were recognizable, complete, and practically meaningful. The purpose was not to verify factual accuracy, which would risk circular reasoning given that the practitioners being consulted were partly the same individuals whose accounts generated the findings. Nor was it to seek external confirmation that the findings were correct, which could introduce entirely new analytical directions late in the study. Instead, Phase 4 was a relevance and completeness check: do the observed patterns and propositions make sense to experienced practitioners? Do they capture what matters organizationally? Are there gaps in the analytical picture that practitioners would identify as significant?

Participants were senior DSO asset managers from the three case organizations, with extensive experience in standardization programs, project delivery, and the Dutch regulatory environment. They were deliberately drawn from within the case organizations to prioritize organizational knowledge over external independence, while the risk of circular reasoning was mitigated by framing the session as a discussion of patterns and propositions rather than a confirmation exercise, and by explicitly inviting participants to flag unrecognized findings or reformulate propositions. Selection criteria were: (i) cross-program responsibility beyond a single embedded case, so respondents could assess the cross-case argument rather than only "their" program; (ii) seniority sufficient to comment on governance arrangements and their evolution; and (iii) prior involvement in the standardization programs analyzed in Chapters 4–6, so validation could draw on substantive familiarity rather than abstract reactions. Two of the three participants had also been Phase 2 case interviewees, while the third held cross-program oversight but was not previously interviewed; this composition balanced continuity of interpretation and reduced recall-bias on the within-case material with a fresh senior perspective that mitigated the circular-reasoning concern raised in Phase 2 supervisor feedback

Participants received a structured summary of the Phase 3 cross-case patterns and propositions before the session. During the session, they were asked to assess the recognizability of fourteen implementation challenges identified in the cross-case analysis, to rank the ten organizational and governance components identified as most consequential, and to react to the central analytical question on the role of governance architecture as contingent determinant of implementation depth. The full validation protocol, including the challenge inventory and the governance components presented to participants, is reproduced in Appendix E.1.2. The session was conducted as a semi-structured group discussion, audio-recorded with consent, and transcribed. The transcript was analyzed through structured thematic reading rather than full coding cycles, given the session's focused purpose: the analytical aim was not to generate new categorical schemes but to assess practitioner recognition, prioritization, and reframing of the existing cross-case patterns. Practitioner responses were grouped into three response categories: recognized findings (where practitioners confirmed the pattern as observed in their organization), reframed findings (where practitioners agreed the pattern existed but proposed a different formulation of its mechanism), and additions (where practitioners identified phenomena absent from the Phase 3 inventory). Each response was directly attributed to the Phase 3 finding it confirmed, reframed, or extended, and these attributions are reported in Chapter 8. The session output therefore functions as Phase 3 refinement material rather than as a separately coded data corpus.

2.6. Synthesis

The synthesis integrates findings across all four phases to address the main research question. The analytical logic proceeds in four steps. First, the mechanisms and propositions generated in Phase 1 are compared with the empirical patterns identified in Phases 2 and 3, and the points of alignment and divergence between literature-derived expectations and observed reality are made explicit (Section 9.5). Second, the cross-case patterns are organized into a structured contingency account of how organizational structure and governance processes appear to shape implementation depth, drawing on the conceptual vocabulary established in Phase 1 (Section 9.3). Third, the Phase 4 additions and reframings are incorporated to refine the account and identify the propositions that the study generates for future research (Section 9.8). Fourth, the contingency account is translated into practical prescriptions calibrated to the position of each factor on the governance-leverage continuum (Section 9.4). The synthesis does not claim to have established causal relationships or to have produced a validated model; it produces a theoretically grounded, empirically illustrated account of implementation patterns and the preliminary propositions that follow from them.

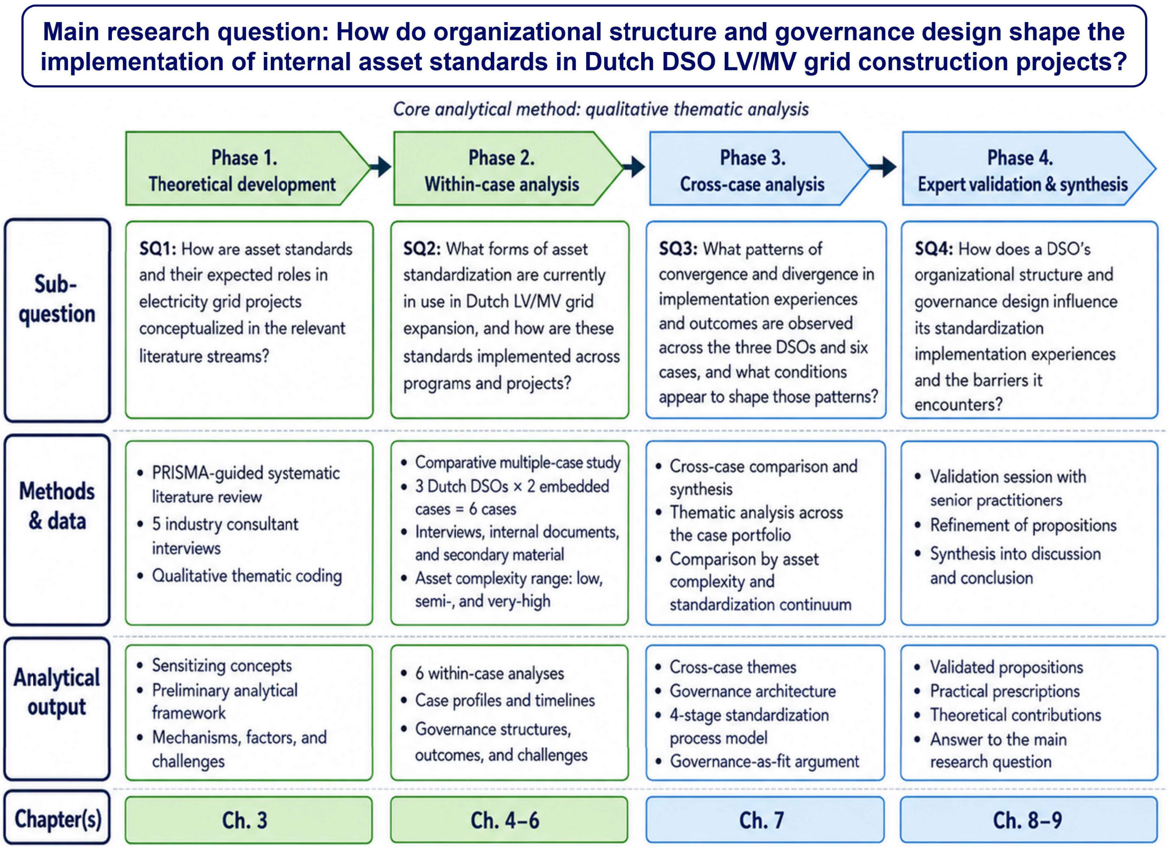
2.7. Reflexivity and researcher positionality

The internship context described in Section 1.8 created a positionality in which the researcher had prior exposure to Accenture's frameworks for thinking about standardization, which introduced a risk of unconsciously privileging those frameworks over alternative analytical lenses.

Several procedural steps were taken to mitigate this risk. Interview guides were designed using categories derived from the SLR rather than from Accenture's own analytical models. The coding scheme was developed deductively from Phase 1 literature findings before any DSO interview data were collected, reducing the influence of pre-existing consulting frameworks on analytical choices. Research questions were explicitly formulated to include the conditions under which standardization does not work, not only those that support it, to counteract any tendency toward a pro-standardization framing inherited from the host organization. Analytic memos were maintained throughout coding to document interpretive decisions, and the Phase 4 session provided an external perspective on whether the analytical interpretation matched practitioner experience. A concise account of the use of generative AI tools as a writing and thinking aid is provided in Appendix A.1.

2.8. Research design summary

The four-phase design (Figure 2.2) is exploratory and descriptive in orientation. It does not test pre-specified causal hypotheses, cannot establish statistical generalization, and does not produce a validated framework in the formal sense. What it produces is an empirically grounded, theoretically structured account of how organizational conditions appear to shape standardization implementation in Dutch DSO LV/MV expansion programs, together with a set of preliminary propositions that future research with larger samples can test more rigorously.



Main research question: How do organizational structure and governance design shape the implementation of internal asset standards in Dutch DSO LV/MV grid construction projects?

Core analytical method: qualitative thematic analysis

	Phase 1. Theoretical development	Phase 2. Within-case analysis	Phase 3. Cross-case analysis	Phase 4. Expert validation & synthesis
Sub-question	**SQ1:** How are asset standards and their expected roles in electricity grid projects conceptualized in the relevant literature streams?	**SQ2:** What forms of asset standardization are currently in use in Dutch LV/MV grid expansion, and how are these standards implemented across programs and projects?	**SQ3:** What patterns of convergence and divergence in implementation experiences and outcomes are observed across the three DSOs and six cases, and what conditions appear to shape those patterns?	**SQ4:** How does a DSO's organizational structure and governance design influence its standardization implementation experiences and the barriers it encounters?
Methods & data	• PRISMA-guided systematic literature review • 5 industry consultant interviews • Qualitative thematic coding	• Comparative multiple-case study • 3 Dutch DSOs × 2 embedded cases = 6 cases • Interviews, internal documents, and secondary material • Asset complexity range: low, semi-, and very-high	• Cross-case comparison and synthesis • Thematic analysis across the case portfolio • Comparison by asset complexity and standardization continuum	• Validation session with senior practitioners • Refinement of propositions • Synthesis into discussion and conclusion
Analytical output	• Sensitizing concepts • Preliminary analytical framework • Mechanisms, factors, and challenges	• 6 within-case analyses • Case profiles and timelines • Governance structures, outcomes, and challenges	• Cross-case themes • Governance architecture • 4-stage standardization process model • Governance-as-fit argument	• Validated propositions • Practical prescriptions • Theoretical contributions • Answer to the main research question
Chapter(s)	Ch. 3	Ch. 4–6	Ch. 7	Ch. 8–9

Figure 2.2: Research design of the thesis project, linking the main research question and four sub-questions to the four empirical phases, the data and methods used in each phase, the analytical output produced, and the corresponding thesis chapters.

3
Theoretical development

This chapter answers SQ1 by establishing the theoretical vocabulary and sensitizing concepts that guide the empirical analysis. It proceeds in three steps. Section 3.1 reports the results of the systematic literature review (SLR) and positions them across the three literature streams named in Chapter 1 (§1.3.1): how asset standardization is conceptualized, which mechanisms connect it to project performance, and which enabling factors and implementation challenges the literature identifies. Section 3.2 presents findings from five exploratory expert interviews with industry consultants that translate the literature-derived picture into the LV/MV grid context. Section 3.3 synthesizes both sources and draws out the sensitizing concepts that structure the empirical phases.

Two framing points are important before proceeding. First, this chapter treats standardization as a *conditional* rather than unconditionally beneficial practice. The literature documents both positive mechanisms and negative trade-offs, and both streams of evidence are presented with equal analytical weight. Second, the output of this chapter is not a validated framework but a set of sensitizing concepts: theoretically grounded starting points that guide data collection and analysis without predetermining what the empirical cases will show.

3.1. Literature review

3.1.1. Review results and corpus

The review applied the PRISMA 2020 protocol described in Section 2.2.1. The combined Scopus and Dimensions searches initially yielded 1,481 records, of which 21 core articles were retained after eligibility assessment. The full inventory of included studies, with short citation and type of standard examined, is reproduced in Appendix Table B.2; the per-record full-text disposition log appears in Appendix B.1.1.

Although none of the 21 studies focuses directly on distribution system operators, all examine design or product standardization in project-based, engineering-intensive settings where assets are capital-intensive, long-lived, and safety-critical. This makes them conceptually close enough to derive transferable mechanisms for grid expansion projects while clearly exposing the gap around DSO-specific theorization that this thesis addresses.

3.1.2. Conceptualizing asset standardization

Across the 21 papers, asset standardization is consistently defined as the deliberate, repeated use of common designs, components, and procedures to create predictable project outcomes rather than as a one-off design choice (Choi, Kwak, & Chi, 2023; Gibb, 2001). The construction literature emphasizes the interfaces between components rather than the components themselves and links technical sameness directly to stakeholder alignment and performance (Choi, Kwak, & Chi, 2023; Gibb, 2001; Kumaraswamy & Chan, 1995). Industrial facilities and small modular reactor contexts extend the concept to corporate systems of standard designs that shift work from one-off construction to repeatable manufacturing (Y. Li et al., 2023; Lyons & Roulstone, 2018; Silka & Butyrin, 2021).

The reviewed studies treat standardization as multi-level. It can refer to individual components and equipment, to pre-assembled modules such as bathpods, containers, and precast panels, and to corporate systems of standard designs and associated business processes (Gibb & Isack, 2001; Y. Li et al., 2023; Robinson et al., 2011; Silka & Butyrin, 2021). BIM- oriented work adds that asset standards are embedded in information models and object libraries, with BIM maturity determining how consistently standardized objects and layouts are reused across projects (Bayzidi et al., 2025). Taken together, these conceptualizations frame asset standardization as the repeated use of shared building blocks and work methods, validated by prior experience, to enable replication, coordination, and industrialized delivery rather than bespoke one-off engineering (Aapaoja & Haapasalo, 2014; Choi et al., 2022; Zuo & Yang, 2024).

The reviewed studies also treat standardization as a continuum rather than a binary state. Gibb (2001) introduces four levels of pre-assembly, from component sub-assembly to full volumetric pre-assembly, which many later studies use as an analog for degrees of standardization. Bayzidi et al. (2025) formalize four modularization grades and four levels of standardization from non-standardization to advanced standardization. Configurational capital-project studies report that actual programs range from roughly 25 to 95% standardized content with a mean around 72.5%, illustrating both the quantitative and structural variation in how far standardization is pursued in practice (Choi, Shrestha, Kwak, & Shane, 2020b; Shrestha et al., 2021; Shrestha et al., 2020). For this thesis, the spectrum framing is analytically interesting: the question for DSOs is not whether to standardize but how far to standardize for a given asset type in a given organizational and system context. The operationalization of this continuum across three analytically separable axes is developed as a sensitizing concept in Section 3.3.3.

3.1.3. Adjacent concepts

Asset standardization in infrastructure is rarely implemented in isolation. The reviewed studies repeatedly intertwine it with modularization, prefabrication, pre-assembly, and design-one-build-many (D1BM) approaches (Bayzidi et al., 2025; Gibb, 2001; Y. Li et al., 2023; Lyons & Roulstone, 2018; Mehta, 2024; Robinson et al., 2011; Silka & Butyrin, 2021; Zuo & Yang, 2024). Beyond the 21 included articles, a broader set of screened but excluded papers reinforces the proximity of additional concepts such as modular integrated construction and off-site construction (e.g. Nguyen & Pishdad-Bozorgi, 2023; Shi et al., 2022; Wuni & Shen, 2019), product-platform strategies (e.g. W. Li et al., 2021; Mignacca & Locatelli, 2021), and design-for-manufacture-and-assembly approaches (e.g. Jarkas, 2011; Lei et al., 2024; Yuan et al., 2020). For this thesis, distinguishing but explicitly relating these concepts sharpens the analytical focus of SQ1 by defining what counts as internal asset standardization while acknowledging that DSOs are likely to operationalize it through combinations of standardized components, modular building blocks, standardized processes, and digital information structures.

A feature of the construction and capital-project literature that is analytically significant for this thesis is that it largely does not distinguish between the decision to adopt a standardization program and the subsequent process of implementing it in projects. Adoption and implementation are typically treated as a single integrated managerial strategy, with drivers, barriers, and critical success factors presented together (Choi, Shrestha, Kwak, & Shane, 2020a; Gibb & Isack, 2001). Building on the adoption–implementation distinction drawn in Section 1.2.2, the empirical analysis in this thesis assumes adoption for all three case organizations and focuses on implementation depth as the dependent dimension of interest. This is the first specific point at which the thesis enters the innovation-implementation literature stream identified in Chapter 1: by importing the Klein and Sorra (1996) adoption–implementation distinction into a construction-and-capital-project literature that has historically conflated the two.

3.1.4. Mechanisms by which standards affect performance

Across the reviewed literature, standardization emerges as a multi-dimensional intervention that reshapes cost, time, quality, risk, and learning dynamics in capital and infrastructure projects. Five recurring families of mechanisms can be distinguished. Each is described below in terms of how it operates, what activates it, and what blocks it. Table 3.1 consolidates the five mechanisms as M1–M5 with their DSO-specific activation and blockage conditions. The complete inventory of effects in the SLR corpus, with mechanism attribution and KPI dimension, is reproduced in Appendices B.12 and B.13.

M1 Design reuse. Reducing design variety allows organizations to reuse validated templates across projects, cutting per-unit engineering hours, lowering design and oversight costs, and avoiding repeated problem-solving for known configurations (Choi, Shrestha, Kwak, & Shane, 2020a; Gibb, 2001; Mehta, 2024). M1 encompasses design-reuse, process-reuse, and interface-stabilization sub-mechanisms (Aapaoja & Haapasalo, 2014; Gibb, 2001): the sustained activation of the family requires that pre-validated designs be made the default ordering route, that interface specifications be stable enough to permit component substitution, and that deviation require justification rather than being the path of least resistance. The mechanism weakens when project-by-project re-engineering remains the path of least resistance, when documentation is scattered across multiple databases, and when local variants accumulate without being fed back into the specification team. Lock-in risk and technological obsolescence (Choi et al., 2022; Ivanovski & Repin, 2001; Mehta, 2024) are reported as long-term consequences of sustained reuse rather than as weakening conditions, and are taken up among the cross-mechanism friction sources below.

M2 Procurement scale economies. A smaller set of standard components purchased through forecast-based long-term contracts enables volume discounts, more reliable supplier delivery, and streamlined procurement processes (Choi, Shrestha, Kwak, & Shane, 2020a; Lyons & Roulstone, 2018; Mehta, 2024; Økland et al., 2018). The mechanism activates when volume can be committed against the standard across multiple projects, when framework contracts span multiple procurement cycles, and when the qualified supplier base reaches a viable size. It weakens when tender-cycle discontinuity prevents volume aggregation, when emergency-supplier qualification timelines exceed program horizons, or when the surviving variant population fragments demand. Supplier concentration risk (Choi et al., 2022; Mehta, 2024) is a separate operational concern rather than a condition that weakens the mechanism itself; it is addressed through paired sourcing policy decisions taken up in the case material.

M3 Schedule control. Standard projects with known designs and predictable assembly sequences allow more accurate planning, shorter lead times for design and procurement, and reduced schedule variance (Gibb, 2001; Økland et al., 2018). M3 encompasses schedule predictability and prefabrication-enabled off-site work as sub-mechanisms (Økland et al., 2018). Empirical studies report shorter delivery times and faster construction for standardized solutions when contextual conditions are favorable (Choi et al., 2022; Gibb, 2001; Økland et al., 2018). The mechanism activates when standard components are pre-positioned in stock, when prefabrication offsets weather and site dependencies, and when project conditions remain within the design envelope of the standard. It weakens when site conditions fall outside the standard envelope, when brownfield deviation forces bespoke engineering on the critical path, and when permit friction extends timelines.

M4 Quality consistency. Concentrating engineering effort into a limited set of validated configurations with clear specifications, standardized testing, and repeatable assembly procedures reduces workmanship variability and error rates (Aapaoja & Haapasalo, 2014; Gibb, 2001; Mehta, 2024). The mechanism activates when specification precision is sufficient for unambiguous interpretation, when off-site inspection is part of the production-and-delivery model, and when field personnel are familiar with the standard. It weakens when specification ambiguity creates supplier interpretation drift, when procurement bypass routes admit non-standard components, or when one-off product variety persists in the active population.

M5 Learning and portfolio improvement. Repeating the same designs across many projects enables cumulative learning, faster onboarding of new staff, and more systematic capture of deployment experience (Aapaoja & Haapasalo, 2014; Lyons & Roulstone, 2018). M5 encompasses deployment-experience feedback loops and continual improvement of products and components (Lyons & Roulstone, 2018; Silka & Butyrin, 2021). Standardization can support predictable operations and maintenance, worked-out procedures for installation and exploitation, easier maintenance, and reduced training needs (Choi et al., 2022; Gibb & Isack, 2001; Ivanovski & Repin, 2001; Økland et al., 2018), extending into improved whole-life cost performance when portfolios are optimized for the operation and maintenance phase (Lyons & Roulstone, 2018; Silka & Butyrin, 2021). The mechanism activates when process discipline maintains feedback loops between deployment experience and specification update, when standardization management systems capture the learning systematically, and when sufficient time has elapsed for cumulative experience to accrue. It weakens when feedback loops are absent or informal, when process discipline lapses under operational pressure, and when standardization management systems are themselves immature or contested.

Cross-mechanism friction sources. Four friction sources operate across multiple mechanisms rather than against any single mechanism in isolation. The first is *contextual fit*, both spatial (greenfield versus brownfield, urban density, site constraints) and regulatory (planning law, permit regimes, sector heterogeneity); contextual misfit weakens M3 most visibly but also constrains M1 and M4 (Gibb & Isack, 2001; Ivanovski & Repin, 2001; Mehta, 2024). The second is *up-front investment and governance burden*: the long-term benefits of standardization require substantial prior investment in standard design development, governance infrastructure, and change-management capability (Aapaoja & Haapasalo, 2014; Choi et al., 2022; Choi, Shrestha, Shane, & Kwak, 2020), and this operates across all five mechanisms. The third is *technological lock-in and reduced innovation*: sustained M1 and M5 activation can create lock-in to a limited design set, making it difficult to introduce improved components or alternative solutions (Choi et al., 2022; Ivanovski & Repin, 2001; Mehta, 2024). The fourth is *perceived rigidity and cultural acceptance*: strong normative prescriptions, even when technically well designed, can provoke practitioner resistance and informal work-arounds that weaken M4 (specification bypass) and M1 (informal variant accumulation) at the deployment level (Aapaoja & Haapasalo, 2014).

Taken together, these mechanism families and their cross-cutting friction sources support a contingent view of standardization: positive effects on cost, time, quality, risk, and learning arise when technical designs, governance arrangements, and contextual conditions align; in mismatched conditions, the same standardization choices can create deployment-level rigidity, contextual misfit, and operational dissatisfaction.

3.1.5. Enabling factors and implementation challenges

Across the reviewed studies, standardization is portrayed as a socio-technical change program rather than a purely technical design choice. Its success depends on a coherent configuration of organizational, contractual, and contextual conditions, and reported failures are typically attributed not to poor standard design but to inadequate implementation conditions. Synthesizing the SLR codes and quotations yields six clusters of enabling factors and associated challenges. The full inventory of factors and challenges with source attribution is reproduced in Appendix B.2.2.

Strategic governance and ownership. A clear, company-wide standardization strategy backed by management commitment, formal decision models, and enforcement mechanisms is repeatedly identified as a prerequisite for sustained standardization (Choi, Shrestha, Kwak, & Shane, 2023; Choi, Kwak, & Chi, 2023; Choi, Shrestha, Kwak, & Shane, 2020a; Silka & Butyrin, 2021). Where governance is absent or fragmented, programs tend to degrade into ad-hoc collections of standards with no systematic update process or compliance accountability; benefits erode quickly and variation re-emerges (Aapaoja & Haapasalo, 2014). Misaligned contracting and risk allocation, the absence of standardization management and strategy enforcement systems, and a lack of benchmark data on project-management performance are particularly prominent barriers in this cluster (Choi et al., 2022; Choi, Shrestha, Shane, & Kwak, 2020; Mehta, 2024).

Project planning, early integration, and constructability. Standardization delivers its schedule and cost benefits only when standard designs are selected and embedded at the concept stage rather than retrofitted during execution (Choi, Shrestha, Kwak, & Shane, 2020a; Gibb & Isack, 2001; Y. Li et al., 2023). Early design engagement, feasibility analysis of standardization, alignment and approval prior to basic design, and early procurement are repeatedly mentioned as enabling conditions. Constructability reviews that test how standards will perform in different site types and project configurations help avoid late-stage redesign; conversely, late integration of standard designs forces costly rework and generates stakeholder resistance.

Stakeholder collaboration and culture. Cooperative culture, vertical and horizontal alignment, and early engagement of affected parties are widely seen as necessary conditions (Choi, Shrestha, Shane, & Kwak, 2020; Økland et al., 2018). High product variety and customized solutions often reflect not just technical needs but also cultural preferences for bespoke work and limited understanding of the value and risks of standardization (Aapaoja & Haapasalo, 2014; Choi et al., 2022; Økland et al., 2018). The literature additionally identifies the *division of responsibility* as a factor in its own right: when component-selection authority sits with turnkey contractors rather than with the asset owner, owner-defined standards are more easily overridden (Choi, Shrestha, Shane, & Kwak, 2020; Gibb, 2001).

Processes, learning, and change management. Standard products by themselves are insufficient; repeatable measurement processes, formal feedback loops, and disciplined change control are required to keep standards current and to realize learning effects over time (Aapaoja & Haapasalo, 2014; Choi, Shrestha, Kwak, & Shane, 2020a; Choi, Shrestha, Shane, & Kwak, 2020). Standard design maturity assessments that use early deployments to set guidelines for subsequent projects are repeatedly flagged (Choi, Shrestha, Shane, & Kwak, 2020). Organizations lacking such process structures allow standards to drift and deviation rates to accumulate, undermining both quality and learning.

Contextual and regulatory fit. Standard designs perform best on new-build, spatially unconstrained sites with stable regulatory environments (Gibb & Isack, 2001; Mehta, 2024). It is markedly more difficult to use standard products on refurbishment and renovation projects, in dense urban contexts, or when existing building footprints and layouts limit what can be installed (Gibb & Isack, 2001). Poor contextual fit is associated with reduced performance and often forces local adaptation or even abandonment of standardized solutions.

Technology, supplier, and digital enablement. Standards must rest on mature, scalable technologies with reliable supplier support. Technology maturity, scalability and interchangeability, willingness and capability in establishing long-term contracts (Choi, Shrestha, Shane, & Kwak, 2020), and legal and regulatory compliance with material sourcing emerge as important conditions. Digital and information standardization, including BIM, ERP integration, and structured data exchange, is increasingly identified as a complement to asset standardization that may rise to the level of a precondition rather than an option (Bayzidi et al., 2025; Choi et al., 2022). Where digital enablers and information standards are absent, standards exist on paper but are difficult to apply consistently in daily project work; design information may remain tacit, documents may be hard to find, and multiple versions may circulate in parallel.

Taken together, these clusters suggest that implementation success depends on how strategic governance, early-phase design decisions, stakeholder culture, processes and learning structures, contextual fit, and technology and digital infrastructure are configured. The same asset standard can therefore produce very different outcomes across organizations and projects, depending on how these enabling conditions are met.

3.2. Industry consultant interviews: practice-based refinement

To adapt the literature-derived insights to LV/MV grid expansion in Dutch DSOs, five semi-structured expert interviews were conducted with industry consultants involved in DSO strategy, engineering, and digital transformation engagements with two to eight years of relevant experience (Int. I.1–5). The aim was to validate core mechanisms from the SLR, translate construction-based insights into the specific realities of grid expansion, and surface DSO-specific contingencies and challenges that are underrepresented in academic work.

3.2.1. How DSO standardization works in practice

Across the interviews, consultants portrayed DSO standardization not as a one-off technical choice but as an ongoing, negotiated process spanning programs and projects (Int. I.1–5). They described four interconnected layers.

At the *strategic level*, adoption is triggered by portfolio-level pressures such as connection backlogs, congestion, resource scarcity, and regulatory cost constraints (Int. I.1, I.3–5). Several interviewees explicitly linked these pressures to the energy transition, arguing that legacy custom-based processes cannot cope with the required build-out and that standardization is one of the few levers to increase throughput without an unattainable increase in specialized staff (Int. I.1, I.3–4). Importantly, interviewees framed urgency as a condition with *ambivalent* effects rather than as a one-directional accelerator: it makes the need for standardization unavoidable and creates political space for adoption, but it also compresses the time available to develop the infrastructure standardization requires before scale, suggesting that the sequencing of urgency relative to governance development matters for outcomes (Int. I.1, I.3–5). This is consistent with SLR-derived recognition that "time is needed to plan for standardization" (Aapaoja & Haapasalo, 2014; Choi, Shrestha, Kwak, & Shane, 2020a).

At the *design and specification level*, DSOs create internal standard products (e.g., standard distribution rooms, cable families, connection modules) through cross-functional design sessions involving asset management, engineering, procurement, and operations (Int. I.1–5). Interviewees emphasized that asset standardization in practice is as much about the documentation that describes an asset as about the components themselves: standards take the form of end-to-end document sets specifying what the component is, how it should be installed, and which materials and tests are required (Int. I.1, I.3, I.5). The design process is iterative: initial standard concepts are piloted in a small number of projects and revised based on constructability experience, supplier feedback, and local permitting outcomes rather than being fixed from the outset (Int. I.2–5).

At the *governance level*, once a standard product is introduced, program-level governance becomes central (Int. I.2–5). Consultants emphasized the importance of clear ownership structures, formal deviation procedures, multi-disciplinary standardization teams, single sources of truth for standards, and regular review cycles where feedback from projects, procurement, and operations is translated into updates to the standard (Int. I.3–4). In practice, this governance is frequently under-specified: interviewees described standardization initiatives that struggled because there was no implementation organization, no systematic procedure to ensure that standards were embedded in every stage of project delivery, and no long-term ownership for content updates (Int. I.1–2, I.5). Other consultants pointed to cases where technical content had been defined but enforcement systems were weak, leading to reverse engineering from what was being built back into the documentation instead of the other way around (Int. I.1). This *reverse engineering* pattern is analytically significant: it is a vivid practitioner description of what happens when standards exist normatively and procedurally but not structurally, foreshadowing the institutional-versus-behavioral compliance distinction developed in Section 3.3.

At the *project level*, standardization is experienced as a starting point rather than a strict rule (Int. I.1–5). Project teams use standard templates and component sets as their default but routinely negotiate exceptions because of site-specific constraints, third-party interfaces, municipal requirements, or legacy asset incompatibilities. Interviewees stressed that modules and standard products can rarely be applied at 100% penetration across a heterogeneous distribution network; there will always be exceptions that require local adaptation and brownfield integration (Int. I.1–2, I.4–5). Consultants characterized this as a continuous trade-off between throughput and local feasibility, with unmanaged deviations sometimes becoming informal micro-standards that fragment the catalog without being fed back into the official specification (Int. I.2–4).

Taken together, the interviews depict DSO standardization as a program-plus-project process: strategic intent and internal productization at portfolio level, combined with adaptive use and negotiated exceptions at project level, mediated by governance mechanisms and organizational conditions that are still evolving (Int. I.1–5).

3.2.2. Performance effects and mechanisms in the DSO context

Across the five interviews, consultants broadly confirmed the five mechanism families identified in the SLR while adding DSO-specific detail. The complete inventory of positive and negative effects identified in the consultant interviews, including the mechanism through which each effect operates and the interview source attribution, is reproduced in Appendices B.2.4. The resulting consolidated mechanism overview, which is refined upon consultant insights, is represented in Table 3.1. Three areas of nuance that the SLR does not provide in comparable detail warrant explicit attention.

First, the significant *upfront costs* are made explicit: consultants estimated that DSOs may need to free up on the order of 10–20 FTEs of their most experienced specialists for one to two years to develop and embed standards, creating real organizational strain in an energy-transition context where operational capacity is already stretched (Int. I.3–4). Second, *vendor concentration risk* is surfaced as a concrete operational concern rather than an abstract trade-off: when a small number of suppliers provide all standard components, a supply disruption or a supplier's specification change can create disproportionate disruption across the entire portfolio, mitigated through a balanced single-/multi-supplier strategy and by holding strategic standard assets in inventory (Int. I.4). Third, *work-culture and autonomy effects*, largely absent from the academic literature, are identified: standardization can reduce perceived professional autonomy, create feelings of repetitive or "production-line" work, and prompt knowledge loss through the departure of staff who find highly standardized environments unrewarding (Int. I.1, I.4–5). Interviewees also warned that if an organization works in a fully standardized way for a long period, its improvisation and creative problem-solving skills for non-standard cases may erode (Int. I.1).

Interviewees explicitly linked implementation hurdles to breaks or frictions in the mechanism causal pathways. In their interpretation, standardization mechanisms do not fail in the abstract; instead, specific organizational or system conditions prevent them from activating as assumed (Int. I.1–5). When deviation management is weak, M1 and M2 are undermined by proliferating local variants; when digital infrastructure is immature and standards are scattered over multiple databases and document versions, M5 is blocked because standards and performance data cannot be tracked consistently (Int. I.1, I.4).

Table 3.1: The five standardization mechanism families synthesized from the systematic literature review and refined with DSO-specific activation and blockage conditions from the industry-consultant interviews. Mechanism IDs M1–M5 are referenced consistently throughout the empirical chapters and the cross-case analysis. M1 encompasses design-reuse, process-reuse, and interface-stabilization sub-mechanisms; M3 encompasses schedule predictability and prefabrication-enabled off-site work; M5 encompasses deployment-experience feedback loops and continual improvement. Variant reduction is treated within M1 (where reuse implies variety reduction) and M2 (where reduced variants enable volume commitment). The full inventory of effects with mechanism attribution and KPI dimension is reproduced in Appendices B.12 and B.13.

ID	Mechanism	Activates when...	Is blocked when...
M1	Design reuse	Standard pre-authorized for default use; engineering knowledge captured in retrievable form; deviation requires justification; single source of truth available in IT systems	Project-by-project re-engineering remains the path of least resistance; deviation easier than compliance; documentation scattered across multiple databases; reverse engineering from as-built back into specification
M2	Procurement scale economies	Volume committed against the standard; multi-year framework contracts; consolidated demand across projects; supplier qualified on the standard envelope	Tender-cycle discontinuity; emergency-supplier qualification timelines; supplier diversity below minimum-viable threshold; surviving variant population fragments demand
M3	Schedule control	Standard pre-positioned in stock; prefabrication offsets weather and site dependencies; project conditions within design envelope; assembly sequence pre-validated	Site conditions outside the standard envelope; brownfield deviation; permit friction; bespoke engineering on the critical path; informal exceptions accumulate into micro-standards
M4	Quality consistency	Specification precision sufficient for unambiguous interpretation; off-site inspection; field-personnel familiarity with the standard; quality audits embedded in procurement contracts	Specification ambiguity creating supplier interpretation drift; procurement bypass routes; one-off product variety; documentation versions diverge across teams
M5	Learning and portfolio improvement	Structured field-feedback loops; pilot-validated specification; release cycles aligned with deployment cadence; KPI tracking of deviations and adherence	Absent measurement infrastructure; workforce-growth knowledge dilution; tender-cycle resets discontinuing learning; lack of long-term ownership for standard maintenance

3.2.3. Enabling factors and challenges in the DSO context

The complete inventory of factors and challenges identified in the consultant interviews is reproduced in Appendix B.2.5. Compared to the SLR factor framework, the consultant insights broadly confirm the importance of all six SLR clusters; the value of the interviews lies less in introducing wholly new categories than in adding granularity within them, and in surfacing a small number of factors and challenges that the construction-standardization literature treats only thinly. Rather than re-list the inventory, this section highlights, per cluster, one factor or challenge that the consultants foregrounded but that has no clean SLR counterpart, and notes where the remaining factors in the cluster substantially overlap the SLR baseline.

Within *strategic and organizational governance*, the consultant-specific addition is governance and operating-model alignment: new standardization structures must be fitted to the organization's existing decision rights and accountability lines rather than layered on top of them as parallel bodies (Int. I.2–3, I.5). The remaining factors in this cluster, management commitment, a strategic "standard unless" approach, and a dedicated multi-disciplinary standardization team, map closely onto the SLR factors of management commitment, strategic standardization approach, and dedicated standardization team.

For *project planning and early-phase integration*, the consultant material adds little at the factor level and instead corroborates the SLR directly: the claim that standards introduced after basic design produce far less benefit than those integrated into early procurement and early stakeholder engagement (Int. I.3–5) restates the pre-basic-design alignment factors already established in the literature. The one element with no SLR equivalent is located at the challenge level and is taken up under human capital below: the difficulty of freeing the specialist capacity that early-phase integration presupposes.

In *stakeholder collaboration, culture, and change*, the highlighted addition is the explicit preservation of autonomy through a bounded tailoring allowance (an "80/20" rule that retains room for local adaptation within a standardized envelope), which consultants tied directly to professional identity and job satisfaction (Int. I.1–5). The cluster's other factors, cross-functional cooperation, stakeholder co-creation, and an innovation-embracing, cohesive culture, overlap the SLR factors of cooperation among stakeholders and cooperative culture; the autonomy and 80/20 framing is the genuinely additional contribution.

Within *processes, learning, and change management*, the consultant-specific factor is a single source of truth for standards, supported by train-the-trainer diffusion, so that one authoritative version is used rather than scattered local variants (Int. I.3–5). The remaining factors, formal feedback loops, periodic releases, and rigorous change management, overlap the SLR factors of formal lessons-learned processes and value-based change control.

For *technical design and constructability*, the consultants did not add a factor beyond the SLR but sharpened its emphasis: interface specifications matter more than component specifications, because stable interfaces let components be substituted as suppliers and technologies evolve (Int. I.1, I.3–5). This restates, rather than extends, the SLR factors of interface-focused design and constructability (Gibb, 2001), together with modularization and pre-assembly as design strategies.

In *technology maturity and digital enablement*, the SLR factor of digital and information standardization is confirmed, but the consultants reframed it through a specific gap absent from the literature: asset standards are often relatively mature while documentation and data standards remain fragmented, producing reverse engineering and local workarounds rather than consistent reuse (Int. I.1, I.4–5). The supporting factors, searchable storage and integration into project-management, ERP, and design tools, overlap the SLR baseline.

Beyond these six clusters, the consultant interviews add granularity on several implementation challenges that academic work discusses only thinly: the difficulty of freeing up 10–20 FTEs for one to two years; the sequencing problem of which assets to standardize first; the limited transferability of standards between DSOs; the depth of cultural change required to reconcile standardization with the perceived autonomy and creativity of experienced engineering staff; and the risk that standardization erodes improvisation and innovation capabilities if implemented in an overly rigid way (Int. I.1, I.3–5).

Two consultant observations carry particular analytical weight for the sensitizing concepts developed in Section 3.3. First, several of these challenges, notably historical fragmentation, cultural resistance, and tacit-knowledge loss in workforce transition, were described by consultants not as transition friction that disappears once implementation succeeds but as recurrent features of the operating environment that governance must continuously contain (Int. I.1, I.3–5). This raises the analytical possibility that the appropriate evaluation criterion for a standardization program is not whether challenges are resolved but whether their frequency and severity are kept at an organizationally acceptable level; the case material will examine whether this containment framing is supported empirically. Second, governance is not optimized once at program initiation but accumulates capability over multiple procurement cycles when functional feedback loops exist, and degrades when they do not (Int. I.1–3, I.5). This points to a dynamic dimension that the SLR's largely static treatment does not show and that the synthesis section takes up explicitly.

3.3. Synthesized insights

3.3.1. Convergences between literature and practice

The interview-based picture of DSO standardization strongly aligns with construction and facility design standardization across four dimensions.

First, both streams converge on internally created solution templates for multi-project portfolios as the unit of analysis. Consultants framed DSO standardization as choosing the scope and granularity of internal product families, building on IEC/NEN baselines while defining organization-specific catalogs and option sets. This is consistent with capital-project work that treats standard facility designs and corporate systems of standard designs as internal assets (Choi, Shrestha, Kwak, & Shane, 2020a; Y. Li et al., 2023). Second, both streams emphasize cross-functional co-design as central to success: DSOs negotiate standards through design workshops balancing asset management, engineering, procurement, and operations, and construction literature similarly stresses that standardization programs succeed when governance mechanisms cut across organizational silos rather than being owned by a single function (Aapaoja & Haapasalo, 2014; Choi, Shrestha, Kwak, & Shane, 2020a). Third, both streams point to standardization as a socio-technical program that requires governance infrastructure, process discipline, and cultural change on top of technical design work. Fourth, both streams treat standards as adaptive templates with built-in options and routine exceptions rather than as rigid prescriptions (Gibb, 2001). DSO practitioners described controlled deviations as normal for municipal requirements, ground conditions, or supplier limitations, but noted that unmanaged exceptions erode program benefits.

3.3.2. Extensions and tensions

The industry consultant interviews extend the academic picture in three directions that the SLR does not cover adequately.

First, they make the *organizational transformation* dimension explicit: standardization in DSOs is not primarily a design exercise but a multi-year change program requiring dedicated governance infrastructure, sustained leadership commitment, and deliberate cultural change management (Markard, 2011; Verbong & Geels, 2007). A direct implication is that governance architecture is not a static design choice optimized once at program initiation; it accumulates capability through iterative procurement and deployment cycles when functional feedback loops exist, and degrades when they do not. The SLR's largely cross-sectional treatment of governance does not make this dynamic visible.

Second, the interviews surface the *strategic–tactical–operational layering* of standardization in project-based organizations, showing that program-level governance choices directly influence whether project-level implementation is consistent or fragmented. The presence or absence of a dedicated implementation organization with standardized processes appears to be closely associated with whether standards remain "on paper" or translate into changed day-to-day work.

Third, the interviews highlight the role of *digital and information standardization* as a necessary complement to physical asset standardization, which the construction literature treats as a background consideration rather than a primary enabling factor. In DSO practice, fragmented documentation, multiple databases, and lack of KPI infrastructure are themselves perceived as core implementation barriers. The analytical implication is stronger than the construction literature acknowledges: digital and information infrastructure is the substrate on which any structural enforcement of standards must operate, and its absence forces organizations back onto behavioral compliance mechanisms whose limitations are documented in the same data.

Several tensions also emerge from the combined evidence. Strong governance and process discipline, which the SLR presents as broadly positive, can overload organizations already stretched by congestion and create a blueprint-heavy culture that inhibits organizational adaptability. Aggressive standardization can conflict with short-term operational urgencies, leading either to backsliding into bespoke solutions or to unsafe deviations from standards when project teams cannot obtain formal approval for necessary exceptions quickly enough. Highly standardized environments can reduce perceived professional autonomy and creativity, creating a tension between efficiency and job satisfaction. These tensions are not incidental failures but structural features of operating a standardization program in a regulated infrastructure context under volume pressure.

3.3.3. Sensitizing concepts for the empirical analysis

Drawing on the SLR and industry consultant interviews, three sensitizing concepts structure the data collection instruments, coding schemes, and analytical logic used in Phases 2 and 3: *asset complexity*, *governance architecture*, and *implementation depth*. They are not hypotheses to be confirmed or rejected; they are analytical lenses that guide attention toward the theoretically significant dimensions of each case. Together they form an initial governance demand–capacity model: asset complexity sets the governance demand a standardization program must meet, governance architecture is the governance capacity the organization deploys to meet that demand, and implementation depth is the outcome of the demand–capacity relationship as observed in case material.

The model integrates two theoretical streams that operate at different levels of analysis. Contingency theory (Donaldson, 2001; Shenhar, 2001) supplies the demand side: it specifies the conditions under which different governance architectures are required given asset and organizational contingencies. Innovation implementation theory (Klein & Sorra, 1996) supplies the capacity side: it specifies the mechanisms through which a governance architecture, once in place, produces implementation effectiveness.

Asset complexity. The governance demand of a standardization program is expected to increase with the complexity of the asset being standardized. The construct itself is brought into the empirical phases from the SLR (Aapaoja & Haapasalo, 2014; Choi, Shrestha, Kwak, & Shane, 2020a; Choi, Shrestha, Shane, & Kwak, 2020; Ivanovski & Repin, 2001; Lyons & Roulstone, 2018) and the industry consultant interviews (Int. I.1–5). The construct as it stands is understood along six dimensions.

First, *component count and interface density*: the number of discrete components an asset integrates and the physical and functional interfaces between them. A cable interfaces with the grid at two termination points; a medium-voltage compact station assembles transformer, switchgear, low-voltage panel, civil enclosure, earthing system, and remote terminal unit into a single co-located system, each with its own supplier and performance envelope. Component count and interface density propagate directly into specification consensus burden, reversibility risk, and supply chain coordination (Bayzidi et al., 2025; Lyons & Roulstone, 2018). Second, *stakeholder density in specification decisions*: how many functions and parties must be coordinated to write the standard (Aapaoja & Haapasalo, 2014; Choi, Shrestha, Kwak, & Shane, 2020a). Third, *deployment feedback speed*: how quickly post-deployment performance information returns to the specification team (Aapaoja & Haapasalo, 2014; Choi, Shrestha, Shane, & Kwak, 2020). Fourth, *international normative coverage*: the extent to which IEC, NEN, or equivalent norms guide the technical specification work the DSO must do internally (Bayzidi et al., 2025; Gibb, 2001). Fifth, *reversibility risk* once designs are deployed at scale, derived from the long-asset-lifetime and lock-in observations (Ivanovski & Repin, 2001; Lyons & Roulstone, 2018). Sixth, *external interface count and ownership distribution*: the number of adjacent assets the standardized asset must interface with at deployment, weighted by whether those adjacent assets are owned by the same DSO function, by a different function within the same DSO, by another DSO in a consortium, or by an external party (transmission operator, customer, contractor). Ownership distribution is a multiplier rather than a count: cross-organizational interfaces require coordination mechanisms that within-function interfaces do not.

These six dimensions, as visualized in Figure 3.1 together provide a multi-axis profile rather than a single ordinal measure: an asset can be high on some dimensions and low on others, and the *pattern* of complexity rather than its overall level is what shapes the governance demand the program must meet. The empirical chapters report each case's complexity profile in the within-case syntheses (Chapters 4–6); the cross-case comparison in Chapter 7 examines whether complexity-profile differences align with the governance architecture differences predicted by the framework. Supply chain concentration, considered as a possible seventh dimension during analysis, is treated as a procurement-context factor that interacts with M2 rather than as a property of the asset itself, since two assets of equivalent technical profile can face very different procurement environments.

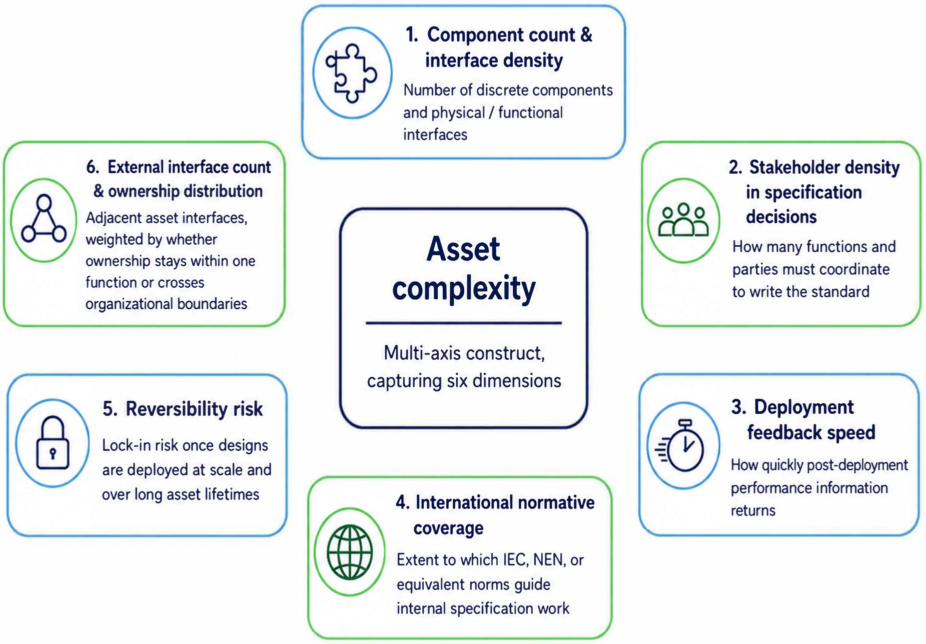


Figure 3.1: Asset complexity as a multi-dimensional construct. The six dimensions indicate how technical, organizational, and lifecycle characteristics of an asset shape the governance demand of a standardization program.

Governance architecture. The configuration of normative commitments, procedural mechanisms, and structural compliance enablers that an organization deploys to govern its standardization program is expected to be a primary determinant of implementation depth. Governance architecture in this sense is itself a form of organizational standardization layered on top of the asset standardization that is the primary object of analysis, consistent with the nested-layers view introduced in Section 1.2.2. Synthesizing across the SLR and the industry consultant interviews, governance architecture is treated as a layered construct with three tiers, each necessary but individually insufficient.

The *normative tier* establishes the principle that a standard exists, is authoritative, and applies as the default. Without this tier, compliance is optional. It is operationalized through senior management commitment, explicit ownership assignment, and policy that places the burden of justification on deviations rather than on standard use. SLR anchors include management commitment to standardization and a strategic standardization approach (Choi, Shrestha, Kwak, & Shane, 2020a; Silka & Butyrin, 2021). Consultants identified visible management commitment and a "standard unless" narrative as the threshold condition without which standardization remains a side project (Int. I.1, I.3).

The *procedural tier* operationalizes normative commitment through four mechanisms: cross-functional specification pre-authorization (multi-disciplinary team formats); designated specification change management with controlled release cycles; formal deviation request processing that places the burden of proof on the requester; and systematic field feedback loops that return deployment experience to the specification team. SLR anchors include rigorous management of change and discipline and value-based change control (Choi, Shrestha, Kwak, & Shane, 2020a; Choi, Shrestha, Shane, & Kwak, 2020). Industry consultant support runs through the multi-disciplinary standardization team, single-source-of-truth, and formal-deviation-procedure codes (Int. I.3, I.4).

The *structural tier* converts compliance from a behavioral obligation into a system default by making non-standard configurations structurally harder to procure than standard ones. Its operational form is IT-mediated ordering constraints, supply-chain default routing, and procurement-system integration. The SLR signals this tier negatively, through the recurrent code "lack of standardization management and strategy enforcement system" (Choi, Shrestha, Kwak, & Shane, 2020a), and positively through the digital and information standardization literature that documents what structural enforcement requires (Bayzidi et al., 2025; Zuo & Yang, 2024). Consultant confirmation is most exemplary in the "reverse engineering" pattern that consultants described, where as-built configurations flow back into the specification rather than the other way around (Int. I.1), which is precisely what happens when an organization has the normative and procedural tiers but lacks the structural one.

A complementary distinction sharpens the architecture. Compliance mechanisms within governance architecture can be *behavioral*, operating through cultural norm, team gatekeeping, and individual decision-maker compliance, or *institutional*, operating through system constraints that do not depend on individual choice. Behavioral mechanisms are cheaper to establish but degrade under workload pressure, personnel change, or operational urgency. Institutional mechanisms are more expensive to establish but provide governance resilience that behavioral mechanisms alone cannot match. Together, the three tiers and the institutional/behavioral distinction provide the analytical vocabulary that the empirical phases use to characterize each case organization's governance arrangement, as represented in Figure 3.2.

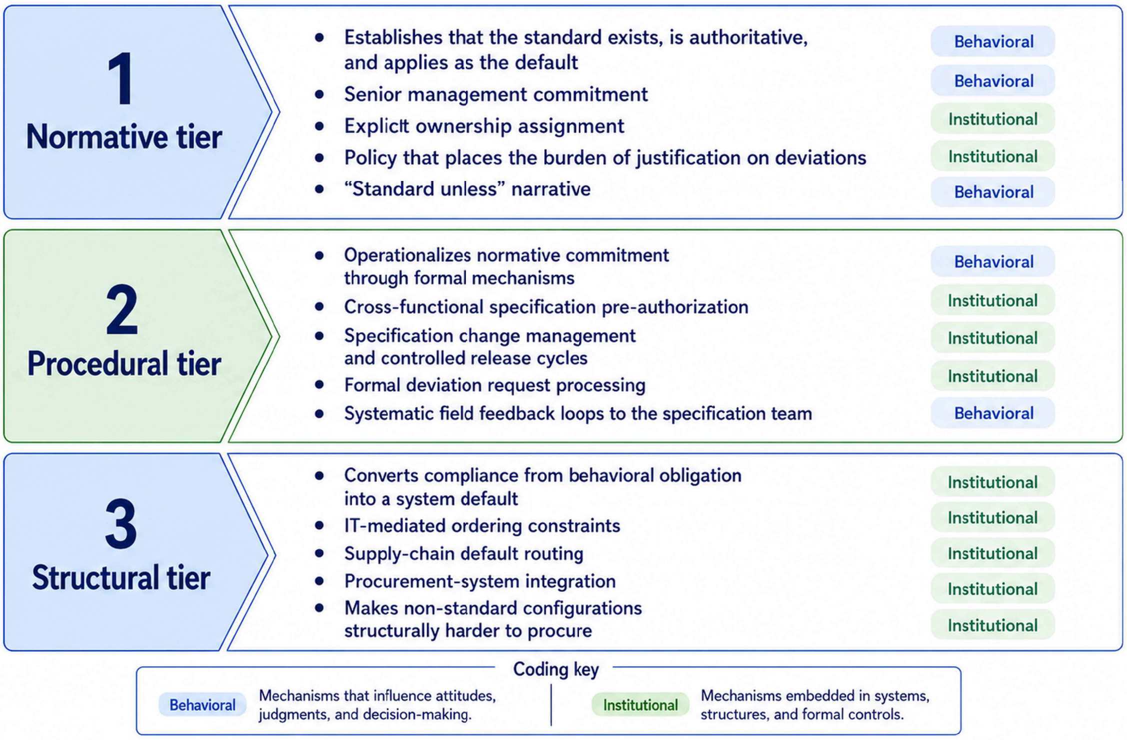


Figure 3.2: Governance architecture as a layered three-tier construct. The figure distinguishes normative, procedural, and structural governance mechanisms and shows how these mechanisms support implementation depth through behavioral and institutional compliance substrates.

Implementation depth. Implementation depth refers to the extent to which the standard is actually applied consistently across projects. It is distinct from program intent: high governance investment can fail to produce implementation depth if structural compliance mechanisms are absent, and conversely, low governance investment can produce adequate depth for lower-complexity assets. Industry consultant interviewees emphasized that even strong standard designs can remain underused when project organizations retain wide discretionary freedom (Int. I.1–5). The empirical phases operationalize implementation depth through measures available in case material: *ordering compliance rate* (the share of orders for an asset class that pass through the standard procurement channel), *variant reduction over time* (the trajectory of the active standard set), *deviation frequency* (approved deviations per year), and the *ratio of approved-to-informal deviations* (a proxy for whether the deviation governance procedure captures the population of exceptions). These proxies are imperfect, since systematic before-and-after KPI tracking is not present at any of the case organizations, a structural gap that itself becomes a finding of the study (Chapter 7).

Because all six cases involve ongoing rather than fully completed programs, the study does not measure verified outcome improvements; practitioner perceptions of whether mechanisms are activating or being blocked serve as supporting evidence within each case. This explicit focus on perceived outcomes ensures that the empirical analysis stays aligned with the exploratory and descriptive nature of the research design rather than implying outcome verification.

The standardization continuum: three analytically separable axes The three sensitizing concepts above compare case organizations on governance demand, capacity, and depth, but they presuppose that the cases are comparable in kind: that the standards being implemented are themselves of broadly similar character. This presupposition does not hold across the six embedded cases. A cable standard, a distribution-station standard, and a transportation station standard differ not only in the asset they govern but in the *form* of standardization they instantiate. Comparing implementation depth across cases without first specifying how the underlying standardization forms differ risks comparing categorically distinct objects under a single label.

This subsection therefore introduces three analytically separable axes along which any specific standardization arrangement can be positioned. The axes are conceptually independent but empirically often correlated: movement along one axis frequently accompanies movement along another, but the three can be specified separately and each tracks a distinct dimension. Together they define what "the standard" is for a given asset, which is a precondition for comparing implementation depth across cases.

The variant-reduction axis records the number of configurations admitted under the standard, from bespoke per-project engineering at the low end to a single article number at the high end, with intermediate points corresponding to regional variants, formalized variant families, and few standard variants.

The prefabrication axis records the extent to which the standardized asset is pre-assembled before site delivery. Gibb (2001) four-level pre-assembly continuum provides the construct vocabulary, from component sub-assembly to volumetric pre-assembly. In terms of empirical cases: cables sit high on this axis because they arrive at site as essentially complete assemblies; distribution stations sit in the upper-middle range because they are increasingly assembled off-site as compact modular units; the transportation station sits lower because the transport–distribution-regulation features requires substantial on-site assembly given its high-voltage interface requirements and site-specific integration (Lyons & Roulstone, 2018; Silka & Butyrin, 2021).

The customer-order decoupling point (CODP) axis records the point in the order fulfilment process at which the customer's order specification enters production. Jonsson (and others) adapt the routes (concept-to-order, engineer-to-order, make-to-order, assemble-to-order, make-to-stock, ship-to-stock) to industrialized construction (Jonsson & Rudberg, 2014).

The three axes track conceptually independent dimensions even where they correlate empirically. A cable program can be high on variant reduction, high on prefabrication, and high on CODP. A transportation station program can be moderate on variant reduction, lower on prefabrication, and lower on CODP given site-specific integration requirements. Treating the three as a single axis would collapse these distinctions and obscure what makes each program analytically distinct. The cross-case analysis in Chapter 7 positions each case along the three axes before comparing implementation depth, with the comparison interpreted relative to the standardization form rather than against a universal benchmark; the consolidated positioning table is reproduced as Table D.1 in the Appendix.

3.3.4. Implications for the case study design

The literature and interview findings have three direct implications for the design of the empirical phases.

First, they inform case and embedded-unit selection. The six cases were chosen to provide variation along the asset complexity dimension within and across organizations that together perform most of distribution network operation in the Netherlands, enabling the cross-case analysis in Chapter 7 to examine whether asset complexity is in fact associated with different governance requirements and implementation patterns, without claiming statistical generalization.

Second, they structure the interview guides and coding schemes. The Phase 1 consultant guide (Appendix B.1.4) and the Phase 2 DSO guide (Appendix C.1.2) probe four substantive blocks aligned with the sensitizing concepts: program governance and ownership of the standard, which probes governance architecture predominantly at the normative and procedural tiers; deviation management and exception handling, which probes the procedural tier directly and the structural tier indirectly; organizational and contextual factors underlying implementation challenges, which probes the case-specific manifestation of asset complexity and surfaces the emergent themes of organizational fragmentation and benefit measurement; and perceived effects and limitations of the standard, which probes practitioner perceptions of mechanism activation. The structural tier of governance architecture is not probed by a dedicated question stem in either guide and was investigated where it surfaced inductively during the interviews. The mechanism families M1–M5 are probed indirectly through the perceived-effects block rather than by direct mechanism-by-mechanism questions, because mechanism activation is observed through reported effects.

The Phase 3 DSO codebook (Appendix C.1.3) extends both prior layers. It contains three classes of codes. The first class is deductive extensions of the SLR and consultant codebooks, covering effects, success factors, and implementation challenges; these codes map onto the three sensitizing concepts and onto the six SLR factor clusters of Section 3.1.5. The second class is cross-case moderating factor codes, organized under sub-headings that correspond to asset complexity and the emergent constructs developed in Chapter 7. The third class comprises inductive structural codes added during within-case analysis to support narrative reconstruction (case context, program timeline and key moments, organizational actors and governance roles, project phases and operational steps, and situation around the standard). The third class captures the temporal, role, and state structure of each program and underpins the within-case descriptions in Chapters 4–6.

Third, they define the cross-case analytical logic. Within-case analysis builds narrative accounts of how standardization programs have unfolded in each DSO, organized around the sensitizing concepts. Cross-case analysis then compares those accounts to identify patterns and to develop the themes that operate above the level of individual case findings, including the emergent constructs of organizational fragmentation and the structural measurement gap.

3.3.5. Chapter conclusion

The SLR and industry consultant interviews together provide the theoretical foundation for the empirical analysis. The central insight is that standardization benefits are conditional rather than automatic: they depend on governance infrastructure, organizational context, asset complexity, and the wider technical and regulatory system in ways that mean similar standards can deliver very different perceived outcomes across organizations. This conditionality justifies both the contingency perspective adopted in Chapter 1 and the comparative case study design adopted in Chapter 2.

The three sensitizing concepts developed in this chapter, organized through the governance demand–capacity model, structure the empirical analysis and enable the cross-case comparison in Chapter 7 to move beyond cataloging implementation challenges toward an analytical account of why different organizations and asset types encounter different patterns of challenge and achieve different levels of implementation depth. Further dimensions emerged inductively across the cross-case analysis: organizational fragmentation is developed as Theme 2 in Chapter 7, the inherent variability that prevents complete standardization as Theme 3, and the structural absence of benefit-measurement infrastructure as a sub-finding of Theme 1. The three-axis standardization continuum provides the descriptive vocabulary against which implementation depth across cases can be interpreted.

The chapter prepares for the empirical exploration of how organizational structure and processes influence the implementation of asset standards in Dutch DSO LV/MV grid expansion programs and projects. Chapters 4–6 develop within-case narratives organized around the three sensitizing concepts; Chapter 7 compares those narratives to identify the patterns that the demand–capacity model can structure; Chapter 8 tests whether the theoretically derived propositions are recognized as real and significant by senior practitioners; and Chapter 9 integrates the empirical findings with the theoretical framework developed here to derive the study's contributions to the three literature streams identified in Section 1.3.1.

4

Within-case analysis: DSO-A

4.1. DSO-A: organizational context

DSO-A is one of the three largest Dutch distribution network operators, serving more than 3 million households and businesses across multiple provinces (DSO-A secondary source S-A.1; see Appendix C.1.4). It manages more than 100,000 km of electricity and gas networks combined, and reported gross investments increased 19% in 2025 over 2024 (sources S-A.1, S-A.2). The 2026 investment plan projects multiple billion across 2026–2028, a 27% increase over the 2024–2026 plan (source S-A.3). DSO-A's corporate ancestry reflects successive mergers of approximately 54 predecessor provincial and municipal utilities, a structural legacy whose consequences are discussed in Section 4.1.2. For most of its history DSO-A operated under a maintenance-and-operate logic; the energy transition has disrupted that logic fundamentally, as DSO-A's own program documentation states that the network built over a hundred years must now be essentially replicated within ten (source S-A.4). As one interviewee puts it: "the primary driver is labor capacity [. . .] with as few hands as possible from our own organization, as much work as possible can be done outside" (Int. A-1).

4.1.1. Organizational structure

Specification authority for all distribution network assets sits within the Asset Management (AM) function, specifically the modular-construction subdepartment that owns DSO-A's standardization program. This team develops and maintains component specifications, governs European tender processes, and runs the two governance bodies through which changes are ratified: the core team, in which technical specialists develop proposals, and the multi-disciplinary team (MDT), which brings representatives from across the organization to reach collective agreement before any specification update becomes operational (Int. A-1; source D-A.1, D-A.2).

The Strategic Resource Management (SRM) function provides the procurement enforcement mechanism: it controls which component variants are payable under framework agreements, making specification compliance financially mandatory rather than merely formally required (Int. A-1; Int. A-2). The net architecture function in Client and Design determines station siting and capacity requirements; spatial planning, sustainability, and an LV net specialist also contribute requirements to the MDT (Int. A-1; Int. A-4). The Operationeel Installatieverantwoordelijke (OIV) function holds independent electrotechnical safety authority and constitutes a mandatory commissioning gate (Int. A-1; Int. A-3).

Two realization chains handle field deployment. The new-grid chain executes large-scale construction, combining a small DSO-A presence with contractor teams of up to 40 people laying MV cable routes of 10 to 60 km (Int. A-4); in 2025 DSO-A laid more than 2,600 km of electricity cable and constructed or modified more than 2,200 distribution stations (source S-A.2). The smaller-works chain handles individual connections and modifications. Thirteen regional branches carry out maintenance and legacy network work; as descendants of predecessor utilities, they retain distinct technical cultures that the standardization programs are designed to bridge (Int. A-2 to Int. A-4). DSO-A supplies standardized components directly from central stock to contractors, so logistics sits at the intersection of procurement rhythm and field deployment.

4.1.2. Organizational standardization adoption driver

Component standardization existed in incipient form before the energy transition, but the urgency to drive systematic governance and internal alignment was largely absent: "everything could be bespoke, because we had enough people, enough materials, the labor market also looked different" (Int. A-1). Int. A-4 captures the scale of the shift: "with the grid congestion, we have essentially received the assignment to lay the network again in about 10 years that we laid in the past 100 years.

That is something entirely different from managing and maintaining. You are building networks". DSO-A's total workforce stood at approximately 10,400 FTE in 2025, having grown by an average of 1,000 FTE relative to 2024 to address technical labor scarcity (sources S-A.1, S-A.2). The 2025 annual report nonetheless acknowledges that further headcount expansion does not translate linearly into increased output: technician scarcity, induction lead time, and spatial and permitting constraints all impose ceilings (source S-A.2). DSO-A has executed approximately 10% more work each year since 2019, with investment commitments continuing to outpace physical realization capacity, a gap the modular-construction program documentation explicitly frames as requiring industrialized production logic (sources S-A.2, S-A.4).

4.2. Case A.1: MV-LV transformer distribution stations

4.2.1. Historical background

DSO-A's network diversity is a structural inheritance from the consolidation of approximately 54 predecessor companies, each with autonomous technical traditions (Int. A-2; Int. A-3). When distribution-station manufacturing was transferred to an external party around the early 2000s, the initial contract preserved existing product designs and transferred staff, leaving no incentive for technical change. Technical divergence began only when that contract expired and a formal European tender became legally required, by which time a new generation of specifiers made different choices: the previous contract had already offered four or five enclosure variants before internal options were counted, so variant multiplication was embedded in the procurement architecture itself (Int. A-2; Int. A-4).

A first rationalization attempt around 2014–2015 dissolved without a binding specification because urgency was absent (Int. A-1; Int. A-2): "ten years ago we started with great enthusiasm, and then it faded away" (Int. A-2). That changed after the Dutch Climate Agreement of 2019, which set binding 2030 emissions reduction targets and triggered planning across all DSOs to expand the electricity network at unprecedented pace (Rijksoverheid, 2019) (source S-NL.1). The modular-construction program document projected doubling the network before 2030 and quadrupling the annual work package (source S-A.4); subsequent reporting has quantified the trajectory at approximately 37,000 km of additional cable and 25,000 distribution stations over the coming decade (source S-A.2). Maintaining over a thousand design variants was structurally incompatible with that production rate. The contrast between the 2014–2015 working group that faded away and the 2018–2019 relaunch is itself analytically instructive: the same technical problem twice, but only the second attempt inherited the structural urgency capable of sustaining it. This is an instance of the organizational-fragmentation pattern developed cross-case in Chapter 7 (Theme 2, Section 7.5.2): variant proliferation was not a governance failure but a structural inheritance from merger-origin fragmentation that required deliberate program-level effort to contain.

4.2.2. Timeline and key milestones

Program relaunch and contract award (2018–2021). The 2018–2019 relaunch proceeded through the standard European Public Procurement Directive sequence from definition and scope through market reflection, formal tender publication, and a verification phase. Because a compact station requires a concrete mould that cannot be economically produced before contract award, assessment proceeded on drawings rather than physical prototypes: "you have to assess on paper whether it is a good working MSR" (Int. A-2). The total elapsed time from first initiation to award was approximately seven years (Int. A-1; Int. A-2), attributable not to technical complexity but to the coordinative overhead of aligning a large, heterogeneous organization: "everyone has an opinion about it" (Int. A-1). The primary supplier announced its multi-year framework contract in late 2021 (source S-S.1). The tender produced contracts with two suppliers under a dual-source philosophy. The range covers a small variant up to 630 kVA serving approximately 70 to 80% of deployment contexts, and a medium variant up to 1,000 kVA for higher-capacity nodal situations. The configuration tool permits 1,085 distinct permissible combinations across parameters such as transformer type, LV rack width, cladding, and accessories, introduced to steer engineers into the ordering framework (Int. A-1 to Int. A-3; source D-A.3).

Waterproofing failure and emergency supply response (2024). The waterproofing failure of the primary supplier's compact-station product, made public in early 2024, was the most significant quality incident of the current period (source S-S.2). Approximately 800 deployed stations were found non-watertight, and DSO-A could not halt acceptance without stalling grid expansion: "we cannot shut down BV Nederland" (Int. A-3). The second contracted supplier lacked the capacity to absorb the shortfall, and onboarding an emergency third supplier consumed two years and yielded only 50 units at what Int. A-3 described as "golden station" unit costs. This exposed the two-supplier architecture's fundamental resilience gap: a supplier developing to a defined standard cannot simply be replaced; the new entrant must develop to the exact specification, extending qualification timelines independently of commercial urgency. The minimum viable supplier count for components of this criticality is therefore at least three, a conclusion directly informing the third tender architecture (Int. A-1; Int. A-3).

Mid-program specification disruptions. Two further disruptions illustrate the systemic risk of scaling a standardized design rapidly. Regulatory pressure to phase out SF6 in medium-voltage switchgear, formalized through EU F-Gas Regulation 2024/573 which bans SF6 in new MV switchgear up to 24 kV from 1 January 2026 and extends progressively through 2032 (European Union, 2024), required a redesign of the ring main unit (RMU), affecting interfaces between the RMU, station enclosure, and cable entry geometry. DSO-A has placed a physical SF6-free RMU at a technician facility so that field personnel can familiarize themselves before encountering it on site, reflecting an organizational recognition that specification changes require deliberate workforce onboarding (Int. A-1). Separately, a compatibility failure emerged when net architects began specifying 630 mm^2 aluminum cables for configurations the station had not been dimensioned to accommodate, requiring an interim copper transition joint at additional cost and installation time per station (Int. A-1 to Int. A-4). Both episodes confirm that specification errors, once embedded in a scaled design, replicate across all deployments until a correction is issued through the change-management process.

High-volume operational deployment and variant rationalization (Q4 2025–2027). By Q4 2025, approximately 97% of distribution-station orders were placed via the configuration tool in compliance with standard variants, at a volume of approximately 300 to 400 compact stations per quarter (Int. A-1). A rationalization effort is simultaneously underway to reduce the 1,085 configurable combinations including color etc. and around 150 without, to six electrical variants (Int. A-1; Int. A-2; source D-A.3), a reduction selected through a documented two-stage scenario appraisal weighing configuration count, coverage, and cost (source D-A.3). Even the rationalized target retains internal multiplicity once supplier and switchgear brand combinations are factored in. The authority to drive this reduction does not reside with those who most acutely experience its necessity: "I would really like to tackle that once. My authority does not extend that far" (Int. A-3). This governance gap, in which the proliferation problem is visible at the field level but can only be resolved through a cross-directorate decision, is itself analytically significant. As Int. A-2 frames the trade-off plainly: "standardization is sub-optimization" at the technical level, but the organizational gains, faster ordering, simpler production, reduced supplier inventory, and more predictable delivery, collectively constitute an optimization that project-level technical overcapacity does not negate. The third tender, planned for 2027, will be structured into three to four lots: core lots for high-volume standard variants and a dedicated innovation lot for urban integration solutions, designed to contain innovation within a governed boundary (Int. A-1).

Current state of the standard. The operational standard consists of two contracted product lines (a small variant up to 630 kVA and a medium variant up to 1,000 kVA). Within that range the specification permits variation along three axes: electrical configuration (RMU field count, transformer type, LV rack width up to fourteen outgoing fields), aesthetic and physical integration (cladding finish, colour, optional roof and facade treatments collected in a municipal options brochure), and secondary equipment (smart-station electronics). Two categories sit outside the standard altogether: approximately 40 walkable stations per year for sites where the compact footprint cannot satisfy municipal demands, and indoor-placement projects for which no standard exists.

4.2.3. Actors and governance structure

Specification authority rests with the modular-construction team within AM. The governance process operates in two sequential bodies: the core team, which assesses technical merit and develops change proposals, and the MDT, which confers organizational legitimacy by bringing representatives from all affected disciplines to collective agreement (Int. A-1; source S-A.4). The entire organization can submit improvement proposals; approved changes are incorporated via biannual release cycles or deferred to the next tender, ensuring change management does not destabilize active supplier relationships while allowing the specification to evolve. The distinction between the bodies is functional: "the core team contains genuinely technical, substantive specialists. The MDT consists of representatives of other organizational units, where it is much more about whether my interest has been properly incorporated" (Int. A-1). For the third tender, a basis-of-design document prepared collectively by all relevant disciplines before specification work begins is intended to surface conflicts in advance.

MDT composition reflects the distribution station's status as a boundary object across functions: net architects, spatial planning, OIV, VMK (labor ergonomics), sustainability, finance, SRM, logistics, and both realization chains all carry legitimate stakes, a composition corroborated by the cross-disciplinary sign-off recorded on DSO-A's rationalization decision document (source D-A.3). External actors include the two primary suppliers, construction contractors, municipalities as ground-acquisition gatekeepers, and the external safety authority. This actor density is simultaneously the program's governance achievement and its defining organizational challenge: regional units retain predecessor-organization cultures, and in the absence of enforcement mechanisms managers can sustain divergent practices (Int. A-2 to Int. A-4). This amplifies governance demand beyond what asset technical complexity alone would require, an instance of the organizational-fragmentation pattern developed cross-case in Chapter 7 (Theme 2, Section 7.5.2). The new-grid realization chain operates a deliberate triage logic in which assignments maximizing straightforward new-grid work are retained while projects with site problems or non-standard requirements are redirected through the net architect, who functions as a de facto scope filter (Int. A-4): residual complexity is systematically routed away from the standardized production stream.

The governance response combines front-loading with structural enforcement. The MDT collects disciplinary input before the specification is locked. SRM controls which variants are payable under the framework contract, making circumvention financially unviable rather than merely formally disallowed. The configuration tool encodes permissible combinations digitally, structurally guiding engineers into compliant configurations: "a compact station goes through a configurator [. . .] you press the button, and essentially that is already the order" (Int. A-2). A formal request-for-deviation process exists for residual cases the standard cannot absorb, because "a standard works 90 to 95 per cent of the time, but there are situations where you simply cannot make it work" (Int. A-1). The 97% Q4 ordering compliance achieved by this combination of mechanisms is the measurable expression of the implementation-depth sensitizing concept from Chapter 3: a program may produce high adoption (the standard is known and accepted) without producing depth (the standard is consistently applied), and DSO-A's compliance figure reflects the depth that procurement enforcement plus tool-level constraint together can sustain.

One limitation is feedback visibility. Field problems reach AM through technical manager meetings and MT escalation, and supplier-quality complaints are processed via a logistics-managed complaint channel, but the return signal to those who raised them is limited: "you indicate something, and you are told: we are going to work on it. But actually little to no feedback [. . .] Some things simply take a year" (Int. A-4). The configuration tool visibly updates over time, confirming the loop functions, but with latency that renders it invisible to field actors.

4.2.4. Operational outcomes and benefits

Process simplification and reduced engineering overhead. The modular-construction program framework identified savings potential of 20 to 50% in design and planning, 50 to 90% in materials call-off, 20 to 70% in engineering effort, and 30 to 50% in maintenance (source S-A.4, p. 5). These are 2020 targets, not independently audited outcomes. The most clearly perceived benefits cluster around process simplification: engineers select a configuration from the tool rather than designing per project; OIV commissioning proceeds on standard checklists, reducing to "tick the box, done" once supplier quality is confirmed (Int. A-1; Int. A-3); ordering errors, previously common, are substantially reduced. "We no longer teach people to engineer or design. We teach people a procedure: if this, then that" (Int. A-3). Standardization substitutes procedural compliance for engineering judgment at the project level, lowering the skill threshold and expanding the pool of staff capable of placing a compliant order.

Workforce uniformity and compliance-based dispute resolution. At the workforce level, technicians organization-wide encounter only the standard switchgear types: "all of DSO-A knows how an ABB or Siemens switch works, because that is our standard. You explain it once. Anything else becomes a kind of exotic exception" (Int. A-3). Standardization also enables compliance-based dispute resolution: contested deliveries are referred to the agreed specification rather than re-negotiated.

Partial inventory gains and motivation effects. Inventory gains are partially realized. The configurator has improved order-volume predictability for suppliers, but stations remain project-reserved rather than fungible stock. At the time of interview, approximately 250 stations stood on the compound while other configurations were simultaneously short (Int. A-1; Int. A-3); the move to six variants is partly motivated by shifting the order-decoupling point far enough back to enable true stock production. A significant gap concerns performance measurement: the contribution of station standardization to overall throughput cannot be isolated from parallel investments in contractor capacity, workforce expansion, and digital planning tools (Int. A-1; Int. A-3). This pattern, in which benefits are described in perceived rather than measured terms, is the within-case manifestation of what Chapter 7 develops as the cross-case measurement gap (Section 7.5.1). The new-grid chain's production-volume logic illustrates both the ceiling and the human cost: "for me that is an ideal world. No waiting for materials, I know it is always right, I can barely do anything wrong" (Int. A-4), but the narrow skill profile this requires prompted one regional engineer to compare the work to a carpenter spending three days hanging toilet seats in identical houses. Deep standardization changes the nature of the work itself and requires managing a workforce whose professional motivations are not uniformly aligned with a repetition-production model.

4.2.5. Implementation challenges

The greenfield/brownfield distinction is the structural conditioning factor for all challenge domains and is recognized across all four interviews. In new-grid contexts the network architect specifies from scratch and sites can be dimensioned around the station; standardization approaches its theoretical optimum. In brownfield contexts, the inherited network was built by approximately 54 predecessor organizations, and incompatibilities such as different transformer vector groups, inverted phase color conventions, and non-standard coupling geometries require custom adaptation. Dense urban environments add spatial constraints and historic assets where "there is no space to put down a compact station" (Int. A-3). "Applying a standard to an existing network is very difficult [. . .] everything that is renovation remains custom work". Int. A-3 reframes this as a realistic governance target rather than a failure: "I am already happy if I can place 70% as standard".

Spatial and permitting constraints. Although the station was designed to fall below the 15 m^2 permit-exempt threshold (source S-A.4), required emergency escape clearances mean the actual ground footprint substantially exceeds the enclosure alone. Municipal influence persists regardless of permit-exempt status through ground-acquisition conditions: aesthetic demands including green roofs, sedum coverings, bee hotels, and specific cladding finishes, several of which are technically irreconcilable with station operating requirements (Int. A-3). Water authorities in flood-risk areas have required stations to be placed on raised platforms, conflicting with the freestanding placement geometry. DSO-A has developed a municipal brochure offering a menu of pre-approved customization options to channel these demands rather than generate bespoke deviations. Where the standard cannot satisfy municipal demands at all, approximately 40 walkable stations per year are procured outside it, and indoor-placement projects fall entirely beyond the current standard's scope.

Internal resistance and circumvention. The reduction of engineer discretion encounters structurally predictable resistance. Technicians confronted with a suboptimal specification generate accumulated practical objections hoping to justify reversion to the prior regime (Int. A-2), and net architects must actively choose the standard rather than passively receive it. Systemic enforcement ultimately resolves what persuasion cannot: "at some point it is said: we have talked about this long enough, this is the choice. And then the systems no longer cooperate. If you keep kicking against it, your colleagues will simply say: yes, but that is not how we work anymore" (Int. A-4). This confirms the governance-architecture sensitizing concept from Chapter 3 (§3.3.3): durable governance makes resistance progressively more effortful until it ceases to be a rational use of organizational energy.

Where prohibition alone proved insufficient, DSO-A has applied a "hard hand method": during the 10 kV to 20 kV cable transition, suppliers were instructed via procurement that delivery of 10 kV cable would result in payment difficulties, effectively making non-compliant supply commercially unviable

(Int. A-2; Int. A-3). The walkable-station case illustrates the limits of outright prohibition: despite being formally outside the standard, approximately 40 units per year are procured because the ordering engineer and the AM specification authority report to different directors. The lesson drawn is that "if you forbid something, there is a chance it happens anyway" (Int. A-2): a governed, standardized channel for the walkable variant absorbs demand while preserving cost discipline more effectively than prohibition alone. The 97% compliance rate suggests DSO-A's most durable mechanism is friction asymmetry: making the compliant path sufficiently more efficient than alternatives that circumvention becomes irrational.

Interface rigidity. The station integrates components procured under separate framework contracts with different expiry dates, so component-contract cycles routinely run ahead of station-tender cycles: "it is really an ongoing process" (Int. A-3). The SF6-free RMU transition required a full station layout redesign because the new switchgear has different physical dimensions and heat dissipation characteristics. The 630 mm^2 cable incompatibility required a 400 mm^2 copper transition joint adding workdays per installation. Int. A-2 draws an analytically important normative distinction: the RMU is governed by international norm, transformers by European norm, but the LV rack has no normative anchor, "literally a Meccano construction kit", giving DSO-A greater specification freedom but also full internal responsibility for defining acceptable product parameters.

Organizational fragmentation and communication. Int. A-2's formulation is precise: "we do not have one organization. That is a very serious assumption. We have one director, and that is not the same thing". Regional network design conventions vary by area, generating variant proliferation upstream of the order itself (Int. A-2 to Int. A-4). Every specification update must propagate consistently across contractors, realization chains, and client-facing functions within the biannual release cycle, yet existing mechanisms are frequently insufficient: "we are really bad at implementing new things at DSO-A. We think it can be done with an online session where everyone is half asleep behind their Teams" (Int. A-3). Explaining one such change to the engineer population required thirteen separate regional rounds to overcome practical objections (Int. A-2). The practical implication is that broad communication is insufficient; what matters is ensuring it lands well with those directly involved.

Supplier dependency and resilience. The 2024 waterproofing failure demonstrated that a two-supplier architecture is insufficient when one supplier encounters a production-halting quality event and the second lacks the capacity to absorb the shortfall. The conclusion is a minimum of three qualified suppliers for components of this criticality (Int. A-1; Int. A-3). The Russia-Ukraine conflict in 2022 reinforced dual-sourcing as a supply-resilience strategy rather than merely a competitive procurement mechanism. A further tension is that mid-contract specification changes must be commercially negotiated with suppliers, adding time and cost not incurred under bespoke procurement.

KPI measurement limitations. Task-level time savings do not automatically translate into realized capacity gains because the freed time must also be scheduled productively (Int. A-3), and the contribution of station standardization to overall throughput cannot be cleanly isolated from parallel investments including workforce expansion to approximately 10,400 FTE by 2025 (source S-A.2), expanded contractor capacity, and digital planning tools.

Case synthesis. Case A.1 most clearly illustrates governance architecture and implementation depth: the modular-construction team has iteratively constructed a three-tier arrangement combining normative commitment, procedural mechanisms (MDT, deviation process, biannual release cycles), and structural enforcement (SRM payability controls, configuration tool), achieving 97% ordering compliance. It also illustrates the organizational-fragmentation pattern as a structural amplifier of governance demand: merger-origin technical diversity and regional cultural heterogeneity require continuous coordinative work that asset technical complexity alone would not generate.

4.3. Case A.2: MV-LV distribution cables

4.3.1. Historical background

Cable standardization at DSO-A occupies a structurally different position from the distribution-station program. The cable specification history is much older, and procuring cables on a non-standardized basis would be “almost a no-brainer” to avoid given the organizational complexity it would create at DSO-A’s deployment volumes (Int. A-1). A cable is a continuous manufactured product with well-defined physical parameters; a station is a configurable electrotechnical system at the intersection of civil construction, electrical engineering, secondary systems, and spatial planning.

The maturity of cable standardization reflects a well-developed international normative infrastructure. Dutch NEN standards, European CENELEC documents, and IEC standards provide a multi-layer scaffolding within which DSO-A selects DSO-specific variants rather than constructing specifications from first principles (Int. A-1; Int. A-2; source D-A.4). Large European cable producers have a commercial incentive to advocate for harmonized norms; station manufacturers historically have not had the equivalent incentive, meaning the institutional work of constructing a shared technical language remains largely an internal DSO-level task for stations: “there is no European HD document for MSRs at all” (Int. A-2). As a result, for cables “the number of variables is many times smaller, and the number of people who have an opinion about it is also many times smaller” (Int. A-1). This contrast illustrates the asset-complexity sensitizing concept from Chapter 3 (§3.3.3): lower stakeholder density, stronger external normative coverage, and simpler interface architecture collectively reduce governance demand. The current standard encompasses four principal MV conductor cross-sections, of which 240 mm^2 (standard station connection cable) and 630 mm^2 aluminum (ring cable in new-grid configurations) are the most heavily deployed. At the LV level, the 4x150 mm^2 aluminum XLPE cable has been the operational standard for approximately 33 years, a duration Int. A-3 regards as evidence of successful functional specification rather than inertia.

4.3.2. Timeline and key milestones

Evolutionary program establishment. The cable program represents an evolutionary rather than revolutionary trajectory. The initial formally structured European tender predated the station tender and followed a comparable sequence but without the governance vacuum and failed first attempt that characterized the station trajectory. The stakeholder alignment phase was less contentious because the asset’s narrower functional profile generates fewer internal stakeholders; verification was also more tractable, since cables can be assessed through field-technician joint-making exercises on sample lengths drawn from existing production runs (Int. A-2).

Supply resilience restructuring and reactive updates (2022). Earlier contracts concentrated suppliers; the Russia-Ukraine conflict in 2022 accelerated a shift toward a multi-supplier model, and the current framework accommodates more than seven suppliers to prioritize supply continuity (Int. A-1; Int. A-2). Two specification incidents illustrate the reactive update cycle. A batch of grey LV cable that appeared near-white under ambient light, within the literal specification but triggering safety concern from a historical incident in which cable had been confused with a pipeline, prompted a RAL color code update replacing the natural-language description. A supplier’s yellow-to-blue color ratio on an earth conductor, technically compliant with the literal text but inconsistent with operational intent, required a further retrospective amendment.

Cross-specification incompatibility (2017–2025). The 630 mm^2 incompatibility with the compact station (Case A.1) exposed a structural coordination gap between the two specification programs and has directly informed the third station tender preparation. DSO-A’s investment trajectory from €565 million in 2017 to €2.1 billion in 2025 produced a corresponding step-change in cable procurement volumes (source S-A.2).

Large-scale framework procurement (2025–2034). The April 2025 cable tender, a €1.6 billion framework with a minimum of seven suppliers covering 2026–2034 and projecting 45,000 to 73,000 km of MV and LV cable (source S-A.2), is the most ambitious cable procurement in DSO-A’s history. Given that distribution cables have operational lifetimes of 40 to 60 years, the specification choices embedded in it carry consequences extending well beyond the contract horizon.

Current state of the standard. The operational cable standard is structured around four principal MV conductor cross-sections (with 240 mm^2 and 630 mm^2 aluminum as the workhorses) and a 4x150 mm^2 aluminum XLPE LV cable that has been stable for approximately 33 years. Permitted variation runs along three axes: supplier identity (more than seven approved manufacturers in the 2025 framework), conductor cross-section by network role, and supplier-origin physical tolerance variation (notably the

52 mm versus 57 mm LV outer diameter difference). Two further sources of variation sit alongside the standard: pre-approved exceptional variants requested through the formal change process (such as thicker copper earth screens for electromagnetic-influence cases), and irreducible jointing-accessory dependencies that constrain how cable parameters can change.

4.3.3. Actors and governance

Cable standardization rests on a voluntary organizational choice rather than a legal mandate: "standardization is still a company choice. Every norm not mentioned in law, and that is almost all of them, is in principle a company choice" (Int. A-2). The pragmatic driver is supplier market depth: European norms allow approaches to multiple continental suppliers, whereas a DSO-specific norm would restrict competition to domestic manufacturers. Sustaining the standard therefore requires continuous institutional maintenance.

The governance architecture is identical to that described for Case A.1: the modular-construction core team and MDT, with SRM enforcing compliance through payability controls. One structural difference is significant: for cables, IEC, CENELEC, and NEN bodies perform a substantial portion of the normative work that in the station context must be done entirely by the core team and MDT, leaving DSO-A to specify only DSO-specific parameters (Int. A-2). This externalization reduces internal workload and the risk of internal contestation considerably. Compliance is further reinforced by the logistics architecture: DSO-A supplies cable directly from central stock, so contractors receive the specified type as a given with no operational pathway to substitute (Int. A-1 to Int. A-4). This supply-chain-level enforcement is not replicated to the same degree for stations. External actors include cable manufacturers proposing continuous product modifications and jointing-accessory suppliers whose products must remain compatible with all current cable types simultaneously, requiring a systemic view of the full cable ecosystem.

4.3.4. Operational outcomes and benefits

The primary perceived benefit is the elimination of per-project engineering overhead: contractors receive cable type and required length as fixed parameters with no discretion over material selection. "You can really only choose how many meters you need" (Int. A-4). This represents the most complete realization of the standardization objective within DSO-A's asset portfolio. Field uniformity enables technicians trained on the standard cable types and jointing accessories to work across all thirteen regional branches without asset-specific retraining (Int. A-2; Int. A-3), supporting the cross-regional workforce flexibility that the scaled construction program requires. This aligns with the modular-construction program's safety rationale: standardized work instructions mean technicians "perform the same switching and operating procedures more frequently, and always work with the same materials and configurations" (source S-A.4). The LV cable standard's 33-year stability is analytically significant: a well-specified, functionally adequate standard reduces ongoing governance burden over time, in direct contrast to the continuous rationalization and redesign activity required for the distribution station.

One operational limitation concerns the mismatch between procurement rhythm and deployment rhythm. Framework contracts commit DSO-A to delivery volumes calibrated to program projections, but when programs are delayed by permitting friction or contractor capacity constraints, deliveries continue to arrive, creating standing stock that Int. A-3 describes as covering "football-field-sized" areas of the logistics compound. This is not a failure of standardization per se but an unintended consequence of the framework contract structure that standardization enables.

4.3.5. Implementation challenges

Interface and contextual rigidity is the most consequential challenge. The cable and station specifications must be dimensionally and electrically compatible but are governed by separate contracts with imperfect coordination, with the 630 mm^2 mismatch the clearest manifestation (Case A.1). The constraint is trilateral: when DSO-A requested a more flexible single-conductor cable, suppliers proposed stranded rather than solid-core conductors, which DSO-A could not accept because it would render existing jointing accessories incompatible: "we want them to be more bendable [. . .] But we want a solid core, the supplier says: we can do it, but then with stranded conductors. Yes, but we do not want that, because then we have to adjust our jointing accessories" (Int. A-3). A further field case involved electromagnetic influence on an adjacent gas pipeline requiring a thicker copper earth screen outside the standard cable range (Int. A-4). The ideal resolution is a governed extension of the standard through an additional configuration tab for pre-approved exceptional variants, preserving ordering discipline while accommodating irreducible field variation. A further LV-level interface problem emerged when cables from two approved suppliers had outer diameters of 52 mm and 57 mm respectively, both compliant with applicable NEN/CENELEC standards but arising from different national manufacturing conventions, requiring the station supplier to increase the conduit inner diameter (Int. A-3). Interface dimensions must therefore be managed across contract boundaries, not only within them.

Specification precision and supplier interpretation. Writing specifications that are simultaneously precise enough to ensure conformity and general enough to allow competitive supply requires sustained effort: "you have to be extremely sharp about what you are asking, but it must remain functional [. . .] it is a balance" (Int. A-1; Int. A-2). The RAL color and earth-conductor incidents illustrate the consequences when that balance is not achieved. A distinct variant arises from supplier-country manufacturing conventions: a Portuguese supplier's cable included a plastic binding layer between sheath and earth screen, conventional in Portugal but neither specified by DSO-A nor prohibited by any applicable norm (Int. A-2). All such incidents required retrospective specification clarification, confirming that completeness requires an active field-to-governance feedback loop rather than exhaustive anticipation of failure modes.

Supplier innovation pressure and standard stability. Cable manufacturers continuously propose product modifications in response to sustainability obligations, material cost pressures, and process innovations. Such changes may be technically compliant with the existing specification while introducing subtle changes in workability, dimensional tolerances, or aging behavior that DSO-A has not independently evaluated; each must be assessed not only for the cable but for compatibility with the full jointing-accessory ecosystem (Int. A-3). Component discontinuations create a parallel pressure: when a supplier withdraws a part the standard depends on, an alternative must be qualified at the speed of deployment rather than the speed of specification governance (Int. A-2).

Sector-level standardization limits. The compact connection module (CAM), jointly adopted by all Dutch DSOs since January 2023, indicates that cross-DSO standardization is achievable for bounded components (source S-A.5). However, a full cable specification is considerably broader in scope than the CAM interface object. Sector-level cable alignment is on DSO-A's strategic roadmap but the institutional overhead is disproportionate to the near-term benefit: "if achieving alignment within one organization took seven years, achieving it across the sector would probably take fifteen," absent cross-DSO governance structures that do not presently exist (Int. A-1). This identifies an institutional ceiling on standardization scope: cross-organizational benefits are real, but transaction costs escalate non-linearly with the number of organizations involved and the absence of a superordinate governance authority.

Case synthesis. Case A.2 most clearly illustrates asset complexity and the perceived-rather-than-measured outcome pattern: the cable's narrow stakeholder environment, mature international normative coverage, and simpler interface architecture collectively reduce governance demand to a level where benefits are perceived to be more completely realized than for stations, yet without independent measurement that perception remains an organizationally credible interpretation rather than an audited outcome. The 33-year stability of the LV cable standard further illustrates how a well-specified low-complexity asset can sustain implementation depth with minimal continuous governance investment.

4.4. Chapter conclusion

DSO-A operates not as a collection of isolated standardization programs but as an organization-wide attempt, driven by its modular-construction program, to standardize its product portfolio and working methods, with governance architecture shaped by the specific properties of each asset.

The distribution cable, embedded within a mature international normative infrastructure and subject to a narrower internal stakeholder environment, has followed a longer and less contested path, with governance challenges located in ongoing maintenance rather than initial construction of the standard:

managing interface rigidity across asset boundaries, preserving specification precision against supplier interpretation variance, and navigating the limits of cross-organizational alignment. The distribution station, by contrast, required deliberate construction of a governance architecture, the core team, MDT, deviation process, and procurement enforcement logic, precisely because asset technical complexity, stakeholder density, and merger-origin fragmentation created conditions in which specification authority had to be institutionally produced and continuously defended. Both assets are shaped by the same forcing condition: the energy transition mandate that has quadrupled DSO-A's annual work package and rendered technical variety economically and operationally unsustainable (source S-A.2).

Measured against the Chapter 3 sensitizing concepts, Case A.1 illustrates governance architecture and implementation depth most directly: the program has iteratively constructed a three-tier arrangement combining normative commitment (board-level mandate), procedural mechanisms (MDT, deviation process, release cycles), and structural enforcement (SRM payability controls, configuration tool), achieving 97 per cent ordering compliance as the current implementation depth. Case A.2 illustrates asset complexity and the perceived-rather-than-measured outcome pattern: the cable program's lower stakeholder density, stronger external normative coverage, and simpler interface architecture collectively reduce governance investment to a comparable implementation depth, while the organizational-fragmentation pattern operates across both cases as a structural amplifier of governance demand. Whether these patterns are specific to DSO-A's institutional history or reflect structural conditions that transcend the individual organization is what the cross-case analysis in Chapter 7 is designed to establish.

5

Within-case analysis: DSO-B

5.1. DSO-B: organizational context

DSO-B is a Dutch distribution system operator serving approximately 2 million household and business connections across several areas (DSO-B secondary sources S-B.1, S-B.2; see Appendix C.1.4). The spatial composition is analytically significant: dense demand for compact station footprints must be accommodated alongside soil-type and spatial variety that the standardization program must absorb rather than eliminate. As of June 2023, DSO-B managed approximately 26,500 MV-LV transformer stations (source S-B.3). Investment rose from €832 million in 2023 (266 stations installed, 892 km of cable laid) to €1,294 million in 2025 (503 stations and over 1,200 km of cable) (sources S-B.1, S-B.2).

DSO-B's current form reflects successive mergers of regional network operators, legal unbundling from the supply business, and a public capital injection in 2023 (source S-B.4). The MV network currently operates at approximately six distinct voltage levels, alongside variation in rotation directions and configuration parameters accumulated across predecessor organizations (Int. B-1; Int. B-2). Migrating a network segment to a different voltage level requires complete replacement of all connected equipment, making it cost-prohibitive at speed and feasible only over very long planning horizons. This physical heterogeneity constitutes a hard boundary condition for the current program: material-level standardization must function across this variation rather than presupposing its resolution, an instance of the organizational-fragmentation pattern developed cross-case in Chapter 7 (Theme 2, Section 7.5.2).

5.1.1. Organizational structure

Specification authority is centralized in the Asset Management (AM) department, organized around dedicated product lines responsible for network standards, procurement specifications, and governance of primary LV/MV assets. Within AM, the Policy and Innovation unit, which has grown from six staff to approximately sixty over the program's duration (Int. B-2), holds primary specification authority for the transformer station and compact connection module asset classes. Its mandate covers three interlocking functions: determining the solution direction for the network under a Product Lifecycle Management framework, innovation and product development, and policy management. The unit describes its role as that of a solution architect, translating functional specifications into "fixed building blocks" (Int. B-2); a system specialist within this unit owns procurement specifications end-to-end (Int. B-1).

A notable structural feature is that the departments involved in specification have been placed at the same organizational level rather than in a hierarchical sequence. Policy can only be formally ratified once departments have reached collective agreement, a horizontal coordination logic operationalized through a multi-functional team (MFT) which gives operational chains a formal mandate to review and score both requirements and supplier responses during tendering (Int. B-1). Commercial Projects is one such operational chain, executing all MV and LV works for new residential developments, grid reinforcements, voltage complaints, and reconstructions (Int. B-4). A field-instruction translation function converts specification outputs into field-applicable work instructions (Int. B-1; Int. B-4; Int. B-5), and procurement maintains the calendar that triggers formal European tender processes at contract expiry. Field execution itself has been progressively outsourced to contractors as part of a deliberate strategy to concentrate internal capacity on coordination, specification, and governance.

5.1.2. Organizational standardization adoption driver

Applying standards is not new for Dutch DSOs: "applying standards is something that grid operators have been doing for decades" (Int. B-2). What distinguishes the current program is its scope, intentionality, and procurement-level formalization. In the pre-transition period, work pace was manageable, the workforce was technically knowledgeable about diverse materials, and time was available to absorb variation. The energy transition removed these conditions: "the current market demands solutions to new problems that are mainly related to speed" (Int. B-2). What changed was a deliberate upward shift in the level at which standardization decisions are made, from compliance with external norms to active design of proprietary product configurations and supply chain architectures (Int. B-1; Int. B-2).

Three drivers shaped this shift. The primary driver is the structural mismatch between the energy transition's growth rate and the throughput achievable under bespoke procurement. The annual installation rate of transformer stations approximately doubled to over 500 per year, making bespoke specifications economically and operationally untenable (Int. B-1; source S-B.2). Standardization also generates production-economics benefits, articulated by Int. B-1 as "chain thinking": "starting up an entire chain and then tomorrow we have another flavor, instead of this week we only have flavor one, start the machine". A labor-scarcity argument reinforces this: technician shortages and the compression of apprenticeship trajectories from years to months position standardization as a quality-preservation mechanism (Int. B-1; Int. B-3). The second driver is competitive procurement pressure: standardization causes individual order volumes to accumulate into legally tender-obligatory contract packages.

The third and structurally deeper driver is legacy MV network heterogeneity. DSO-B has established a design-level ambition to migrate the entire MV network toward a single voltage level of 21 kV, a process estimated to take approximately 100 years (Int. B-2). The current program is therefore an intermediate step within a multi-decade trajectory: the four-variant station matrix is the maximum achievable standardization outcome given current voltage heterogeneity, not the terminal state. DSO-B has explicitly recognized that holding a desired network image is insufficient without structured transition policy: "we were actually not very good at transforming; we did have a desired network image, but did not actually shape the path to get there [. . .] We want to draw up a clear transition policy" (Int. B-2). This positions transition governance as the organizational capability gap that the current standardization program must close, consistent with the governance-architecture sensitizing concept from Chapter 3 (§3.3.3).

5.2. Case B.1: MV-LV transformer distribution stations

5.2.1. Historical background

The pre-standardization condition was defined by an inheritance of more than 82 distinct station drawing types, covering transformer sizes of 160, 250, and 400 kVA, multiple MV voltage levels (10, 10.5, 13, 21, 23, and 25 kV), and incompatible LV wiring color sequences locally determined by predecessor companies (Int. B-1). DSO-B was formed through successive consolidation of seven smaller network operators (Int. B-4); the constituent predecessors each developed technically autonomous approaches, producing a network in which no single design served as a point of reference and every brownfield deployment required site-specific adaptation. Stations were historically constructed on-site from masonry; the transition away from fully bespoke construction occurred approximately ten to twenty years before the interviews, with the current tender representing the most formally institutionalized phase of that trajectory.

The first formally tendered procurement under European public procurement rules occurred around 2012 or 2013, conducted with a single incumbent supplier and specifications written as plain Word documents of 14 to 16 pages per component (Int. B-1). Prose requirements generated significant interpretation differences between DSO-B and suppliers, and the award process structurally favored incumbents by requiring suppliers to physically build and present a station. The current tender represents the first systematically executed, end-to-end standardization process for this asset class.

5.2.2. Timeline and key milestones

Network topology redesign as upstream precondition. The critical upstream precondition for station standardization was the network topology decision known as *ontmazen* (de-meshing): converting ring-structured MV networks into radially isolated islands (Int. B-1; Int. B-2; source D-B.3). In the former ring topology, each station had to remain compatible with adjacent network configurations including transformer rotation direction, vector group, and LV wiring color coding. By abandoning N-1 redundancy, DSO-B removed the inter-station interface constraints and reduced the required schemas from 82 to 3 or 4, the point at which standardization became technically achievable. The design embedded quality assurance into the product rather than the work instruction: the LV rack connection uses a break-bolt mechanism that self-indicates incorrect assembly. A second topology-level precondition remains unresolved: residual MV voltage heterogeneity cannot be addressed at the station specification level and requires a network-wide migration that is cost-prohibitive at speed. The current four-variant matrix is therefore a partial outcome constrained by this residual heterogeneity, illustrating the systems-level gap identified in Chapter 3 in which upstream technical hierarchy constrains what can be standardized at lower levels.

Tender preparation and design logic. The procurement calendar provided a structural trigger (Int. B-1). A structural consequence of the European public procurement framework is that the standard is inherently time-bounded, with each contract cycle spanning four to eight years and concluding in a mandatory open tender; standard management is therefore continuous preparation for the next cycle (Int. B-4). The specification was characterized as a large puzzle assessing each component area for standardization potential, with the overarching design principle being delivery of five stations per week to logistics regardless of short-term demand: “the energy transition demands a system in which a station is simply an article number [. . .] five standard units must be delivered to logistics per week” (Int. B-1). Several decisions exemplify a deliberate over-engineering philosophy. Transformer capacity was standardized at 630 kVA unless a specific calculation justified 1,000 kVA, with a lifecycle cost analysis showing efficiency losses from mild oversizing were negligible over the 40-year asset lifespan compared to supply chain simplification gains (Int. B-1; Int. B-2; source D-B.1). External cable strain relief was universally deployed regardless of soil type, since restricting deployment to peat-dominant subsiding zones created logistics mismatches (Int. B-1; Int. B-3). The service area was divided into two regional implementation blocks, each supplied by a different station supplier (Int. B-2). A requirements documentation tool records all specification requirements and their rationale, enabling roughly 75% of a new tender’s content to be carried forward from the previous one (Int. B-1).

Award, testing, and rollout (2023–2024). The tender resulted in June 2023 in contracts with two suppliers for a combined delivery of 500 prefabricated transformer stations per year at a total contract value of €160 million, with a minimum term of four years and an option to extend to eight (source S-B.3). The use of 3D design submissions in the award process required suppliers to design specifically to DSO-B’s requirements before any physical production, lowering the entry threshold for non-incumbent parties (Int. B-1; Int. B-3; Int. B-4). After award, suppliers completed a design freeze, prototype production, and Factory Acceptance Testing, with first stations installed in early 2024. A significant governance gap was discovered post-award: requirements were stated but no burden of proof was demanded, so suppliers could legally declare conformity without a specified test having been conducted, generating significant implementation problems because the requirements were also new to manufacturers (Int. B-1; Int. B-3). The lesson drawn was that the next tender cycle must address how compliance is actually verified, a distinction between standard content and standard governance the current program did not adequately institutionalize.

Compact station policy formalization. Approximately one to one and a half years before the interviews, DSO-B formalized the “compact, unless” policy, making the non-walkable station the default and permitting walkable stations only when technically or spatially necessary (Int. B-1; Int. B-4). The formal policy decision consolidated what had been an emerging practice into an organizational rule.

Current state of the standard. The standardized range is structured around a two-by-two matrix: walkable and non-walkable enclosures, each available with a 630 kVA or 1,000 kVA transformer, producing four core variants (Int. B-1; Int. B-4). A masonry-clad fifth variant exists but constitutes only an external finishing difference; the internal configuration is identical to the equivalent walkable variant. Reduced from approximately 100 historical configurations, the current matrix represents an order-of-magnitude reduction (Int. B-2; source D-B.3). Permitted variation runs along three axes: enclosure type, transformer capacity (which deterministically cascades into the LV rack configuration), and aesthetic finish (pine green RAL 6009, anthracite grey, or municipality-driven masonry cladding). Two categories sit outside the standard: non-standard color requests, classified as special orders adding six weeks to the 18-week delivery program, and fully bespoke stations requiring approximately one year of redesign. Since the program operates with two awarded suppliers each producing all four variants independently, the effective supply-side variant count is eight.

5.2.3. Actors and governance structure

Specification responsibility is concentrated in the AM system specialist, who leads the tender end to end (Int. B-1). Network strategists shape upstream topology conditions including de-meshing policy. The MFT operationalizes the horizontal coordination logic, giving operational chains a formal scoring mandate in both specification writing and supplier evaluation, a deliberate departure from the previous arrangement in which AM made decisions with input from one or two consulted delegates holding no formal decision weight. The most valued outcome of cross-functional involvement was not confirmation that requirements were correct but identification of what had been overlooked: "you want to hear especially that last thing, so that you think: oh yes, we missed a turn-off" (Int. B-1). Int. B-4 validated this from the operational chain perspective as a deliberate correction of the "ivory tower" pattern.

The Technical Management team within Commercial Projects, a boundary-spanning function established approximately one year before the interviews, translates written specifications into project-level guidance and mediates conflicts between the standard and site conditions (Int. B-4). It does not hold final decision authority over exceptions; a formal deviation process routes non-conforming requests to a higher organizational layer. Technical Management is one of the primary sources of friction in the organization, returning creative special designs to project leaders with the instruction to first explore whether a standard-conforming solution exists.

The transformer station functions as a boundary object: it is simultaneously a technical artifact, a logistical unit, an urban installation, and a land-use negotiation object, giving AM, Logistics, Operations, Commercial Projects, and municipalities legitimate stakes from their own domain logics (Int. B-1; Int. B-2). A placement detail such as bollards illustrates this: AM may oppose them on emergency-egress grounds, a net coordinator may require them to prevent vehicles from blocking maintenance access, and a project leader may accept a municipal demand for perimeter hedging that renders both positions moot (Int. B-4). The two awarded suppliers provide stations under a mutual contractual backup arrangement (source S-B.3). Contractors occupy a deployment role only, executing foundation, placement, and cable connection (Int. B-4; Int. B-5).

Int. B-2 offered a pointed observation: while the program reduces variation in the supply chain, it increases the decision-making burden within DSO-B itself, because every station is now locked to a constrained option set that previously could be freely adapted. The success condition is therefore not the technical quality of the standard but the intensity and quality of the coordination that sustains it: "it is now only more important that we do that intensively together [. . .] That is ultimately what makes it a success" (Int. B-2). This corresponds to the governance-architecture sensitizing concept from Chapter 3: durable governance is not a fixed structure but a continuously sustained coordinative practice.

The governance gap most explicitly documented concerns the absence of a systematic performance measurement framework. No organizational leader has formally requested an evaluation: "what I personally find a bit strange is that nobody at DSO-B, none of our managers, is currently asking us to evaluate anything" (Int. B-1). Learning is occurring at the individual level of the system specialist but is not being institutionalized. A related conservatism mechanism operates through the tender cycle itself: knowledge about the standard accumulates over the contract period but dissipates at each renewal as the organization resets toward a new supplier and a partially rebuilt specification (Int. B-4). This pattern, in which benefits are described in perceived rather than measured terms, is the within-case manifestation of what Chapter 7 develops as the cross-case measurement gap (Section 7.5.1) and mirrors the KPI gap documented at DSO-A. The implementation-depth sensitizing concept is illustrated here in a different register than at DSO-A: in the absence of a quantitative compliance proxy comparable to DSO-A's 97% ordering rate, depth at DSO-B is sustained primarily through the structural-enforcement combination of regional supplier allocation, configuration-locked deliveries from logistics, and the schedule penalty for non-standard variants.

5.2.4. Operational outcomes and benefits

Chain thinking and ordering simplification. The reduction from more than 82 drawing types to three or four active schemes enables chain thinking: the supplier works from a single known standard, simplifying production sequencing, reducing component inventory, and enabling faster manufacturing cycles (Int. B-1; Int. B-2). Supply chain standardization converts procurement from a bespoke engineering exercise into a replenishment-based flow.

Supplier interchangeability and supply resilience. The low variant count enables each supplier's station to substitute one-to-one for the other at any assigned location, creating supply resilience infeasible under customized procurement: "two suppliers received exactly the same requirements [. . .] they can simply replace each other one-to-one. That is an additional advantage of standardization" (Int. B-1; Int. B-4).

External stakeholder communication and inventory simplification. The reduced variant palette provides "strong handles for having a conversation with municipalities" (Int. B-2). Inventory holding simplifies correspondingly: "you need less stock, because it is not an Ikea warehouse" (Int. B-1).

Workforce ergonomics and embedded quality assurance. Because the asset is universal and fixed, it becomes worthwhile to invest in design solutions that embed quality assurance into the product rather than relying on installer competency (Int. B-1). The break-bolt LV rack connection illustrates this: incorrect assembly is physically self-evident, transferring quality assurance from workforce skill to product architecture.

Factory-complete prefabrication. Because internal configuration is fully fixed, stations arrive on site with all internal wiring, components, and rack assemblies completed under factory conditions, reducing field work to external cable connection only (Int. B-2; Int. B-4). This approaches a plug-and-play deployment model and is structurally dependent on standardization.

Measurement gap. Benefits are consistently described in qualitative terms; no formal KPI tracking regime exists (Int. B-1; Int. B-2; Int. B-4). Int. B-1 identified a concrete evaluation design: a minimum deployment threshold of approximately 20 placed stations per variant across diverse area types, anchored in the procurement calendar so findings are available before the next tender cycle is initiated. This is again an instance of the perceived-rather-than-measured outcome pattern (Chapter 7, Section 7.5.1).

5.2.5. Implementation challenges

Spatial and permitting constraints. Standard compact stations are exempt from formal building permit requirements under Dutch planning law given their small footprint and public-interest function; the primary statutory obligation is land acquisition or easement negotiation (Int. B-4). DSO-B's territory includes areas on sand, peat, and water-saturated soil, each imposing different foundation risks (Int. B-1). Brownfield integration is the primary execution challenge: adding new stations to existing networks often requires preparatory projects to establish correct cable lengths, identify network cut points, and obtain permits before placement. The fixed internal layout means cable exit points are determined by compartment position, constraining station orientation on site, and a safety regulation requires that station doors may not swing over the road surface (Int. B-4). The fixed 20 m^2 land parcel requirement introduces a distinct spatial constraint in dense urban environments. DSO-B approaches municipal placement negotiations with a consistent societal-cost framing: any deviation from the standard imposes real costs because non-standard stations require approximately twice the engineering effort and twice the build cost (Int. B-4; source D-B.2). The deeper practical implication is that DSO-B has been reconfigured around the standard to the point where it is no longer capable of operating without one: internal processes, supply agreements, and testing infrastructure that once supported bespoke procurement have been dismantled, making the standard self-reinforcing through organizational path dependency.

Variant proliferation and inventory complexity. A structurally distinct challenge concerns the combinatorial logic through which network heterogeneity propagates into inventory obligations. MV switchgear can be specified at a voltage rating covering the full range of MV levels in use; transformers cannot, because the primary winding must be matched to the local MV voltage (Int. B-2). With four active base voltage levels remaining, the transformer variant space begins at a minimum of four types before capacity is considered. Reducing station stock variants therefore requires first reducing transformer variants, which requires reducing active voltage levels. The 21 kV migration ambition has a direct operational rationale: each voltage level eliminated removes an entire dimension of transformer variation.

Sustainability trade-offs from transformer standardization. Standardizing on the 630 kVA transformer introduces a sustainability cost in low-demand contexts: a unit operating significantly below rated capacity runs at higher relative losses than a load-matched 400 kVA unit would (Int. B-4). The 1,000 kVA variant is estimated to be required in approximately 5% of cases, as the standard permits departure from 630 kVA only under defined criteria such as high-density or indoor-placement contexts (source D-B.1). The lifecycle analysis concluded the simplification benefits outweigh the efficiency penalty at the portfolio level (Int. B-1); the sustainability dimension was not foregrounded.

Internal resistance and the compact station transition. The "compact, unless" policy has encountered resistance across three dimensions, only one of which is purely cultural (Int. B-1; Int. B-4). The first and most prominent is ergonomic: staff prefer walkable stations because maintenance work in an enclosed space is more comfortable in adverse weather. Many operations staff were previously field technicians, giving them embodied experience of this difference. The second is technical: where compact station cable geometry cannot be accommodated by the available site orientation, a walkable station resolves the placement problem. The third is municipal aesthetic pressure: some authorities require masonry cladding, achievable only on the walkable variant. DSO-B addressed broader cultural resistance through regional presentations, but staff are at different stages of understanding: "how do you ensure that everyone in operations understands why we are doing this? And then it sometimes seems: goodness, who came up with this?" (Int. B-1). A deeper source of resistance concerns the acceptance of deliberate suboptimality: the standard requires locally suboptimal solutions when the optimal solution would require a non-standard configuration; for engineers whose professional identity is built around finding the best solution per situation, this is genuinely difficult to internalize.

Interface rigidity and component compatibility. The standardized station enclosure must accommodate MV switchgear sourced from separately tendered contracts and remain compatible with whichever switchgear supplier holds the relevant contract at any given time (Int. B-2). When a new switchgear supplier's product has a different explosion-resistance rating than the one originally validated against the enclosure, the combined assembly must be re-tested, often requiring physical modification. This interface rigidity is structurally parallel to that documented at DSO-A; the interview material does not evidence a formal interface governance protocol that prevents such cascades systematically, flagged here as a data gap.

Supplier dependency and market structure. The two-supplier architecture depends on the mutual backup arrangement remaining functional across procurement cycles; European tender law requires each renewal to be open to new entrants, so continuity is not structurally guaranteed (Int. B-1; Int. B-4). A challenge to market competition arises from DSO-B's practice of setting requirements based on its own operational needs rather than existing market offerings: "DSO-B has set its requirements not on the basis of what was already being offered in the market, but simply on the basis of unlimited possibilities. And that is one of the reasons, I think, that it has all taken much longer" (Int. B-1). This reinforces specification conservatism: the specification must be ambitious enough to incorporate previous-cycle lessons but not so novel that supplier onboarding risk threatens delivery continuity.

Innovation constraints and the structural innovation ceiling. The eight-year contract cycle imposes a ceiling on technical innovation that interviewees identified as a sector-level structural condition rather than a DSO-B-specific governance failure (Int. B-4). A modular station architecture in which transformer capacity could be upgraded by exchanging a standardized module was cited as a technically feasible direction that has not been explored, because the organizational and market conditions required to develop it do not exist within the procurement structure. Network operators face a structural conservatism that is rational from each individual actor's perspective but collectively forecloses technical possibilities that could resolve known limitations of the current standard.

Case synthesis. Case B.1 most clearly illustrates governance architecture and the organizational-fragmentation pattern. The program has iteratively constructed a three-tier arrangement combining normative commitment (the "compact, unless" policy), procedural mechanisms (the MFT, the requirements documentation tool, the deviation process, the six-week schedule penalty for non-standard colors), and structural enforcement (logistics-level article-number supply, regional supplier allocation). The organizational-fragmentation pattern (Chapter 7, Theme 2, Section 7.5.2) operates as a structural amplifier of governance demand: the legacy of seven predecessor operators and six MV voltage levels generates coordinative work that asset technical complexity alone would not require. The proof-of-compliance gap in the first-generation specification illustrates that structural-tier completeness cannot be assumed and must be explicitly designed.

5.3. Case B.2: compact connection module

5.3.1. Historical background

The compact connection module (CCM), publicly designated as the Compacte Aansluitmodule (CAM), standardizes low-voltage connections between DSO-B's grid and unattended client objects in public space, including EV charging points, public lighting, advertising pillars, and parking meters (source S-B.5). The institutional origin of the CAM lies in ElaadNL, the Dutch DSOs' joint knowledge and innovation platform for electric mobility established in 2012 to investigate the grid impacts of EV charging (Int. B-3).

The pre-standardization connection process was organized as a sequential handoff across multiple parties at the same physical location: the Charge Point Operator (CPO) placing the charging point, a contractor earthing it, a road-crossing party installing the cable duct, the DSO's contractor making the grid connection, and finally the CPO returning to meter, test, and commission (Int. B-3). Each visit required its own planning notification, excavation permit, and road closure; elapsed time routinely reached approximately three weeks, despite total productive labor content of approximately four hours when performed in a single visit. The pre-standardization condition was simultaneously characterized by the absence of any market-available plug-and-play solution: "the market had no plug solution available. As a network operator we are of course from the outset extremely conservative. Which meant that a great deal of innovation was held back. Besides that, there was also no real necessity" (Int. B-2). The EV charging rollout provided the forcing function (source S-B.6). Unlike the transformer station case, the CAM exhibits a tighter urgency-as-accelerant dynamic: the CPO and Operations functions issued explicit requests for a faster connection solution.

5.3.2. Timeline and key milestones

Trigger and innovation procurement design (2016–2021). The concrete trigger was a regional EV charging concession in the south-western Netherlands, tendered around 2016–2017, which brought a single major CPO contract to market (Int. B-3). The concentration of deployment volume made the interface problem structurally visible: existing connection boxes, designed for residential indoor use, were thermally unsuitable for outdoor public space installation and physically oversized for integration into charging point housings. The non-discrimination principle under the Elektriciteitswet meant any new connection standard had to apply to all comparable unattended objects in public space, including public lighting, traffic management installations, telecommunications cabinets, camera masts, and advertising pillars.

The CAM was developed as a joint national initiative across all Dutch DSOs, coordinated through ElaadNL (source S-B.5). The practical lead was taken by the three largest DSOs (DSO-A, DSO-B, DSO-C); the three smaller DSOs participated but did not carry the procurement workload (Int. B-3). The tender was organized as an innovation partnership rather than a conventional specification-based procurement: the consortium invited market parties to propose solutions to a defined problem and compensated shortlisted parties for prototype development. The tender embedded a reproducibility condition and a design-ownership clause: "we have design ownership so that, should the supplier perhaps go bankrupt or whatever, we can always continue using this design" (Int. B-2).

Beyond the connection module itself, the CAM program encompasses a parallel standardization of cables. Cable drums are supplied by DSO-B to the supplier's production facility, where cables are cut to one of five standardized lengths and terminated with the plug connector under 100% quality inspection, color-coded to the uniform national sequence applicable across all DSO territories (Int. B-3). From DSO-B's operational deployment perspective, the cable program reduces to a single standard cross-section of 4x16 mm^2 for all new connections, with one separately orderable exception variant of 4x10 mm^2 retained for replacement connections at older charging points (Int. B-5). The plug interface is identical across both variants.

Award and post-award co-development (2022–2023). The innovation partnership process proceeded through a competitive prototype phase in which three shortlisted parties produced trial assembly components and conducted prototype installations in the field (Int. B-3). The award was made on prototype quality combined with price, resulting in a contract with a single manufacturer (source S-B.5). The awarded product was a version 0.8 rather than a finished article: the consortium proceeded from a jointly developed prototype that both parties recognized as requiring further refinement, and the innovation partnership contract structure provided contractual room for continued product development after award.

Rollout and national adoption (2023–2024). The first CAM-connected charging point was installed at ElaadNL in Arnhem in January 2023 (source S-B.5). On 6 March 2023, the three DSOs simultaneously announced national adoption, with a target to retire old modules by the end of Q2 2023. A phased retirement approach was adopted, consuming existing inventory first. The national connection request portal, aansluitingen.nl, was adapted to incorporate the CAM certification requirement as a mandatory question. Within DSO-B's operational deployment, the relevant team began active CAM placement in July 2024 and was at the time of data collection processing between 4,000 and 4,500 CAM connection requests per year, with approximately 10,000 units placed in total (Int. B-5). ElaadNL and the DSO consortium were extending the program to address charging point foundations, enabling full charging point replaceability without cable cutting or civil excavation (Int. B-3).

Current state of the standard. The operational CAM standard consists of a single-manufacturer plug-and-play connection module supplied with prefabricated cables in five standardized lengths, covering load ranges from single-phase 6 mm^2 to three-phase 80 mm^2 (Int. B-3). At DSO-B's operational level the cable program reduces to a single standard cross-section of 4x16 mm^2 (Int. B-5). Permitted variation runs along three axes: cable length (one of five prefabricated standard lengths), cable cross-section (the standard or the legacy-replacement 4x10 mm^2), and application variant (three-phase versus single-phase for camera-mast and similar low-load applications, source S-B.5). Connection requests where the existing main cable cannot accommodate the load require a separate K15 main-cable project, extending the timeline by approximately one year.

5.3.3. Actors and governance structure

Internally, the AM Policy and Innovation unit includes a dedicated asset specialist for the CAM (Int. B-3; Int. B-5). Operations functions responsible for EV connections and public lighting are the primary internal client functions generating CAM requests; a public-space objects department handles municipality-driven objects (Int. B-5). The MFT serves as the internal alignment body. In the CAM tender, two rounds of trial assemblies were conducted with technicians under COVID-period constraints (Int. B-3). The channel through which field experience feeds back into specification improvement is informal: improvements identified by technicians are expected to reach AM through individual initiative rather than through a formal reporting process (Int. B-5).

Externally, the single contracted CAM manufacturer occupies a structurally different position from the dual-supplier transformer station arrangement: as the sole supplier and co-designer for all Dutch DSOs, it is simultaneously manufacturer, co-developer, and single point of production failure (source S-B.5). A concrete inter-operability risk arising from this configuration is that the single CAM manufacturer receives cables from all three DSOs for assembly, yet each DSO maintains its own cable approval regime: cases have occurred in which a cable from one DSO's drum stock was dispatched to another's project (Int. A-1). DSOs were working to mutually approve each other's cable types at the time of data collection. CPOs and their object manufacturers form a third external actor ring, required to type-approve their products through ElaadNL before connecting to the CAM (source S-B.5). Municipalities and public-space managers form a fourth actor ring. The DSO holds unilateral authority over the technical requirements that client objects must meet for grid connection.

The requirement framework underpinning the CAM is grounded in existing statutory and normative obligations (including NEN 61439, NEN 1010, NEN 3011, the Netcode, and the Elektriciteitswet and its successor Energiewet) (Int. B-3). The six major Dutch DSOs collaboratively established a national certification team in which two representatives from each large DSO participate. The three-DSO joint structure also provided a market acceptance advantage: by communicating requirements jointly through shared webinars, joint manufacturer visits, and coordinated outreach, the consortium conveyed that the CAM interface represented a sector-wide commitment rather than a single operator's preference. The enforcement mechanism is structural: manufacturers whose objects do not meet the CAM interface cannot have their products certified through ElaadNL, and without certification their clients cannot obtain a grid connection, making compliance a commercial necessity. DSO-B also proactively engaged municipalities by providing standardized tender language that, included in municipal procurement specifications, obliged object suppliers to meet CAM interface requirements before any award. The CAM MFT operates within the constraints of the joint standard agreed by the three-DSO consortium; unilateral DSO-B-specific variations are not permissible. Specification authority is therefore distributed across the inter-organizational consortium rather than held solely by DSO-B's AM function, a fundamentally different governance configuration from the transformer station case. The KPI tracking gap documented in Case B.1 is present in this case as well (Int. B-2; Int. B-3).

5.3.4. Operational outcomes and benefits

Connection speed and process collapse. The primary stated benefit is connection speed: "with this we can connect charging points, parking meters, and advertising pillars at least three times faster" (source S-B.5). The speed benefit operates across two dimensions: within a single connection event, field labor is reduced by plug engagement replacing manual wiring; across the project sequence, multi-visit fragmentation is replaced by a single coordinated visit, collapsing a three-week elapsed timeline to a single mobilization (Int. B-3). From the field technician's perspective the cable arrives on site with a factory-terminated plug already attached rather than requiring on-site stripping, conductor exposure, and manual termination (Int. B-5).

Quality assurance and skill threshold reduction. Connection quality is better assured because the plug interface eliminates the torque-sensitive manual wiring work that previously required precise mechanical skill from the installer (Int. B-2; Int. B-3). The plug engagement operation is substantially less technically demanding, broadening the workforce pool that can execute CAM connections without specialist training (Int. B-5).

Cross-DSO uniformity and contractor cognitive burden. The CAM replaces previously divergent per-region connection types with a single connection type applicable across the entire Dutch DSO landscape (Int. B-2; Int. B-3; Int. B-5). Object manufacturers certify their products once for use across all Dutch DSOs, reducing certification costs and accelerating time-to-market (source S-B.5). A Dutch provincial procurement agency's procurement of dynamic passenger information panels, for example, had previously required compliance with three separate requirement sets; the CAM reduced this to a single unified specification.

Elimination of pre-CAM enclosure diversity and dispute reduction. Before the CAM, the absence of uniform national requirements meant the market supplied a wide variety of enclosure types with varying quality and safety levels; in extreme cases enclosures were assembled on-site from improvised materials: "previously there was also building on site, just knocking something together from wood" (Int. B-5). Field disputes with clients about whether a given object met connection requirements fell from approximately 25% to approximately 1% of non-charging-point unattended object connections, although the time saving is not visible to AM as a measured efficiency gain because the certification workload AM has taken on represents a corresponding increase in AM's own time expenditure (Int. B-3).

Measurement gap. The three-times-faster figure is a public claim that cannot be verified against a controlled baseline, and no systematic before-after measurement regime is documented (Int. B-2; Int. B-3). A pilot demonstrated a 60% reduction in connection time: "we are not able at this moment to actually measure the effectiveness [. . .] whether we can also connect more or do more and whether it has become cheaper, we cannot do that" (Int. B-2). The perceived-outcome pattern is the same as documented in Case B.1.

5.3.5. Implementation challenges

The two DSO-B cases differ structurally in standardization tractability. The transformer station required convergence of multiple independently governed subsystems into a single validated design while satisfying safety, sustainability, affordability, and spatial requirements. The CAM addressed a narrow application scope with a small stakeholder field and a single-interface technical problem (Int. B-2). Int. B-2 identified this structural complexity differential as the primary explanation for the difference in standardization pace between the two cases. The CAM challenges are predominantly inter-organizational and process-level rather than internally technical.

Transition asymmetry across object categories. The transition was easier for EV charging connections than for other unattended object categories. CPOs had themselves raised the request; for public lighting, traffic management, and telecommunications, no uniform national connection requirements had previously existed, and at DSO-B identical objects were sometimes connected under different requirements on opposite sides of a major river dividing DSO-B's service territory (Int. B-3). For object manufacturers operating across DSO territories, consolidating up to three distinct DSO requirement sets into a single national standard required a one-time redesign cost but eliminated the ongoing burden of maintaining parallel product variants.

Underestimated object certification volume. The scale of external object certification workload significantly exceeded initial expectations: more than 100 distinct object types had been presented for certification by the time of data collection, a market breadth that had not been mapped in advance (Int. B-3). DSO-B determines only the connection interface requirements; the object itself is specified by the client. Large commercial clients operate multiple enclosure variants from multiple suppliers, each requiring separate certification (a major Dutch telecommunications operator maintains four to five distinct variants). Resistance from established commercial parties added to the workload: large operators raised objections on grounds of design standardization across markets and circular economy requirements; DSO-B maintained the requirement, referring to the statutory and normative basis of the specification.

Internal process harmonization. Implementation required substantial adaptation across DSO-B's internal project processes. Different internal chains had different processes for incorporating the CAM, and achieving internal uniformity while coordinating with contractors across all regions was a challenge resolved with considerable effort: "towards the contractors it must be uniform. We find that difficult. It has worked out, but it is difficult" (Int. B-3). Contractors with pre-ordered or pre-configured materials under the old method faced ambiguity about written-off inventory and partially prepared work (Int. B-5).

Spatial and interface constraints from client object diversity. Although the CAM itself is fully standardized, the diversity of client objects introduces variation at the CAM-to-object interface. Where an object's housing does not provide adequate space for the CAM's physical dimensions, the plug-and-play benefit is partially negated by non-standard civil preparation (Int. B-3).

Transition management for existing inventory. The phased retirement approach created a period in which both old and new connection methods were simultaneously active, requiring contractors and field staff to maintain competence in both, temporarily increasing rather than decreasing the skill burden (Int. B-3).

Supplier dependency and single-source resilience. The CAM's single-supplier model introduces a qualitatively different resilience risk than the dual-supplier transformer station arrangement. Resilience is protected through design ownership rather than supplier redundancy: "we have design ownership so that, should the supplier perhaps go bankrupt or whatever, we can always continue using this design" (Int. B-2). The CAM's status as a jointly owned national standard means any re-tendering process could draw on the broader three-DSO consortium's collective bargaining position. Whether design-ownership offers equivalent practical resilience to operational supplier redundancy is flagged as a data gap.

Three-DSO governance complexity. Any specification change affecting the shared CAM standard must be agreed across all three DSOs before implementation, creating a longer decision-making pathway than a DSO-B-internal update would require (Int. B-3). The cable-approval inter-operability gap documented above (Int. A-1) is a concrete operational consequence of this multi-principal architecture.

External limitations from non-standardized object interfaces. Where legacy object types with non-CAM interfaces remain in service, field teams must manage interface heterogeneity the CAM cannot resolve (Int. B-3). A related constraint concerns charging point foundations: the plug interface was designed to make charging points exchangeable without cutting the connection cable, but this is not yet fully realizable because foundations are not standardized across manufacturers, increasing replacement time from an estimated 30 minutes (with standardized foundations) to approximately four hours under current conditions. When an object that has not been approved against the CAM interface is presented for connection after a full civil mobilization is already on site, the options are abort and reschedule for three to four weeks later, or proceed in a way not currently permitted under safety regulations. To address this, DSO-B was piloting a "parking box": a component screwed to the rear wall of the object housing into which the plug can be safely inserted and left energized in a position not accessible to the client while the object manufacturer resolves the compliance issue.

Case synthesis. Case B.2 most clearly illustrates asset complexity and the federated dimension of governance architecture. The CAM's narrow application scope, single-interface technical problem, and stable international normative scaffolding through ElaadNL collectively reduce internal governance demand to a level qualitatively different from the transformer station case; benefit realization, however, exhibits the same perceived-rather-than-measured outcome pattern, confirming that the absence of evaluation is structurally organizational rather than asset-specific. The federated three-DSO governance architecture is categorically different from any configuration of internal organizational fragmentation alone: specification authority is distributed across an inter-organizational consortium, enforcement runs through a binary regulatory connection condition rather than internal organizational pressure, and resilience is architected through design ownership rather than supplier redundancy.

5.4. Chapter conclusion

DSO-B pursues a single organizational logic of industrialized grid expansion across both asset classes, with each governance architecture shaped by the specific technical, institutional, and market properties of the asset it governs.

The transformer station case required deliberate construction of an internal governance architecture: the *ontmazen* topology decision eliminating mandatory inter-station interface variation, the MFT alignment structure preventing specification authority from collapsing into a single department, and the region-based supplier assignment decoupling resilience from operational complexity. This was necessary because the legacy of multi-predecessor consolidation had produced a specification landscape in which standardization authority had to be institutionally produced rather than assumed. The CAM case, by contrast, required not rationalization of existing variety but deliberate construction of a new interface standard where none previously existed. Its governance architecture is federated rather than hierarchical, enforced through a binary regulatory connection condition, and resilience-architected through design ownership rather than supplier redundancy. These are categorically distinct institutional responses to asset-specific standardization conditions, shaped by the same forcing condition: the energy transition has elevated the annual transformer station installation rate to over 500 units per year and made public EV charging connection one of the most operationally binding constraints (source S-B.2).

Measured against the Chapter 3 sensitizing concepts, Case B.1 illustrates governance architecture and the organizational-fragmentation pattern: the program iteratively constructed normative commitment (the "compact, unless" policy), procedural mechanisms (the MFT, the requirements documentation tool, the deviation penalty for non-standard colors), and structural enforcement (logistics-level article-number supply, regional allocation), with the proof-of-compliance gap in the first-generation specification illustrating that structural-tier completeness cannot be assumed. Case B.2 illustrates asset complexity from a different angle: lower inherent technical complexity but higher inter-organizational governance complexity, with the federated three-DSO consortium representing a qualitatively different governance demand than any configuration of internal organizational fragmentation alone. Implementation depth is achieved through different mechanisms in the two cases (procurement enforcement and configuration constraint in Case B.1; binary regulatory certification in Case B.2); the perceived-rather-than-measured outcome pattern is the shared limitation across both. Whether these patterns reflect DSO-B-specific conditions or constitute structural features of DSO-scale infrastructure asset standardization is what the cross-case analysis in Chapter 7 is designed to determine.

6

Within-case analysis: DSO-C

6.1. DSO-C: organizational context

DSO-C is the largest of the three regional Dutch DSOs by network length, managing approximately 146,000 km of electricity cable and 46,000 km of gas piping across five Dutch provinces, serving approximately 5.2 million customer connections (DSO-C secondary sources S-C.1, S-C.2; see Appendix C.1.4). Its service territory is mixed urban and rural, anchored by several mid-sized regional cities and extending into the low-density rural zones of spread-out provinces (source S-C.1). DSO-C invested €1.9 billion in network expansion and reinforcement in 2025, a record figure involving the placement of 1,631 km of low- and medium-voltage cable, the construction of 670 MV/LV stations, and the addition of 1,260 MVA of new network capacity (source S-C.2). The network must at minimum double in scale within fifteen years (source S-C.3).

DSO-C's current form reflects the consolidation of three predecessor lineages that were technically autonomous for decades, each developing its own specifications, procurement norms, and operational cultures (source S-C.6; Int. C-6). Consolidation was not accompanied by systematic asset rationalization, producing an inherited variant population that DSO-C has been reducing since approximately 2010 (Int. C-3; Int. C-6). Critically, one regional sub-network operates as a fully earthed medium-voltage grid while another operates as a floating system, imposing different functional requirements on primary assets and generating legacy variety that both standardization cases address. The variant population is therefore a structural inheritance from merger-origin fragmentation, an instance of the organizational-fragmentation pattern developed cross-case in Chapter 7 (Theme 2, Section 7.5.2).

6.1.1. Organizational structure

Asset Management (AM) holds formal ownership of all technical standards, issues procurement mandates, and manages production chains in what interviewees describe as an explicit customer-supplier relationship (Int. C-3). Within AM, component policy responsibility is subdivided by category: separate policy experts hold ownership of the station building, the distribution transformer, the cables, and the secondary techniques, with the formal renaming of the AM department to "standardization" reflecting the constitutive status of that function (Int. C-2; Int. C-4). A second department, Technical Expertise (TE), contains among others the role of *operationeel installatieverantwoordelijke* (OIV), bearing statutory responsibility for safe network operation independent of production pressure; AM and TE together determine asset standardization policy (Int. C-6).

The principal governance bodies are the Contract Management Teams (CMTs), which bring together AM, TE, procurement, logistics, and suppliers around specific component clusters. The CMT for compact stations integrates governance of three sub-components (the ring main unit, the distribution transformer, and the low-voltage rack) into a single domain (Int. C-6). DSO-C maintains separate CMTs for large MV installations, for power transformers, for low-voltage components, and for underground MV connection assets. For the transport station asset class, a structurally analogous but newer body, the *standardization collective*, was under construction at the time of data collection (Int. C-1; Int. C-2; Int. C-3).

Compact station deployment is distributed across a dedicated production stream; for the transportation station program, deployment also runs through a supra-regional production stream, with DSO-C's supra-regional high-voltage engineering division originally anchoring the engineering knowledge base before withdrawing from active program support (Int. C-1; Int. C-3). DSO-C's ten regional branches serve as the default delivery channel for non-standard projects: where a project deviates from the standard in ways that cannot be accommodated within its bounded variation menu, it is routed to the responsible branch, which has the engineering generalism and historical experience to handle bespoke work (Int. C-2; Int. C-5). The branch engineering role combines design, project ownership, municipal engagement, and contractor coordination in a single function. For the transportation station program specifically, the complete engineering, execution, and production chain sits with external contractors, meaning DSO-C's internal staff hold governance ownership for a program whose technical work they do not perform (Int. C-3).

6.1.2. Organizational standardization adoption driver

The primary driver at DSO-C is the structural mismatch between the deployment volume required by the energy transition and the throughput achievable under bespoke engineering. In the transport station domain, DSO-C was realizing approximately ten deployments per year historically; the transition pipeline demanded 100 to 130 stations per year, making the gap not a matter of incremental improvement but of a qualitatively different delivery model (source S-C.4). As the program leader described the initiating recognition: "it was so substantially large for the organization that we could not handle it in the regular way we had always done it" (Int. C-1). Both internal personnel growth and partner-side scaling were ruled out as sufficient responses, and standardization was identified as the necessary precondition: "at the moment that you work with standardization, you can scale up much more. You need less engineering, and you can deploy scarce capacity much more selectively" (Int. C-1).

This urgency dynamic is comparable to DSO-A's urgency-as-accelerant but institutionally distinct: DSO-C did not face a single acute crisis but a planning-horizon revelation made numerically undeniable by transition investment plans, producing a deliberate program design response rather than an emergency governance intervention. For the compact station asset class, urgency preceded the transportation station program by approximately a decade and operated through volume accumulation: DSO-C committed to placing approximately 1,600 compact stations per year, a scale at which bespoke configuration becomes economically untenable (Int. C-3; Int. C-4).

Labor scarcity is a further shared driver (source S-C.3). The available workforce is quantitatively limited, and its skill profile has contracted in ways that make deviation handling increasingly unreliable, making standardization a quality-preservation mechanism (Int. C-3; Int. C-4). The decision to deploy all transportation stations initially de-energized exemplifies this logic: "all stations are initially placed cold, meaning energized later, which means you can also more easily work with lower-qualified personnel for the scaling" (Int. C-1). An operational interviewee identified three reinforcing mechanisms through which variety reduction enables production speed (Int. C-3): attracting technical personnel has become substantially harder, making the reduction of required knowledge depth at execution level a practical necessity; variety directly impedes process acceleration because each variant demands its own analysis, partner instructions, and monitoring logic; and full standardization enables bottleneck visibility that variety structurally forecloses, since identical stations make a specific time cost per unit visible and measurable. Standardization is therefore a precondition not only for speed but for the organizational learning that makes further speed improvement possible. The optimization target shifts from material minimization to labor minimization through repetition: "just produce the same thing a hundred times, then those costs will automatically go down" (Int. C-3).

6.2. Case C.1: MV-LV transformer distribution stations

6.2.1. Historical background

Prior to the active standardization program, DSO-C operated with more than 70 distinct compact station configurations, the accumulated legacy of the municipal and provincial operators absorbed through successive consolidation (Int. C-2; Int. C-4; Int. C-6). Predecessor organizations had developed their own specification norms, component preferences, and procurement relationships; structural divergence ran deep, with transformer clock positions differing between regions, public lighting control configurations being locally specific, and the earthed/floating architecture split imposing different functional requirements on every primary asset (Int. C-3; Int. C-6). The variant population was therefore technically grounded rather than simply a product of undisciplined procurement: reducing it required resolving actual electrical incompatibilities rather than merely harmonizing preferences.

The dominant procurement relationship was with a single incumbent compact station supplier whose proprietary configurator tool had structured the specification process for approximately fifteen years

(Int. C-4). The configurator generated a theoretical space of approximately 101 component combinations, of which approximately 49 were actually ordered in practice. Because each order was a custom specification, the supplier produced to order rather than to stock, resulting in lead times of approximately six months per station. The logistics consequence of bespoke ordering was a recurring stranded stock problem: stations produced against project orders that were subsequently delayed or canceled could not be redeployed because their configuration was project-specific. This contradiction between visible supplier inventory and project-level station scarcity prompted the Tender Board to ask the AM component policy expert whether standardization was achievable, initiating the analysis process that culminated in the 2023 standard (Int. C-4).

6.2.2. Timeline and key milestones

First rationalization wave: tender-driven network-architecture consolidation (approximately 2010 to 2015). The first formal rationalization effort was initiated through a procurement tender around 2010, with standardization embedded as a tender requirement rather than pursued as a separate internal policy exercise (Int. C-6). The tender outcome reduced the variant population from more than 70 distinct configurations to seven variants organized around two principal network groupings, with the primary differentiator being transformer clock positions required for connection to the respective network architectures. The existence of successive tender cycles within a continuous procurement relationship is independently corroborated by the supplier's announcement of its January 2020 contract award (source S-S.3). An intermediate step subsequently reduced the seven variants to three, one per principal network segment, distinguished only by transformer clock positions and public lighting control configuration; internal component choices of transformer capacity, rack size, and RMU configuration remained variable throughout this period.

Second rationalization wave: segment consolidation with pilot validation (approximately 2023). The 2023 article-number standard was driven by the energy transition rather than initiated through a new procurement tender, with the program leader describing the transition as having compelled the organization to act (Int. C-6). The standardization concept originated jointly within AM and TE as a shared mandate. The team proceeded incrementally: connection diagrams were first aligned across the three segments and updated work instructions distributed before any physical change to the ordered station type was introduced. Before the pilot was initiated, the proposed design was circulated as a structured desk check to operational technical specialists and field execution teams, complemented by targeted interviews at branches selected through deliberate resistance-mapping logic: the AM team identified in advance which branches and individual workers were most likely to oppose the change and chose them as primary interview partners.

The internal specification logic of the pilot underwent deliberate evaluation before the final configuration was fixed. The AM team initially retained component-level variation within the unified housing (three transformer capacity options of 250, 400, and 630 kVA; three LS-rack sizes; two RMU options), then concluded that fixing the transformer at the 630 kVA maximum and the LS-rack at the 12-direction maximum across all stations was justified because the cost difference was recoverable through simplification gains in articles, work instructions, commissioning, and logistics (Int. C-6). A bounded pilot conducted between two provincial sub-networks with structurally different MV grid architectures validated that field actors would execute with the new unified station rather than revert to previous regional configurations. Implementation was followed by a formally structured aftercare phase and a physical field audit at installation sites, which confirmed no reversion to previous regional configurations. The standard-setting process simultaneously reduced the configurator's 101 theoretical combinations to base variants defined by transformer capacity and building size, with explicit acceptance of marginal over-specification at unit level in exchange for operational simplicity at program level (Int. C-4).

Transition to triple-source supply (2023 onwards). Following the standard-setting phase, the supply-resilience risk of single-source dependency on the incumbent supplier became the trigger for introducing additional suppliers (Int. C-4). From the AM perspective, "standardization and supplier independence must be designed together": a standard deliverable by only one supplier transfers the supply risk from configuration complexity to single-source dependency without eliminating it (Int. C-6). The deliberate design goal was therefore functional equivalence across multiple suppliers, with the specification defined at the interface level: "you pull one out, you put another in, and it works". The 2018–2019

European procurement tender had been designed around approximately 300 stations per year, whereas current demand stands at approximately 1,600 per year (Int. C-4; source S-S.3). Within the expanded supply arrangement, the incumbent delivers approximately 1,000 stations per year, a second supplier approximately 400, and a third fewer than 200.

The procurement route followed was a deliberately chosen non-tendering procedure, internally referred to as *bewust aanbesteden* (deliberate tendering): a risk assessment was presented documenting what single-source dependency implied if the incumbent could not deliver, and the proposal was submitted to the Tender Board, which provided initial endorsement before passing the proposal to the Board of Directors for authorization within a defined period and budget ceiling kept below the threshold triggering a mandatory European tender (Int. C-4). The current authorization is anticipated to run until the second half of 2027, when a new European tender for compact station supply is expected. The multi-sourcing logic has a direct parallel in the transformer component stream, where DSO-C currently works with five to seven suppliers simultaneously: all suppliers delivering the same transformer capacity share a single article number, meaning an ordering engineer does not specify a supplier and supplier origin has become operationally invisible (Int. C-4).

Make-to-stock logistics model and inherited inventory clearance (ongoing). The reduction to article-number variants enabled DSO-C to move from project-specific ordering to a make-to-stock model in which standard stations are pre-positioned at supplier warehouses and called off against forecasted demand (Int. C-3; Int. C-4). The realized lead time improvement is concrete: a standard compact station ordered today is available for placement within approximately six weeks compared to approximately six months under the bespoke ordering model, with most placements drawing directly from existing supplier stock. At data collection, the make-to-stock model had produced an inventory surplus of approximately 600 standard compact stations held at supplier warehouses, calibrated to a directorate-approved target of 1,600 to 1,650 placements per year that actual placement rates had not yet matched. The surplus is described as a manageable condition precisely because the stations are standard: every unit in stock can be deployed immediately at any location requiring a compact station, the structural inverse of the pre-standardization stranded stock problem.

Active standard evolution (ongoing at data collection). The compact station standard is not static: from the current year onward, SF6-containing switchgear installations may no longer be deployed under applicable regulation, requiring a component substitution that the CMT manages in the background with the supplier without changing the article number or ordering process (Int. C-4). A parallel transition concerns a new distribution automation box and remote control unit. A more substantial development concerns the four-cable-field configuration: approximately 200 of the 1,600 stations placed annually require an additional cable field that does not fit within the existing 630 kVA variant footprint, and DSO-C is developing an elongated variant with the incumbent supplier to accommodate this configuration under a new article number. DSO-C is also pursuing a further evolution that extends prefabrication to MV cable connection: rather than field-terminating large-diameter MV cables within the spatial constraints of the RMU installation, the RMU would arrive with a flexible prefabricated cable already mounted at the connector interface (Int. C-6). The development is being pursued collaboratively across all three Dutch DSOs.

Current state of the standard. The current active variant set comprises three types defined by transformer capacity and door geometry. The 250 kVA variant is supplied exclusively by the incumbent supplier and represents approximately 10% of total annual volume, equivalent to roughly 160 stations per year (Int. C-4). The 630 kVA category was initially defined by two named types which are functionally interchangeable but differ in deployability: the preferred variant concentrates all access doors on a single facade, reducing the effective plot footprint; at data collection DSO-C had agreed to phase out the other variant. A third legacy product designation is also being phased out. Permitted variation runs along three axes: transformer capacity (250 or 630 kVA, with deterministic cascading into LS-rack and RMU options), supplier identity (three approved suppliers, all delivering against a shared specification at the interface level), and 3-field versus 4-field RMU configuration. Two categories sit outside the standard: the formally defined specials category (absorbing distribution automation requirements, non-standard colors, and 20 kV configurations) and the cataloged specials route.

6.2.3. Actors and governance structure

The standardization initiative originated as a bottom-up proposal: the Tender Board observed the stranded stock and station scarcity problem and asked the AM component policy expert whether the variant population could be rationalized (Int. C-4). AM holds formal specification ownership and drives variant minimization and supply chain resilience. Within AM, component policy responsibility is subdivided: one policy expert holds the electrical sub-components (distribution station, distribution transformer, RMU) and a separate role covers the station building and housing. TE holds the OIV role, providing safety endorsement independent of production pressure (Int. C-6). The ten regional branches are the primary deployment actors, alongside the compact-station production stream that handles large-scale new-build programs in which contracted parties take on complete engineering, preparation, and execution responsibility for an entire district (Int. C-5). The production stream operates almost entirely within the *new-build unless* logic. Municipalities constitute an external stakeholder exerting spatial and aesthetic pressure that in some cases exceeds what the variant mechanism can absorb, with below-ground placement requirements and historically distinctive cylindrical enclosure geometries as concrete examples necessitating bespoke deviation (Int. C-6).

These interests are coordinated through the CMT, which integrates governance of the RMU, transformer, and LS-rack into a single domain. This integration is not merely organizational convenience: it prevents the component-silo procurement decision-making that produced the MV-switchgear dimensional-grid incompatibility in the transportation station domain (Int. C-2). The CMT is composed of role-differentiated functional members rather than being a single-discipline body: procurement, logistics, AM, and TE each hold a defined role, and the functional scope determines which category of issue is led when a question arises. The CMT receives all change proposals, complaints, and improvement suggestions from operations, suppliers, and procurement, and adjudicates whether changes are absorbed, deferred, or rejected. Change management within the standard operates through a formally defined process applying equally to proposals from field operations, suppliers, and AM or TE: each enters the same process, is documented, and is brought to the CMT in regular meetings structured to address complaints and improvement proposals together rather than through separate processes (Int. C-6).

The CMT's adjudication authority extends beyond changes to the standard to include project-level deviations from it. When a project actor intends to procure outside the standard framework, the deviation is submitted to the CMT for evaluation: if the actor can demonstrate that the standard genuinely cannot serve the requirement, the CMT approves the deviation and routes the procurement through a parallel bespoke process (Int. C-6). The governance consequence is not merely procurement authorization but lifecycle commitment: a bespoke station placed in the network requires dedicated spare parts and replacement stock for as long as it remains in service, providing a structural disincentive that reinforces the standard's dominance without categorical prohibition. The empirical frequency of CMT-approved deviations is approximately 5% of total compact station demand, consistent with the standard's approximately 90% coverage, with land constraint and municipal spatial requirement as the dominant triggers.

The CMT holds four further governance functions spanning the procurement and asset lifecycle: continuous specification ownership (updating the program of requirements between tender cycles); supplier factory audit conducted with a split team covering both procurement-side and technical-side compliance; hardware change notification governance (assessing supplier substitutions against the program of requirements before production introduction); and lifecycle qualification through factory acceptance testing, site acceptance testing, and FMEA-based assessments (Int. C-6). That the transportation station standardization collective was explicitly designed to replicate this model confirms the CMT's status as the governance archetype within DSO-C (Int. C-1; Int. C-2). The governance-architecture sensitizing concept from Chapter 3 (§3.3.3) is well illustrated here: the CMT's integration of all three sub-components into a single domain represents the kind of procedural mechanism that prevents interface failures from propagating across component boundaries.

6.2.4. Operational outcomes and benefits

Engineering simplification through article-number ordering. The reduction to two article numbers transformed the engineering logic of deployment: project engineers select a standard unit from stock rather than assembling a bespoke configuration, eliminating the configuration step for the vast majority of placements (Int. C-3; Int. C-4; Int. C-6). The benefit logic was not framed primarily as a cost reduction argument at initiation: the governing rationale was timeline compression, with cost reduction understood as a downstream consequence (Int. C-6). The upfront investment in over-specification (the LS-rack accommodating up to twelve cable connection positions even where five suffice) is the structural price of this timeline gain.

Lead time compression. Delivery time fell from approximately six months under the bespoke ordering model to approximately six weeks after the transition to make-to-stock, and in practice most placements are fulfilled directly from existing supplier stock without triggering a new production run (Int. C-4). The organizational consequence is that compact station availability has shifted from a project scheduling constraint to a routine logistics variable. A complementary administrative simplification operates at the procurement level: because the article number, specification, and price are pre-determined within the framework contract, an engineer can place an order without generating a bespoke purchase order or waiting for a quotation response, with savings accumulating across approximately 1,600 annual placements (Int. C-5).

Maintenance and fault response simplification. Variant reduction reduces not only station inventory but the population of spare components required for in-service fault response and scheduled maintenance: when the installed asset population comprises only a small number of defined types, the spare component inventory required to service it can be defined, bounded, and pre-positioned accordingly (Int. C-6). A single connection diagram applies across the entire installed population of each station type, allowing the technician to move directly from arrival to diagnosis without a variant-identification step. Process uniformity extends to the contractor base: every team encounters the same foundation geometry, cable entry specification, and installation sequence regardless of which regional branch is the client (Int. C-2; Int. C-3; Int. C-4).

Logistics resilience through interchangeability. The single-article-number model enables a logistics resilience architecture infeasible under variant-rich procurement: because all transformer units of the same capacity are interchangeable regardless of manufacturer, DSO-C can draw on its own buffer stock to supply a station builder experiencing a delivery shortfall, substituting one manufacturer's unit for another without consequence for the installed station's technical configuration (Int. C-4).

Cost outcomes and measurement gap. A senior interviewee with more than fifteen years of CMT portfolio responsibility estimated the annual financial benefit of the compact station program at millions of euros on a recurring year-on-year basis, encompassing procurement price reductions, reduced inventory carrying costs, and reduced engineering and maintenance labor (Int. C-6). The figure is not expressed in formally tracked metrics but represents a credible order-of-magnitude assessment grounded in operational experience. This pattern, in which benefits are described in perceived rather than measured terms, is the within-case manifestation of what Chapter 7 develops as the cross-case measurement gap (Section 7.5.1). From the field perspective, the shift from single-source to multi-source supply has introduced more physical enclosure variety into the field than existed under the original single-supplier model: multiple manufacturers produce enclosures with differing geometries, heights, and visual appearances (Int. C-5). The single-article-number model abstracts supplier identity at the ordering interface, but the physical consequences of supplier variety remain visible at the site placement and stakeholder engagement stages.

6.2.5. Implementation challenges

Connection schema integration as the dominant challenge. The most senior CMT interviewee identified the connection schema as the single most significant implementation challenge across the entire standardization trajectory, harder to resolve than any other aspect of the program (Int. C-6). The difficulty is structural rather than organizational: a standard station placed into an existing network connects to a legacy configuration built under predecessor regional specifications, which cannot be modified to accommodate the new standard because the cables and infrastructure are buried. Field technicians and work preparers therefore face a recurring question of how to make a standardized product fit into a pre-existing network context that was not designed around it. Resolution required the connection schema to be made sufficiently flexible and the accompanying work instructions sufficiently detailed to cover the full range of legacy network contexts technicians would encounter.

Cultural resistance and over-specification acceptance. Resistance to standardization reflects a professional engineering culture in which bespoke configuration was historically an expression of expert judgment and local knowledge. Accepting a standard station where a tailored design might be technically superior requires engineers to subordinate individual judgment to a system-level logic (Int. C-2; Int. C-3; Int. C-4). The transformer capacity decision provides the sharpest empirical instance: the elimination of the 400 kVA class and the rule requiring a 630 kVA transformer in all larger stations means that every station placed in a location where 400 kVA would have been technically sufficient carries a larger unit generating measurably higher no-load losses for the asset's entire operational life (Int. C-4). The directorate approved the standard on the basis of a cost presentation including energy loss figures, but without a formally closed business case quantifying maintenance and engineering hour savings; approval rested on directional judgment and cost transparency rather than verified net benefit, a governance vulnerability when cost pressure increases. Field technicians and installers also universally prefer walk-in stations for ergonomic reasons, a preference acknowledged by AM as legitimate but overridden on system-level grounds; the governance response is to direct ongoing prefabrication development toward reducing the field connection workload within the compact form factor (Int. C-6).

Specials route as low-friction exit from the standard. Field evidence suggests that the specials route functions as a low-friction exit rather than a tightly governed exception pathway. A branch engineer described two representative special triggers (a location requiring four MS cable directions, and a placement adjacent to a customer-owned station finished in anthracite where ordering the standard green enclosure would produce visual incongruity) and characterized the process as generating questions at most, with the underlying assumption that a special order carries a valid reason by default (Int. C-5). For the compact station asset class, specials can therefore be initiated at engineer discretion without a formal authorization step, in contrast to the transportation station domain where deviation requires explicit CMT approval.

Site availability constraints on new placement. The *new-build unless* policy depends on the availability of a suitable plot for a new compact station near the location requiring capacity reinforcement, a condition that is not always met in dense urban environments where stations are built directly against existing structures and surrounding land is fully occupied (Int. C-4). When no plot is available, renovation of the existing station becomes the only option, reintroducing bespoke work and removing the deployment from the standard's scope entirely. A further constraint applies when replacing a station that must remain in service during the transition: continuous supply capacity must be maintained throughout the changeover period, requiring either a temporary generator or a temporary station on site, both of which demand space that may not be available.

Standard maintenance under regulatory pressure. The compact station standard faces ongoing pressure from externally driven component changes that require the CMT to manage supplier transitions without disrupting the field-facing ordering and deployment logic. The SF6 switchgear phase-out, the concurrent distribution automation box transition, and the four-field station development each represent challenges where the CMT must absorb the change into the existing article-number shell or develop new variants, balancing variant minimization against genuine network topology requirements (Int. C-4).

Case synthesis. Case C.1 illustrates governance architecture and implementation depth in their most mature observed form across the three DSOs. The CMT's single-domain integration of all three station sub-components, the make-to-stock logistics model decoupling delivery from project-specific ordering, and the *bewust aanbesteden* mechanism enabling deliberate triple-sourcing without continuous European tender cycles together constitute the most complete realization of the governance-architecture concept in the case portfolio. Implementation depth is sustained through a combination of pilot validation, structured aftercare, and field audit verifying that no reversion to legacy regional configurations occurred. Asset complexity operates at a level the governance architecture is visibly designed to manage rather than approaches its upper boundary.

6.3. Case C.2: MV-MV transportation station

6.3.1. Historical background and pre-standardization context

The transportation station is placed at the transition between the medium-voltage transport network and the distribution network and is substantially larger and more technically complex than the compact station. It houses MV switchgear, optionally one or more distribution transformers, a secondary systems cabinet with a Remote Terminal Unit (RTU), and associated protection and measurement equipment (Int. C-1; Int. C-3). On its primary side it interfaces with the DSO-C transportation network; on its secondary side it feeds the medium-voltage distribution ring supplying the compact stations of Case C.1.

Unlike the compact station, which arrives as a factory-assembled unit, the transportation station is assembled on-site from components procured from four separate suppliers: "within a compact station, it comes complete from the factory and you do not have to look at the building. Within a transportation station station I have a separate supplier for the building, the cabinet, the MV installation, and the RTU, so I immediately have more variation and dependencies, which makes it harder" (Int. C-3). Each component is individually standardizable without difficulty; the primary challenge lies in their integration, specifically in how independently supplied components are combined into a coherent assembled station that meets DSO-C's functional and spatial requirements. The internal technical specifications of supplied components such as the MV installation are fixed by existing supplier contracts and lie outside DSO-C's sphere of influence, whereas physical placement, orientation, and positioning of those components within the building remain within DSO-C's control. The standardization challenge is therefore not located at the component level but at the integration boundary.

A functional distinction within the asset class is analytically relevant. The standard *transportverdeelstation* (transportation station) operates at a fixed voltage level, while the *transportverdeelregelstation* (transportation–regulation station) incorporates switching capability between 10 kV and 20 kV (Int. C-1). This distinction is necessitated by the legacy voltage heterogeneity of DSO-C's network: portions of the medium-voltage transport grid were historically developed at 10 kV and are not yet ready for migration to 20 kV. The transportation–regulation station resolves this through a forward-compatibility logic: a station is placed and initially operated as a conventional transportation station at 10 kV, with the voltage upgrade deferred until the connected network segment is ready, decoupling physical deployment from voltage transition timing.

The standardization trajectory is unusually well documented in public sources because the program is positioned by DSO-C as a flagship illustration of how standardized, modular, prefabricated construction can compress the realization timeline of high-complexity infrastructure assets (sources S-C.4, S-C.5, S-C.7, S-C.8, S-C.9). In place of separately engineering each transport-distribution station, a single standard has now been developed; the station building is constructed from prefabricated concrete elements that are assembled on location, while the switchgear installation is fully assembled at the supplier, transported, and lowered into the building by crane before the roof is mounted (source S-C.4).

Prior to standardization, every transportation station was engineered individually, with specifications tailored to load forecast, site geometry, and grid interface conditions. This bespoke model was historically sustainable because annual volumes were modest and the supra-regional high-voltage engineering division could supply specialist expertise project by project (Int. C-3; Int. C-6). The energy transition made the bespoke model untenable: ten transportation station deployments per year had to scale to 100 to 130, requiring standardization as a precondition rather than an optional efficiency measure (Int. C-1; source S-C.4). Standardization front-loads engineering work into the specification itself, after which contractors receive a fixed package and proceed to execution without continuous DSO-C input at the project level. The governing principle is an explicit make-or-keep boundary: only what falls within DSO-C's statutory responsibility or constitutes genuine organizational expertise is retained in-house; everything that can be unambiguously specified and delegated is transferred to the contractor (Int. C-1). The asset-complexity sensitizing concept from Chapter 3 is illustrated sharply here: the transportation station's on-site assembly model and four-supplier component architecture represent a qualitatively higher governance demand than the compact station's factory-assembled, single-integrator model.

6.3.2. Timeline and key milestones

Program initiation and organizational mandate (2021). The transportation station standardization program was formally initiated in 2021, when organizational clarity about grid congestion made its strategic urgency explicit (Int. C-1; Int. C-3). The trigger was a forward-looking ten-year capacity assessment which made clear that DSO-C would need to place at minimum 800 new transport distribution stations within the coming decade, a volume so far beyond the historical throughput of approximately ten per year that it could not be absorbed within the existing bespoke model (source S-C.4). The organizational response was to commission a dedicated program manager with an explicit design mandate (Int. C-1). This mandate was executed in a deliberately sequenced governance logic: basic high-level choices were first aligned with the board, after which the full elaboration was developed collaboratively with the steering group, before translating into the operational production chains.

The standard development was conducted through an informal multi-party body that functioned as the forerunner of the standardization collective (Int. C-1). For each strategic component, the initial elaboration was conducted with a single supplier as a deliberate speed choice: involving multiple suppliers simultaneously would have been preferable but was judged too slow given program urgency, so broad-lines development was completed with one supplier per component before additional suppliers were brought in. A central ambition was the shift toward maximum prefabrication, with large prefabricated components arriving by heavy truck and craned into position. The primary MV installation supplier constructed a new manufacturing facility explicitly configured around the standard transportation station installation, an investment that would not have been economically rational without the volume commitment a stable standard provides. A concrete output of this early design work was the resolution of the asset class into four defined variants: a transportation station in 10 kV and 20 kV versions, and a transportation station with two regulation transformers and one with three.

Proof of concept and pilot phases (2021 to 2023). Initial specification development was anchored by the supra-regional high-voltage engineering division, which held the institutional knowledge base (Int. C-3). The program was structured into two formally separated phases: a proof of concept focused on verifying that the chosen technical configuration was deployable and safe in practice, followed by a pilot phase focused on optimizing the process to achieve required deployment speed (Int. C-1). The first station built under the new standard was placed at a pilot site in one of DSO-C's regions with four supply-chain partners: a main contractor and building supplier, an MV installation supplier, a prefab concrete-elements supplier, and a transformer supplier (source S-C.4). This phase separation reflects program management maturity absent from the compact station trajectory, where specification choices were locked into procurement documents without a prior bounded test. However, the intended learning outcome of the PoC was not fully realized: when the supra-regional high-voltage engineering division was reactivated to support the PoC, its management subsequently withdrew its personnel while the PoC was still executing, before the feedback loop between field execution and specification refinement had closed (Int. C-3).

Baseline drawing set delivery and documentation gap (2022 to 2025). The baseline drawing set was produced by the high-voltage department for the medium-voltage department, formally handed over at completion but subsequently left without further development: no updates were made after handover, and the set was not maintained in BIM (Int. C-2). The departments responsible for working with these drawings lacked the technical staff needed to maintain them. At data collection, the operative paper standard consisted of an internal requirements and compliance document and the drawing set, with documentation development under the main contractor relationship having been stopped in April 2025. The depth of prescription in the installation handbook represents a historically unprecedented departure from DSO-C's prior practice: previously no installation handbook existed at the system level (Int. C-1). The handbook's existence transforms every component change into a system-level event requiring synchronized updates across working methods, supplier instructions, and field process documentation simultaneously. BIM modeling of the standard variants was being actively developed by a drafter with prior high-voltage experience (Int. C-2).

Version 1.0 release and national roll-out (2023 to 2024). Following the pilot, Version 1.0 was released for the transportation station, with the transportation station version following shortly after, so that both configurations entered operational deployment in close succession (Int. C-1). The release did not mark a specification freeze: interviewees describe the standard as still being actively updated in response to field feedback, component supply changes, and regulatory requirements, making Version 1.0 a deployment threshold rather than a completed specification. With the release, the task shifted from developing and validating the standard to managing and sustaining it, and it was at this transition point that the organization encountered the governance challenges described in the implementation challenges section.

Dual-sourcing introduction and the MV-switchgear dimensional-grid incompatibility (2022 to 2024). The introduction of a second MV installation supplier was motivated by supply-chain resilience (Int. C-1; Int. C-3; Int. C-6). The original MV installation supplier had been selected first, and the baseline station footprint was designed around that supplier's dimensional grid; when a second supplier's unit entered the design process, it became apparent that the two suppliers used different dimensional grid references (50 cm and 60 cm respectively), and neither supplier can straightforwardly conform to the other's dimension without abandoning production methods in which they have invested (Int. C-2). The root cause was that the grid reference dimension had not been considered as a standardization parameter during the original specification design: the original supplier's grid reference had been embedded as an implicit assumption rather than as an explicitly neutralized interface requirement. The consequence was that DSO-C was forced to design a second footprint variant to accommodate the new supplier, producing precisely the kind of variant proliferation that standardization was intended to prevent. The structural lesson is that all dimensional parameters that could vary across suppliers must be explicitly identified and neutralized in the specification before any second supplier is introduced.

DSO-C's policy is to maintain at least two suppliers for each of the four strategic components: the building, the MV installations, the transformer cells, and the transformers (Int. C-1). For the transformer component, three suppliers are active. The combinatorial logic of two suppliers per component across four component clusters generates approximately 32 distinct internal configurations, managed through 3D model-based configuration tooling. A structural tension inherent to dual-sourcing with technically capable suppliers is that imposing strict identity would require one or both suppliers to abandon production methods that define their competitive position (Int. C-2).

Standardization collective construction and forthcoming tender (ongoing at data collection). A standardization collective was under construction to provide permanent governance for the transportation station standard, explicitly modeled on the CMT architecture (Int. C-1; Int. C-2; Int. C-3). The main-contractor relationship itself originated not through a formal European public procurement tender but organically from the existing compact station contract: the supplier was asked informally whether it could produce a larger station variant capable of housing more switching fields, and the collaboration that resulted was extended incrementally as volumes grew (Int. C-2). A formal tender process is identified as a pending governance requirement and represents not only a procurement compliance milestone but a structural governance transition. For the MV installation component, European public procurement obligations govern the supplier contract, producing a specification that DSO-C is legally prohibited from modifying unilaterally between tender cycles (Int. C-3).

Current state of the standard. The standardized transportation station range is structured into four core variants: a transportation station in 10 kV, a transportation station in 20 kV, a transportation station with two regulation transformers, and a transportation station with three regulation transformers (Int. C-1). The building component is identical across all four variants; regulation variants require a greater number of building units than the simpler transportation station configurations. Permitted variation runs along three axes: voltage configuration (the transportation station/transportation station distinction, derived from the legacy 10 kV network's deferred migration to 20 kV), regulation transformer count (two or three, derived from network capacity requirements at the specific node), and supplier combination across the four component streams (generating approximately 32 internal configurations). Two categories sit outside the standard: bespoke deviation projects arising from municipal requirements that the bounded exterior typology cannot absorb, and renovation projects on existing transportation station sites where the available plot does not accommodate a standard new-build configuration.

6.3.3. Actors and governance structure

The principal governance body for the transportation station standard is the standardization collective, under active construction at the time of data collection. Its design is explicitly modeled on the CMT architecture but with structural modifications reflecting the transportation station program's dual identity as both an asset standard and an operational delivery program (Int. C-1; Int. C-2; Int. C-3). Under the preceding model, component management was distributed across CMTs in which AM held the lead role, supported by procurement and contract management. The shift to integrated standard management represents a fundamental departure: "you see an important tipping point: before making certain choices on the technical side, you already have to have sought alignment across the full breadth, to check whether things will continue to function" (Int. C-1). This inversion from decide-then-align to align-then-decide requires a continuously active, multi-party coordination apparatus.

The most analytically distinctive feature of the collective's intended design is its dual-leadership structure. The collective does not sit within AM as an organizational unit, yet AM retains full ownership of the standard and holds the owner role within the collective (Int. C-1). Two named lead roles are distinguished: the *owner*, drawn from AM, holds authority over technical content and standard integrity; the *driver*, drawn from the production chain, holds responsibility for process speed and operational implementation. This dual structure is maintained consistently through every level of the escalation hierarchy, ensuring that ownership remains anchored in AM while production pace is represented with equal authority at every governance tier. The design is explicitly contrasted with the CMT model, which operates under single AM-dominant leadership; the second authority vector reflects a deliberate design response to the transportation station program's delivery pressures.

Within AM, component-level specification authority is distributed across four parallel policy expert roles, each holding ownership of one strategic component domain: building and civil structure, transformers, cables, and secondary systems (Int. C-2). The governing interface-specification philosophy is that DSO-C specifies the coupling interfaces between components rather than full products: "standardization is, in my view, defining the coupling. If you define the interface dimensions, anyone can build a kitchen. Every oven, every refrigerator fits, and development of the oven can then proceed independently, as long as it fits in the cabinet" (Int. C-2). In practice, however, DSO-C has not yet fully operationalized this philosophy: when a supplier introduces a new transformer version, the organizational reflex has been to adapt the standard to the new component rather than hold the interface fixed and require the component to conform to it (Int. C-2).

The collective's intended change management process operates on a dual-trigger model: proposals can be initiated either by DSO-C (when internal analysis identifies improvements) or by suppliers (when a component is announced for replacement), with both entering a representative decision-making body that evaluates downstream impact across handbook, working methods, supplier contracts, and field instructions (Int. C-1). Because AM and the logistics center are each relatively small teams while the engineering workforce is substantially larger, granting the full engineering population the freedom to shape specification changes would produce variety at a scale that small governance teams cannot absorb (Int. C-3). The collective's scope is therefore bounded as version management rather than innovation governance: iterative improvements and supplier-driven updates within the existing architecture are in scope; fundamental innovation requiring development outside the running process falls outside its intended remit (Int. C-2).

The actor landscape includes parties whose positions create structural constraints on the collective's functioning. The supra-regional high-voltage engineering division withdrew from active program support following a management-level disagreement, removing the organization's most experienced high-voltage engineering partner at the most intensive specification phase (Int. C-3). The ten regional branches are the primary deployment actors for renovation and partial-replacement transportation station projects but lack the high-voltage engineering competences transportation station-class assets require. The structural source of this gap is the organizational separation between the supra-regional production stream responsible for new-build transportation station deployment and the regional branches, which absorb renovation and partial-replacement projects (Int. C-5). The standard, including its ordering logic and contractor interface, was designed around the supra-regional execution model; when a renovation project arises, it is assigned to the regional branch, but the delivery process, the competence base, and the ordering pathways all presuppose the supra-regional new-build trajectory, producing failure points in a process designed exclusively for the unconstrained new-build case.

The consortium architecture supporting the transportation station program is publicly documented and provides external corroboration of the multi-supplier governance arrangement: a main contractor serves as supplier of the prefabricated buildings; a separate supplier provides the switchgear; a third supplier provides the prefabricated concrete elements; a fourth supplier provides the transformers; and a contracted civil partner executes the cable work (sources S-C.4, S-C.7).

6.3.4. Operational outcomes and benefits

Engineering compression through article-number ordering. The most direct operational expression of the standardization benefit is the reduction of the entire station specification to a single article number: a project engineer ordering a complete transportation station station no longer needs to determine sizing, specify what must be included, or work out the connection configuration, because all of those decisions have been resolved once and encoded into the article number (Int. C-4). The engineering effort eliminated was estimated by a component policy expert at hundreds of hours per station, potentially reaching one thousand hours under the prior bespoke model. Across a program requiring 800 to 1,000 new stations within a decade, the aggregate engineering hour reduction is of an order that no incremental process improvement within the bespoke model could have approached.

Supplier-side production efficiency and price effects. The transportation station standard enables component suppliers to transition from project-specific production toward batch production, generating two distinct benefit classes. Repeated identical production cycles create learning-by-doing efficiencies (Int. C-3; Int. C-6). Volume commitment through a stable standard also generates price reductions: protective relay unit costs fell from approximately €2,000 to approximately €500 per unit through standardized volume procurement, a 75% reduction that is one of the sharpest empirically documented cost outcomes in the DSO-C dataset and would not have been achievable without the scale commitment standardization enables (Int. C-3).

Build time compression through prefabrication. Under the bespoke model, transportation station stations were built up on location, with materials transported to site in limited quantities and weather and external dependencies introducing variability (Int. C-1). Standardization enabled a qualitatively different site logic: stations are now assembled from large prefabricated modules delivered by heavy trucks, approximating what the program leader described as building with Lego blocks. The on-site process follows a defined sequential structure, and a phase-sequential logic underpins the deployment train concept: a team completing one phase at one location moves directly to the equivalent phase at the next location, enabling continuous utilization of specialist capacity across the program. To keep this train running, DSO-C maintains a deliberate buffer stock of transportation station units, sized on calculated demand forecasts. At the program level, DSO-C has publicly quantified the build-time benefit: the standardized construction method shortens station build time from one to one and a half years down to approximately four months (source S-C.4).

Outsourcing scalability through de-energized deployment. Standardization also directly enables outsourcing at scale: “this standardized approach makes it possible to outsource a much larger portion of the work, which fits the strategy of realizing a significant share of production growth through greater outsourcing to our contractor partners” (source S-C.4). The decision to deploy all transportation stations initially de-energized is the operational mechanism through which this logic is realized: because no live-voltage work is required during civil and mechanical installation, workers do not need the qualifications legally required for energized work and can be trained narrowly for a defined type of station (Int. C-1). Contractor partners identified this as enabling redeployment of workers from adjacent labor pools, with road construction cited as a concrete example. The operational sequence is a deliberate two-team model: a civil and mechanical installation team places the station and completes all de-energized work, after which a separate specialist energizing team composed predominantly of DSO-C’s trained staff commissions the station under voltage. This positions the de-energized deployment decision not merely as a labor flexibility measure but as an internal capability preservation strategy under structural workforce scarcity.

6.3.5. Implementation challenges

On-site assembly as a structural coordination burden. The transportation station’s on-site assembly model means DSO-C functions as system integrator across four independently procured component streams, a role absent from the compact station case and requiring a governance maturity the standardization collective has not yet achieved. Scheduling incompatibilities, interface mismatches, and quality-assurance gaps multiply proportionally with the number of independently sourced components (Int. C-3; Int. C-5; Int. C-6).

Governance transition from component to integrated standard management. DSO-C's existing governance apparatus was designed for component-level management, where each component had its own CMT track (Int. C-1). The transportation station standard inverts this entirely: the installation handbook now prescribes execution in a level of detail one interviewee compared to an Ikea assembly manual, fixing the sequence, method, and configuration of every installation step. A change to one component propagates simultaneously through the installation handbook, all supplier contracts, and all field process instructions: "we ran fairly quickly into certain challenges. The organization was set up to manage a component. We were now in a phase where an assembly of components had to be managed, with a manual that must remain internally consistent throughout" (Int. C-1). A further governance precondition not yet met is a shared organizational definition of what the standard itself consists of: AM actors understand the standard as a technical specification of components and interfaces, while production chain actors understand it as a process specification ensuring execution flow and role clarity (Int. C-2).

Organizational misalignment across multiple dimensions. The supra-regional high-voltage engineering division's withdrawal created an internal capability crisis: DSO-C's complete transportation station engineering knowledge base was held by that division and contractors, and when the division withdrew, internal capability was minimal: "the management and standardization of transportation station lies within DSO-C. But the complete engineering, execution, and production phase lies entirely outside. So you also have very limited monitoring, and the people internally at DSO-C are not building up knowledge" (Int. C-3). A second misalignment concerns the boundary between AM's standard ownership role and the production chain's standardization responsibilities, which had not been clearly delineated at data collection, qualified as a temporary condition rather than a deep structural problem (Int. C-2). A third concerns renovation transportation station projects, which are routed to the regional branches lacking a transportation station competence base, producing inconsistent compliance driven by routing logic rather than willingness to comply (Int. C-3; Int. C-5). A branch engineer with direct involvement in a transportation station renovation project described engaging four separate individuals trying to place an order for non-standard buildings without resolution (Int. C-5). The transportation station specials pathway, in contrast to the low-friction compact station specials route, involves multiple organizational actors and creates substantial navigational friction.

Municipal friction and permit bottlenecks. Land acquisition and permitting constitute the largest operational challenge DSO-C has encountered in the transportation station program, identified explicitly as the primary bottleneck constraining deployment pace (Int. C-1). transportation station stations are substantially more visible than compact stations, typically 12 to 13 meters long and often including transformer cells reaching 6 meters in height, making them significantly more likely to trigger municipal objections (Int. C-3). The shift to a standardized form factor has made initial municipal engagement more difficult: under the bespoke model, every station was an individual design with significant room to accommodate municipal preferences, and this flexibility no longer exists (Int. C-1). DSO-C's response is an explicit interior/exterior standardization boundary: internal dimensions and component interfaces are fully fixed and admit no variation, while the exterior is deliberately left open to a bounded range of cosmetic and site-level adaptations. DSO-C was developing a structured typology of finishing concepts at data collection, comprising five distinct options mapped across four defined environment types (Int. C-2). All additions to the standard must themselves be standardized: "those are additions to the standard that are themselves standardized" (Int. C-2). The compensating benefit is a shift from project-level to program-level municipal coordination: where a municipality requires ten new stations, all ten can be discussed simultaneously with the same finishing options applying uniformly.

Standard development sequencing and pre-existing behavioral entrenchment. The transportation station standard was initially developed with one primary supplier per component, then opened to additional suppliers as a deliberate speed-optimization choice (Int. C-1). The MV-switchgear dimensional-grid incompatibility was the direct consequence. A broader sequencing observation extends this lesson: the normatively correct sequence is to define the standard first and then develop and design against it, but DSO-C developed the standard concurrently with its implementation (Int. C-2).

Approximately twenty further stations were already on the production pipeline at data collection, meaning a substantial population of actors had been building under the evolving pre-release standard for two years before a formally closed Version 0.0 existed (Int. C-3). When the formal standard is released, these actors will already have developed ingrained working patterns making realignment to the formal specification politically and organizationally difficult. The interviewee drew a broader normative lesson: a published standard experienced as non-functional or misaligned erodes confidence rapidly: "trust arrives on foot but leaves on horseback. You lose it very quickly, and once it is gone, it is very hard to win back" (Int. C-3).

Cultural and structural barriers to standardization acceptance. A structural cognitive barrier is the tendency of technically driven staff to treat their own labor hours as an invisible cost in economic comparisons between standardized and bespoke approaches: "you have to do a great deal of work to convince them that it actually costs less money. People do not include their own hours and their own time in these kinds of calculations" (Int. C-3). A complementary regional group dynamic is that some differences between regional actors run deep enough that prolonged insistence on a single solution produces resistance that makes downstream decisions harder; the pragmatic governance response is introducing controlled variation on lower-stakes dimensions as a deliberate instrument for securing cooperation on higher-stakes ones. A cross-cutting success condition identified by the program leader is the extent to which the organization internalizes the governing logic of standardization: a custom-built house produces the best fit for one family, but building an entire residential district at pace requires accepting that no individual house is the individually optimized solution it would have been under bespoke design (Int. C-1).

Case synthesis. Case C.2 illustrates the asset-complexity sensitizing concept at its upper boundary across the case portfolio: the transportation station's on-site assembly model, four-supplier component architecture, and permitting constraint collectively represent a governance demand qualitatively higher than any of the other five cases. The case also illustrates governance architecture in a state of construction rather than maturity, with the standardization collective formally modeled on the CMT but distinguished by its dual-leadership *owner/driver* design. The MV-switchgear dimensional-grid incompatibility, the supra-regional engineering division's withdrawal capability crisis, and the governance transition from component management to integrated standard management each represent challenge categories with no direct parallel in Cases C.1, A.1, or B.1, confirming that the transportation station operates in a structurally distinct governance tier. Implementation depth is partial and uneven: the article-number ordering interface and de-energized deployment design have achieved operational realization, while the documentation infrastructure, the regional branch routing logic, and the cross-supplier interface neutralization remain in development. The perceived-rather-than-measured outcome pattern is consistent with the broader pattern at DSO-C: the build-time, engineering-hour, and supplier price benefits are directionally credible and partially externally documented, but absent a counterfactual baseline cannot be independently verified.

6.4. Chapter conclusion

DSO-C presents two standardization trajectories at markedly different stages of institutional maturity. The compact station program, having reduced a variant population exceeding 70 configurations to two primary article numbers through successive procurement rounds since approximately 2010, suggests that multi-component, multi-supplier asset governance can be institutionalized in a technically rigorous and organizationally durable form. Its CMT structure, make-to-stock logistics model, *bewust aanbesteden* procurement governance, and pilot-validated specification together constitute a governance archetype that DSO-C explicitly replicates in the transportation station domain. The transportation station program, formally initiated in 2021 and still constructing its standardization collective at data collection, confirms the compact station's analytical status as benchmark: the tenfold scaling imperative, the deliberate PoC-to-pilot sequencing, the dual-leadership design, and the interface-specification philosophy all reflect an organization that has learned from its more mature asset class and is applying those lessons to a structurally more complex one, while confronting a distinct set of implementation challenges rooted in on-site assembly dependency, the supra-regional high-voltage engineering division's capability withdrawal, and a governance apparatus built for component management rather than integrated standard management.

Both assets are shaped by the same forcing condition: the energy transition has elevated annual compact station deployment to approximately 1,600 units per year and required a tenfold scaling of transportation station deployment, rendering bespoke procurement approaches economically and operationally untenable (sources S-C.3, S-C.4). At DSO-C, however, this forcing condition arrived as a graduated structural revelation rather than a discrete operational crisis, producing a deliberate program design response.

Measured against the Chapter 3 sensitizing concepts, Case C.1 illustrates governance architecture and implementation depth in their most mature observed form across the three DSOs: the CMT's single-domain integration of all three station sub-components, the make-to-stock logistics model decoupling delivery from project-specific ordering, and the layered procurement governance combining *bewust aanbesteden* with structured Tender Board and Board of Directors authorization together constitute the most complete realization of the governance-architecture concept in the case portfolio. Case C.2 illustrates asset complexity at its upper boundary: the transportation station's on-site assembly model, four-supplier component architecture, and TenneT interface constraint collectively represent a governance demand qualitatively higher than any of the other five cases. The organizational-fragmentation pattern (Chapter 7, Theme 2, Section 7.5.2) operates across both cases as a structural amplifier of governance demand: the inheritance of three predecessor lineages and the earthed/floating MV-grid divergence required deliberate technical reconciliation in Case C.1, while the parallel separation between the supra-regional production stream and the regional branches generates the renovation routing failure in Case C.2. The perceived-rather-than-measured outcome pattern (Chapter 7, Section 7.5.1) is the shared limitation across both cases: the millions-of-euros annual benefit estimate for the compact station program and the build-time and engineering-hour reductions for the transportation station are directionally credible but not independently verified against a counterfactual baseline. Whether the patterns documented in this chapter reflect DSO-C-specific conditions or constitute structural features of multi-component on-site-assembled infrastructure asset standardization is what the cross-case analysis in Chapter 7 is designed to determine.

7

Cross-case analysis

7.1. Introduction and comparative logic

This chapter synthesizes the three within-case analyses (Chapters 4–6) into a structured cross-case argument addressing sub-questions SQ3 and SQ4. It proceeds in four movements: it positions the six cases on the two pre-defined structuring concepts of asset complexity and the standardization continuum, so that later comparisons rest on an explicit characterization of each case (Section 7.2); it compares the three distribution station programs across DSOs and examines the lower-complexity assets and the transportation station boundary case (Sections 7.3 and 7.4); it derives three overarching themes that operate above the level of individual case findings (Section 7.5); and it consolidates the remaining implementation challenges (Section 7.6), positions the findings within a four-stage standardization process model (Section 7.7), and states the central governance-as-fit argument (Section 7.8). Section 7.9 concludes.

Implementation challenges appear at different points only where they perform different analytical work. The cross-DSO comparison introduces recurring barriers observed across the station programs. Theme 2 develops fragmentation and engineering resistance as standard-contesting expressions of internal governance demand. Theme 3 develops spatial non-conformance, municipal interface friction, and related sources of variation as inherent variability rather than as standalone barriers. The consolidated challenge section is therefore restricted to residual challenges that contest the standard or its governance after legitimate variation has been accounted for.

7.2. Positioning the case portfolio: asset complexity and standardization continuum

Before the cases can be compared, they must be located on the two structuring concepts developed in Chapter 3: asset complexity (§3.3.3) and the three-axis standardization continuum (§3.3.3). Asset complexity characterizes the governance demand each asset imposes; the continuum characterizes the form the standardization takes. This section establishes both as structural variables before the organizational comparison begins.

7.2.1. Asset complexity across the portfolio

Chapter 3 (§3.3.3) developed asset complexity as a six-dimensional construct: component count and interface density, stakeholder density in specification, deployment feedback speed, international normative coverage, reversibility risk, and external interface count and ownership distribution (Figure 3.1). This subsection maps that construct onto the six cases (Table 7.1); the construct itself is established in Chapter 3, so only its empirical instantiation is reported here.

Component count and interface density. A cable interfaces with the grid at two termination points and is defined by a small parameter set. A station assembles transformer, medium-voltage ring main unit (RMU), low-voltage switchboard, civil enclosure, earthing system, and in recent configurations a remote terminal unit and metering equipment, each with its own supplier and performance envelope. A change in any one parameter propagates into the spatial and electrical tolerances of every interfacing component, so interface specifications must be collectively frozen before a standard can be rolled out. The transportation station exhibits the highest component count of all six cases. Specification effort scales with component count, but the binding constraint is the interface set, which scales faster.

Stakeholder density. MV-LV stations consistently exhibit high stakeholder density: net architects, spatial-integration teams, operations inspectorates, health and safety departments, municipal planning authorities, and realization chains hold legitimate competing preferences for the same asset design.

Cables and the CAM have substantially lower external stakeholder density because their below-ground or low-visibility installation reduces municipal engagement. The transportation station has the highest density, requiring coordination across grid planning, high-voltage engineering, civil works, environmental permitting, and municipal authorities.

Deployment feedback speed. Above-ground stations generate rapid, attributable feedback: aesthetic deviations, dimensional mismatches, and civil failures become visible during construction, enabling iterative refinement. DSO-A's modular construction team typically received feedback on a new station type within weeks of installation. Cables are below-ground and invisible post-installation; quality deviations surface only during failure events, sometimes years later, producing structurally weaker feedback loops. The multi-component architecture of stations means interface failures (a component that does not fit the enclosure, a cable entry that cannot accommodate the specified conductor) surface rapidly and visibly, making failure attribution easier than for single-component assets.

International normative coverage. MV-LV cables are extensively covered by CENELEC and IEC standards, leaving limited room for internal variety reduction beyond the normative baseline. MV-LV stations have substantially weaker coverage: civil design, modular configuration, and component sourcing are largely unconstrained by external norms, which both creates greater opportunity for internal standardization and imposes greater specification-development burden. The partial normative vacuum at station level means each interface between components must be defined internally by the DSO rather than delegated to an external standards body. The transportation station, with its multi-functionality and safety-critical regulatory regime, faces the tightest normative environment of the six cases.

Reversibility risk. Stations installed for forty to fifty years impose long-term interface constraints on adjacent assets; a specification error embedded in hundreds of installed stations is costly to correct. Multi-component architecture amplifies this risk: locking in a transformer capacity, an enclosure size, or a cable entry standard constrains the permissible design space of every interfacing component for the full asset lifetime. All three station programs exhibited deliberate caution about locking in design parameters too early and maintained deviation protocols partly as a hedge against over-standardization. The transportation station carries the highest post-deployment risk given its newness, unit cost, and integration into the transport grid.

External interface count and ownership distribution. Stations interface with adjacent assets (cables, low-voltage racks, customer connections, sometimes transmission-grid components) that are partly managed within the same DSO function and partly by external parties. The transportation station interfaces directly with the transmission operator at the high-voltage side, placing one of the most consequential interfaces under external authority. The CAM (B.2) is specified under a federated three-DSO arrangement, which moves specification authority for the interface outside any single DSO and creates a different ownership-distribution profile from the other five cases. Ownership distribution multiplies stakeholder density: cross-organizational interfaces require coordination mechanisms that within-function interfaces do not.

Table 7.1: Asset complexity profiles across the six cases.

Dimension	A.1	A.2	B.1	B.2	C.1	C.2
Component count and interfaces	Med.	Low	Med.	Low	Med.	Very high
Stakeholder density	High	Low	High	Low	High	Very high
Deployment feedback speed	High	Low	High	Low	High	High
Int. normative coverage	Low	High	Low	Low	Low	Low
Reversibility risk	High	Med.	High	Low	High	Very high
External interface ownership	Mixed	Low	Mixed	Federated	Mixed	Mixed

The primary analytical implication is sequencing: because A.1, B.1, and C.1 share a broadly comparable complexity profile, the governance differences among them cannot be explained by inherent asset properties. They must reflect organizational and contextual differences, making this three-case group the appropriate test bed for the governance-centered argument developed in Section 7.5.

A second implication concerns inter-asset interface management. Several within-case accounts document how standardizing one asset creates binding constraints on adjacent assets. At DSO-A, the distribution station's cable-entry design could not accommodate the 630 mm^2 aluminum cables that network architects had specified for connection routes, an incompatibility discovered during deployment rather than anticipated in specification. Of the three DSOs, only DSO-A assigns cross-asset interface management to a named governance body with formal authority through multi-disciplinary teams; it is largely absent at DSO-B and DSO-C. This cross-program governance gap is returned to in Section 7.6.2.

7.2.2. Positioning on the standardization continuum

The three-axis continuum developed in Chapter 3 (§3.3.3) positions each case on variant reduction, prefabrication level, and customer-order decoupling point (CODP); the consolidated positioning of all six cases is represented in Figure 7.1 and elaborately reported in Table D.1 (Phase 3 additional material). Read across the portfolio, the three axes behave differently as discriminating variables. Prefabrication is effectively constant: all six standards are factory-prefabricated and pre-assembly is near-universal, with the transportation station (C.2) the only partial exception in that its prefabricated blocks are assembled on site. Variant reduction is the common standardization mode across all six cases, correlates most directly with achieved implementation depth, and is the axis along which the three station programs differentiate most clearly. CODP is the axis along which the cases diverge most sharply at comparable prefabrication: DSO-C has moved its production decoupling point upstream to a six-week make-to-stock arrangement, DSO-A operates a primarily project-specific make-to-order arrangement with partial assemble-to-order through the configuration tool, and DSO-B remains make-to-order at the procurement-cycle level. This divergence determines which of the SLR mechanisms each DSO activates most strongly, taken up within Theme 1 (Section 7.5.1).

A potential fourth descriptor, modular product architecture, was examined but is not retained as a separate continuum axis. The case material does not support reading modularity as a graded dimension on which the six programs vary. Across the portfolio, the dominant pattern is convergence on bounded article-number sets rather than demand-driven modular option catalogs. Case A.1 comes closest through its configuration-tool logic, but the current program is moving away from the large combinatorial option space toward a smaller set of focus configurations. The transportation station (C.2) appears modular because it is assembled from independently procured component blocks, but this reflects pre-assembly and interface decomposition rather than a customer-facing modular variety strategy. Treating modularity as a fourth axis would therefore obscure the more economical empirical finding: within these DSO programs, standardization operates primarily through variant collapse, bounded article-number control, and governed residual variation. The theoretical implications of this pattern are taken up in Chapter 9.

The positioning anchors the rest of the chapter. Because prefabrication and pre-assembly are constant, variant reduction is universal and graded by governance, and no demand-driven modular variation exists to compete as an explanation, the central finding developed below, that governance architecture is the primary correlate of implementation depth (Theme 1), is not confounded by adjacent-concept variation. The depth comparison in Section 7.3.2 reads achieved depth directly against this continuum positioning.

7.2.3. Standardization as a nested product, process, and organizational layering

A finding that emerges from positioning the cases concerns the form standardization takes rather than its degree. The research design initially scoped the study to product (asset) standardization and set process and organizational standardization aside to bound the inquiry. The case material does not support that separation as cleanly as the scoping implied. Across the portfolio, product standardization is sustained only where process standardization accompanies it, and process standardization is sustained only where organizational standardization accompanies it. DSO-A's configuration tool is a product standard (six focus configurations) that binds only through a process standard (the IT-mediated ordering pathway that closes alternative routes); DSO-C's six-week make-to-stock position is a product standard that binds only through a procurement-process standard (supply-chain default routing); and the three-tier governance architecture recurring throughout this chapter is itself an organizational standard composed of standardized roles, release cycles, and deviation procedures. The three layers are therefore not separable dimensions of which one can be studied in isolation; they are nested layers that co-evolve, as

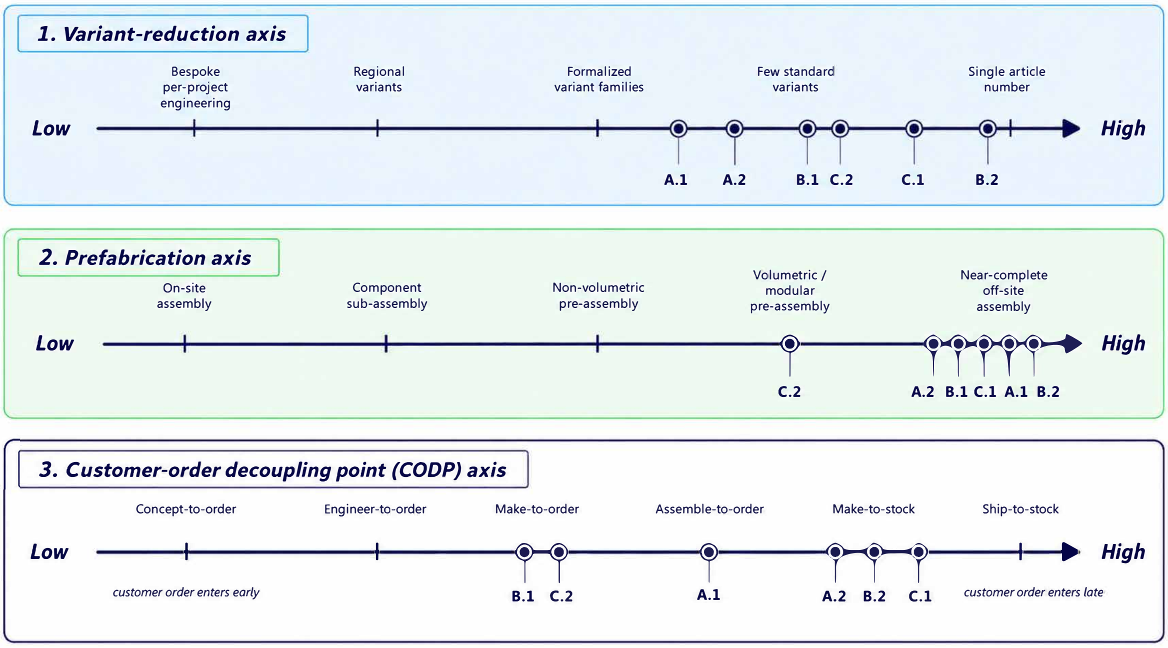


Figure 7.1: Positioning of the six cases on the standardization continuum. The figure compares variant reduction, prefabrication level, and customer-order decoupling point (CODP) as three analytically separable dimensions of standardization form. Prefabrication is nearly constant across the portfolio, with C.2 as the partial exception, while variant reduction differentiates the station programs most clearly and CODP captures the sharpest divergence in production-decoupling arrangements.

visualized in Figure 7.2.

This reading is treated as a finding rather than a definitional preamble, and the construction literature already anticipates it. Aapaoja and Haapasalo (2014) argue that standardization "is not about the standard systems or products, but the systematic approaches to perform things," and Gibb (2001) treat components, methods, and processes as bundled. The cross-case contribution is to document that the three layers must co-evolve: advancing one in isolation produces the specification-without-enforcement failure mode visible at DSO-B and the governance-without-feedback failure mode visible at DSO-C. The contribution is formalized in Chapter 9 (§9.5.1).

7.3. Cross-DSO comparison of MV-LV distribution stations

This section compares Cases A.1, B.1, and C.1 across five dimensions: standardization depth achieved, governance architecture, timeline and urgency drivers, procurement and supplier management, and implementation barriers. The central question is whether the three DSOs face structurally similar challenges that they manage to different degrees, or fundamentally different challenges, with direct implications for the generalizability of the governance-centered argument in Section 7.5.

7.3.1. Adoption drivers

Three drivers recur across all three station programs. The first is energy-transition urgency: connection backlogs, congestion, and ACM-mandated build-out targets created volume demand that project-by-project delivery could not sustain. The second is workforce capacity scarcity: an industry-wide engineer shortage made labor-leveraged delivery a strategic necessity. The third is cost predictability under regulated tariff scrutiny: ACM oversight rewards predictable per-unit costs in ways that favor standardized over bespoke programs. These drivers operate at board level and were articulated as strategic rationale prior to detailed program scoping. They are common to all three DSOs and therefore explain why each organization committed to standardization but not why each achieved different implementation depth, which is the analytical work of the remaining sections. Because all three drivers

Figure 7.2: Asset standardization as nested product, process, and organizational layering. The figure shows that product standardization is sustained only where process standardization supports it, and process standardization is sustained only where organizational governance arrangements support both.

are anchored in the SLR mechanism inventory (Chapter 3, §3.1.4) and the consultant interview findings (Chapter 3, §3.2.1), the empirical confirmation here is convergent rather than new. The drivers map onto the *adoption* stage of the four-stage standardization model (Section 7.7); the differentiating empirical work sits downstream of adoption.

7.3.2. Standardization depth achieved

Implementation depth is operationalized across four sub-dimensions introduced in Chapter 3 (§3.3.3): ordering compliance rate, variant reduction over time, deviation frequency, and the ratio of approved-to-informal deviations. Read against the continuum positioning of Section 7.2.2, depth is measured here primarily along the variant-reduction axis (universal and governance-graded), while the divergent CODP positions are held in view because they condition which benefits each DSO realizes (Section 7.5.1). The within-case material additionally documents the specification scope governed by each standard and the enforcement rigor through which deviations are managed.

DSO-A (A.1) achieves the highest depth across all four sub-dimensions. The configuration tool currently permits 1,085 distinct configurable combinations (around 150 without color and similar), which the active program is reducing to six focus configurations. Ordering compliance measured through the tool reached approximately 97% in Q4 2025. A formal deviation-request process requires engineers to demonstrate exhaustion of standard alternatives before a waiver is approved, placing the burden of proof on the requester. Residual non-standard procurement, primarily approximately 40 walkable stations per year, occurs via channels that bypass the configuration tool, exploiting the organizational authority of regional directors whose reporting lines are independent of Asset Management.

DSO-B (B.1) achieves moderate-to-high depth, supported by its *compact, unless* policy that mandates a compact, non-walkable station as default and requires formal justification for walk-in variants. From a pre-program baseline of approximately 100 historical configurations, of which 82 had been formalized as distinct station drawing types, the program has consolidated to three or four active scheme types. Compliance monitoring relies on Technical Management within the operational division, a mechanism effective when team bandwidth allows but susceptible to pressure during peak workload.

DSO-C (C.1) achieves meaningful depth within a multi-cycle rationalization trajectory initiated around 2010 and extended through a second wave around 2023. Starting from approximately 101 configurable variants in the original supplier configurator, of which 49 were actually ordered, the program has consolidated to two primary article-number variants (a 250 kVA small-variant unit and a 630 kVA primary variant), plus a deliberately preserved RMU field-count distinction (3-field versus 4-field) and a specials category absorbing approximately five to ten per cent of demand. Depth is substantively lower at the regional branches than within the production chains: the two units apply the same nominal standard through different operational processes, and the central Asset Management team has limited visibility into ordering decisions at the regional branch level.

Cross-case observation. All three programs achieved meaningful depth on variant reduction relative to their pre-program baselines, confirming the basic feasibility of MV-LV station standardization in the Dutch DSO context. Depth variance across the three on ordering compliance and deviation-rate sub-dimensions cannot be explained by asset complexity, comparable across the three (Section 7.2.1), or by urgency, present in all three. The primary differentiating variable is governance architecture, examined next.

7.3.3. Governance architecture

Governance architecture refers to the configuration of normative commitments, procedural mechanisms, and structural compliance enablers through which a DSO maintains standardization discipline across projects and over time. Chapter 3 (§3.3.3) developed the construct as a three-tier composite, each tier necessary but individually insufficient. This subsection maps each DSO's empirical arrangement onto that vocabulary.

DSO-A operates a three-tier layered architecture. A technical core team of subject-matter specialists holds primary responsibility for specification content and manages the change process (procedural tier). A multi-disciplinary team (MDT) provides cross-functional pre-authorization: before a specification is finalized or changed, formal representatives of all affected disciplines (net architects, spatial integration, the installation inspectorate (OIV), health and safety, and realization chains) must reach documented agreement, so specification decisions are pre-authorized by all affected parties before reaching procurement (procedural tier). The configuration tool provides IT-enforced ordering compliance (structural tier): engineers can only order stations in the approved portfolio through the normal procurement workflow. An interviewee described the resulting outcome:

> "We have a chart that shows me each quarter what percentage of orders conform to our standard. In Q4 it was around 97%." (Int. A-1, asset management)

DSO-B operates the normative and procedural tiers without the structural tier. The *compact, unless* policy provides a clear normative commitment, and a multi-functional team (MFT) provides cross-functional review and scoring of supplier offers, formalizing cross-functional pre-authorization at the procurement-renewal moment. A requirements-documentation tool supports specification traceability between cycles. What is absent is the structural tier: there is no IT-enforced ordering constraint, and enforcement relies primarily on Technical Management within Operations, which monitors compliance on a best-effort basis and intervenes where deviations are identified. A formal deviation-request process is partially in place but operated more flexibly than at DSO-A. DSO-B is aware of this gap and has initiated an internal program to formalize compliance enforcement and change management.

DSO-C governs its C.1 program through Contract Management Teams (CMTs), which hold primary specification authority and serve as the formal arena in which proposed changes and deviations are assessed (procedural tier). The CMT for compact stations integrates governance of the RMU, the distribution transformer, and the low-voltage rack into a single domain, an integration that prevents the component-silo procurement decision-making that produced the MV-switchgear dimensional-grid incompatibility in the transportation station domain (Section 7.4.2). A formal deviation-request process provides a defined pathway for field engineers or project teams to seek authorization for departures. The governance model is deliberately minimal in the number of actors with specification authority: restricting formal decision-making to CMTs is intended to prevent the variant proliferation that results from distributed engineering discretion. However, the regional-branch-versus-production-chain operating structure creates a structural gap between specification authority (centralized in Asset Management and exercised through CMTs) and ordering authority (distributed across regional branch engineers). There is no IT-enforced ordering constraint (no structural tier), and the systematic feedback mechanism from field deployment back to the specification team remains underdeveloped.

Cross-case observation. The three cases display a clear governance-tier completeness gradient: DSO-A operates all three tiers; DSO-B the normative and procedural tiers without the structural; DSO-C's C.1 a partial normative tier together with a procedural tier (the CMT) but without the structural. The depth gradient of Section 7.3.2 maps directly onto this tier-completeness gradient. All three achieved comparable initial standardization depth on variant reduction, suggesting a complete architecture is not a precondition for initial variety reduction. The gradient is, however, consequential for standardization *discipline*: the ability to maintain specification integrity, manage exceptions in a controlled manner, and update standards without uncontrolled divergence over time. This distinction between achieving and sustaining a standard is taken up in Section 7.8.

7.3.4. Timeline and urgency drivers

All three programs share the same macro-level urgency driver: the Dutch energy-transition grid-expansion mandate that from approximately 2019 to 2021 imposed volume demands project-specific design could not sustain. Yet urgency translated into achieved depth at markedly different rates. DSO-A initiated its program between approximately 2014–2015 and 2018–2019, before grid-expansion pressure became acute, providing a longer maturation trajectory. DSO-B's variety reduction was driven by two converging pressures during peak urgency: the volume demands and the natural renewal cycle of supplier contracts. DSO-C's program has the longest continuous trajectory, with initial variant rationalization through procurement specification around 2010 and successive procurement rounds progressing through dual-source then triple-source supply between approximately 2018 and 2023.

Urgency is uniformly present and was necessary for program initiation in each case, but it does not differentiate the cases on standardization *discipline*. Program age alone is not a sufficient predictor of governance maturity: DSO-C's C.1 is the longest-running and supply-chain-mature, yet faces an ongoing documentation and field-feedback gap that limits enforcement authority. The differentiating dimension is the deliberate organizational design choice to invest in normative, procedural, and structural enforcement mechanisms; this is the substance of Theme 1 (Section 7.5.1).

7.3.5. Procurement and supplier management

Procurement strategy is a central governance instrument: the choice between single-, dual-, and triple-source supplier relationships directly affects both achievable depth and supply chain resilience. All three programs operate under European public procurement law, which mandates open tendering above the relevant thresholds and prevents DSOs from prescribing a specific supplier's product. This creates a structural tension: standardization depth depends on specification consistency across cycles while the procurement regime requires openness to new entrants at each renewal. The three DSOs respond through structurally distinct choices, each mapping onto a different point on the resilience-depth trade-off.

DSO-A adopted a dual-source-plus-reserve model after experiencing supply disruption:

> "There are now two core suppliers and around those we have a few extras, triggered by what we experienced during the war in Ukraine. We chose more sourcing in terms of number of suppliers, but with the same specifications." (Int. A-2, asset management)

DSO-B maintains a predominantly two-supplier model with geographic zone allocation: each supplier is assigned a territory, creating a quasi-single-source arrangement within each zone while ensuring both can produce to design-equivalent specifications.

DSO-C sources compact stations from three suppliers under a distinctive procurement governance route internally referred to as *bewust aanbesteden* (deliberate non-tendering procedure): following a documented risk assessment of single-source dependency on the incumbent, the proposal to add two suppliers passed first through the Tender Board for endorsement and then to the Board of Directors for authorization within a defined period and budget ceiling kept below the European-tender threshold. Of the approximately 1,600 compact stations placed annually, the incumbent delivers approximately 1,000, a second supplier approximately 400, and a third fewer than 200. Incomplete tender specifications are a recurring source of non-compliance: absent the long-term supplier relationship that builds tacit knowledge of DSO-C's requirements, specification documents must be exhaustively detailed to achieve comparable compliance.

Cross-case observation. The three cases illustrate three structurally distinct governance responses to the same procurement-versus-standardization tension. None is universally optimal: the appropriate balance depends on market structure, volume requirements, and risk tolerance. The deliberate tendering route is returned to in Section 7.6.3 as an example of how DSO-level governance can navigate institutional constraints that initially appear to bind absolutely.

7.3.6. Implementation barriers: the three recurring cross-DSO barriers

Despite their shared asset category, the three programs encounter a partially overlapping set of barriers. This subsection develops the three that recur most strongly. Of these, one (engineering culture resistance) contests the standard itself and is developed as a structural co-determinant of governance demand in Theme 2 (Section 7.5.2); the other two (spatial non-conformance and municipal interface friction) drive project-level variation and are carried into Theme 3 (Section 7.5.3). They are introduced here and not re-cataloged in the consolidated challenge section (Section 7.6), which by design treats only standard-contesting challenges. Case-specific barriers are summarized in Table 7.2.

Engineering culture resistance is present in all three programs and contests the standard itself rather than driving project-level variation. Field engineers and network architects accustomed to site-specific design latitude experience standardization as a constraint on professional judgment. At DSO-A, interviewees document explicit workaround behaviors, including ordering non-standard configurations through alternative procurement routes and exploiting the independent authority of regional directors. At DSO-B, the transition to *compact, unless* was described as requiring "a real cultural shift" among staff experienced in walk-in stations. At DSO-C, resistance manifests through the labor-cost-invisibility argument: technically driven staff tend to treat their own labor hours as an invisible cost when comparing standardized and bespoke approaches, making it difficult to convince them that standardization costs less money because "people do not include their own hours and their own time in these kinds of calculations" (Int. C-3). DSO-C's pre-pilot resistance-mapping logic, in which the Asset Management team identified in advance which branches and workers were most likely to oppose the change and chose them as primary interview partners, is itself a governance response to recognized resistance (Int. C-6). This pattern is consistent with Gibb and Isack (2001), who report from 59 UK construction clients that 15% of unprompted first-thought responses about standardization were explicitly negative on grounds of rigidity and loss of identity. The cross-sector recurrence supports treating engineering culture resistance as a structural feature of internally developed standardization rather than an artifact of any specific transition. Because it contests the standard itself, it is developed as a co-determinant of governance demand in Theme 2 (Section 7.5.2).

Spatial non-conformance arises when site conditions do not fit the standard dimensional envelope, and it drives project-level variation rather than contesting the standard. All three programs encounter brownfield integration challenges: standard footprints designed for median site conditions are suboptimal for dense urban environments, flood-prone areas, and existing cable routing geometries. DSO-A has developed a standardized municipal communication package (a *menu*) specifying which aesthetic choices are available within the standard. DSO-B's response to peat-soil subsidence, universal deployment of external cable strain relief regardless of soil type, is a deliberate over-engineering decision accepted because a single universal configuration eliminates variant-management overhead. DSO-C's spatial non-conformance is exemplified by below-ground placement requirements and historically distinctive cylindrical enclosure geometries. Because spatial non-conformance generates variation the standard must accommodate rather than a defect in the standard, it is taken up in Theme 3 (Section 7.5.3).

Municipal interface friction results from local authority requirements for non-standard aesthetic or spatial configurations and is structurally universal. It too is a variation driver. A boundary condition developed in Theme 3 is that DSO-municipality engagement capacity is itself asymmetric: Steekelenburg (2024) documents that larger municipalities are systematically better resourced to engage substantively with DSOs than smaller ones, so even structurally complete governance arrangements on the DSO side encounter a capacity-asymmetric external interface the DSO cannot unilaterally compensate for. The institutional dimension of this friction is taken up in Section 7.6.3; its role as a variation driver in Theme 3 (Section 7.5.3).

7.3.7. Cross-case summary and central finding

Table 7.2 summarizes the cross-case comparison across the five dimensions, including the case-specific barriers not developed in the prose above.

Table 7.2: Cross-case comparison of MV-LV distribution station standardization programs (Cases A.1, B.1, C.1).

Dimension	DSO-A (A.1)	DSO-B (B.1)	DSO-C (C.1)
Implementation depth	Highest: ~97% Q4 2025 compliance; 150 to 6 configurations; IT-enforced	Moderate-high: ~100 to 3–4 schemes; procedure-enforced; no IT constraint	Moderate: 101 to 2 article-number variants; depth uneven across production chains versus regional branches
Governance-tier completeness	All three tiers: normative + procedural + structural	Two tiers: normative + procedural; no structural	One-and-a-half tiers: partial normative + procedural (CMT); no structural; field-feedback loop underdeveloped
Urgency role	Program predated peak urgency; governance established before demand peaked	Urgency concurrent with post-merger integration; governance built during scaling	Long-running program; governance incompleteness constrains discipline rather than initial depth
Procurement model	Dual-source plus reserve; spec coherence via MDT joint review	Two-supplier zone allocation; design-equivalent specs	*Deliberate tendering* route to triple-sourcing (incumbent supplier plus two additional contracted suppliers)
CODP position	Make-to-order with partial assemble-to-order	Make-to-order	Make-to-stock (six-week stock model since 2023)
Case-specific barrier	Cross-asset interface management gap (cable vs station entry); distributed director authority enabling ~40 walkable purchases per year	Peat-soil subsidence forcing universal external strain relief; proof-of-compliance gap in tender specification	Connection schema integration with legacy network; regional-branch vs production-chain ordering authority distribution

Central finding of this comparison. The three DSOs do not face fundamentally different challenges; they face structurally similar challenges that they navigate to different degrees of success. The primary differentiating variable is not the nature of the challenge but the governance architecture deployed to address it, which maps onto Chapter 3's three-tier construct as a completeness gradient. This is the empirical foundation for Theme 1 in Section 7.5.1.

7.4. Lower-complexity assets and the transportation station

7.4.1. Lower-complexity assets: cables (A.2) and CAM (B.2)

Cases A.2 and B.2 occupy the lower end of the complexity spectrum and share several structural features: reduced stakeholder density, lower post-deployment risk per unit, and governance anchored in procurement specification precision rather than multi-stakeholder governance bodies.

For MV-LV cables, standardization is the operational norm rather than an ongoing governance achievement:

> "I would not know how you would not buy standard cable. Then you would have to have things ordered project-specifically. I think a cable is probably the most obvious thing to have as a standard." (Int. A-3, asset management)

Despite this apparent simplicity, the cable program illustrates that specification precision is a permanent ongoing cost, not a one-time design exercise. The grey-color ambiguity incident at DSO-A, in which suppliers delivered cables meeting the literal specification wording but visually too light, triggering a sector-wide concern following a historical safety incident, indicates that specification language requires continuous expert maintenance. Supplier interpretation variance operates below the threshold of formal deviation requests and can only be managed through sustained specification vigilance.

The CAM (B.2) presents a distinct profile: its bespoke design, developed with a single supplier, creates high specification coherence at the cost of supply concentration, which DSO-B currently accepts. The CAM thus represents a point on the resilience-depth trade-off where depth is maximized at the cost of resilience, the mirror image of DSO-A's dual-source decision and DSO-C's deliberate tendering route to triple-source resilience.

A further dimension warrants attention: the CAM is governed not through a DSO-internal arrangement but through the joint Compact Connection Module committee, a federated three-DSO structure in which specification authority is distributed across an inter-organizational consortium. This is categorically different from any internal organizational fragmentation in the other five cases: specification decisions cannot be unilaterally changed by any single DSO, enforcement runs through a binary regulatory channel (an asset either is or is not CAM-compliant), and benefit verification is attenuated by the federated arrangement (a 60% connection-time reduction is reported as a perceived benefit but cannot be measured under the current arrangement). The CAM offers a glimpse of cross-DSO standardization governance at the component-interface level and sets up the institutional limits discussion in Section 7.6.3.

Tentative observation. For lower-complexity assets, specification precision in procurement documents can substitute for the cross-functional governance bodies required by complex assets. This substitution creates two structural vulnerabilities: specification incompleteness, where ambiguous language allows suppliers to introduce variation; and procurement drift, where specifications relax over time without active oversight. A third vulnerability is visible only in the federated CAM arrangement: the loss of unilateral DSO authority to revise the standard in response to deployment experience, which constrains the process model described in Section 7.7.2.

7.4.2. The transportation station as a boundary case

Case C.2 (transportation station) cannot be meaningfully compared with any other case on asset equivalence. It is analyzed for two purposes: as a within-DSO contrast with C.1 that holds organizational context constant while varying asset complexity, and as a boundary-enriching case that extends the observable range of governance demand and program discontinuity.

The C.1/C.2 contrast within DSO-C provides the most analytically controlled test of the relationship between asset complexity and governance architecture adequacy, since the same governance model is applied to both. At C.1, the architecture is functionally adequate: the asset's lower complexity means the CMT apparatus produces sufficient compliance for an approximately 90% deployment coverage rate. At C.2, the same architecture is inadequate: the asset's elevated governance demand exceeded what a CMT could manage, the program experienced a multi-year dormancy period, and the proof-of-concept learning loop was never completed because the supra-regional high-voltage engineering division withdrew its engineering support mid-program:

> "The learning cycle you were supposed to get from the proof of concept, that never came back. But the process of going ahead and building continued. So that learning cycle was not completed, but we did go ahead and build." (Int. C-2, transportation station program)

This within-DSO contrast directly supports the proposition that governance architecture must be calibrated to the complexity profile of the specific asset rather than treated as a fixed organizational attribute. The case also surfaces a governance failure mode not visible in the other five: intra-organizational governance support withdrawal. The mid-program withdrawal of the supra-regional engineering division's staff was a discrete management decision by a single unit that broke a defined learning loop at a critical juncture.

DSO-C's organizational response is itself informative. Rather than upgrading the CMT model to handle transportation-station-class complexity, the program leadership constructed a structurally distinct governance body, the standardization collective, modeled on the CMT architecture but with two modifications: dual leadership through named *eigenaar* (owner, from Asset Management) and *kartrekker* (driver, from the production chain) roles maintained consistently through every escalation tier; and broader membership reflecting the program's dual identity as both an asset standard and an operational delivery program. The C.2 case is therefore not solely an illustration of governance demand exceeding capacity but also of organizational learning in response: an emergent governance architecture purpose-designed for an asset class whose complexity profile the existing CMT model could not accommodate.

7.5. Three overarching themes

The comparisons in Sections 7.3 and 7.4 generate numerous case-level observations. This section synthesizes them into three overarching themes that operate above the level of individual case findings. Theme 1 is anchored in the Phase 1 sensitizing concept of governance architecture; Themes 2 and 3 emerged inductively. Each is stated as a cross-case finding with explicit triangulation evidence and sub-question linkage. The three themes are treated here as analytically distinct findings. Their interaction, and the governance demand-capacity dynamic they jointly substantiate, is consolidated in Section 7.8, where the chapter's empirical findings are translated into the governance-as-fit framework.

7.5.1. Theme 1: Governance architecture is the primary observed correlate of implementation depth

Claim. Across all six cases, and most clearly across the three station programs, governance architecture (the combination of cross-functional specification pre-authorization, designated technical specification authority, and IT-mediated ordering enforcement) is the primary observed correlate of sustained implementation depth. These components map onto the three-tier architecture introduced in Chapter 3 (§3.3.3): designated specification authority and cross-functional pre-authorization operationalize the procedural tier on a foundation of normative-tier ownership assignment, while IT-mediated ordering enforcement operationalizes the structural tier. Asset complexity and the emergent construct of organizational fragmentation (Theme 2) together shape the governance demand that must be met, but they do not determine whether that demand is met. That determination is a governance design choice.

Triangulation evidence. This theme is independently corroborated by evidence from three separate cases (A.1, B.1, C.1) and by the within-DSO C.1/C.2 contrast. Multiple interviewees across all three DSOs independently identify governance-related factors (enforcement mechanisms, cross-functional alignment, ownership clarity) as the primary determinants of whether standards hold in practice. No interviewee at any DSO identifies urgency or technical feasibility as the primary reason their program fell short of potential.

Three governance components. The evidence is consistent with the interpretation that three components are individually necessary and jointly sufficient for high implementation depth in complex asset programs. The first is *cross-functional pre-authorization* (MDT at DSO-A; partial at DSO-B through MFT scoring at the procurement moment; CMT at DSO-C C.1), which ensures specification decisions are pre-authorized by all affected disciplines before reaching procurement, preventing downstream resistance. The second is *designated specification authority* (core team at DSO-A; asset specialists at DSO-B with structured documentation support; CMT at DSO-C), providing a named owner for specification content, a structured change-management process, and continuity of technical expertise across cycles. The third is *IT-mediated ordering enforcement* (configuration tool at DSO-A; absent at DSO-B and DSO-C), which converts compliance from a behavioral mandate into a structural default. DSO-A's compliance rate of approximately 97% in Q4 2025 is plausibly associated with this process asymmetry: the configuration tool makes the standard order a half-hour task, while manually procuring an off-standard station requires substantially more effort.

IT enforcement is the most consequential single gap in DSO-B's and DSO-C's architectures. DSO-B's governance relies on individual Technical Management gatekeeping, effective when bandwidth allows but variable under peak workload. DSO-C lacks the IT constraint while having a CMT responsible for approving deviation requests, and the absence of the structural tier is consistent with the observation that field deployment compliance is harder to monitor at the regional branches than within the production chains.

Production delivery strategy as a mechanism-activation moderator. A sub-finding concerns how production delivery strategy moderates which of the five SLR mechanism families (Chapter 3, §3.1.4, Table 3.1) a given level of governance architecture activates most strongly, picking up the CODP divergence of Section 7.2.2. DSO-C's six-week make-to-stock arrangement produces a substantially shorter perceived lead time than DSO-A's project-specific make-to-order arrangement, and procurement scale economies are reported by DSO-C interviewees in stronger and more specific terms than by DSO-A interviewees for the equivalent program. M1 (design reuse) and M4 (quality consistency) activate at the specification level regardless of CODP position; M2 (procurement scale economies) and M3 (schedule control) reach their theoretical maxima only when production decoupling has moved upstream of the customer order. Standardization is necessary but not sufficient for upstream CODP movement: without a frozen specification, an organization cannot commit to make-to-stock without losing responsiveness, but the shift also requires volume forecasting and supplier coordination that variant reduction does not deliver automatically. This is consistent with Wikner and Rudberg (2005)'s observation that engineering and production decoupling points can sit in different organizations along a supply chain. The implication for the governance argument is that supplier-side capability to operate at the chosen decoupling position is a co-equal coordination problem alongside the internal governance architecture problem.

The measurement gap within governance. A structural feature across all three DSOs is the absence of systematic before-and-after measurement infrastructure for standardization benefits. The Phase 1 sensitizing-concept framing (Chapter 3, §3.3.3) carries the methodological qualifier that all six cases involve ongoing programs, so reported outcomes are treated as practitioner perceptions rather than measured effects. The cross-case analysis additionally surfaces that this absence is not an artifact of the study's timing but a stable feature of how the case organizations manage their programs, documented at all three DSOs and robust to asset-complexity variation.

For the CAM (B.2) the gap is sharper: a controlled pilot demonstrated a 60% reduction in connection time relative to the traditional method, but this cannot be verified at the program level. At DSO-A, perceived station-program outcomes are "plausible and organizationally credible, but the absence of systematic measurement means they cannot be verified" (Int. A-3), and no organizational leader has formally requested an evaluation. At DSO-C, the senior CMT interviewee estimated annual benefits at millions of euros on a recurring basis grounded in accumulated operational experience but not in formally tracked metrics. The pattern is structurally consistent with Gibb and Isack (2001), who report from 59 UK construction clients that "few clients have any meaningful way of measuring success of their projects" and that most reported benefits were qualitative and unsubstantiated. The persistence across construction and DSO contexts supports treating the measurement gap as a structural feature of internally developed standardization rather than a maturity-stage artifact.

Three structural conditions plausibly account for the absence across all three DSOs. First, none has yet experienced a procurement round in which measurement-based justification was structurally required, so measurement infrastructure remains a deferrable investment. Second, when governance capacity is already stretched by specification, deviation processing, and compliance enforcement, investment in measurement competes for the same attention and is consistently lower-priority because its absence does not produce visible operational failure. Third, the regulated tariff regime includes its own external evaluation logic at the portfolio level (ACM tariff review) that displaces some demand for program-internal benefit verification, even though that review does not provide the specification-level feedback that cross-cycle improvement requires (Section 7.7.6).

The analytical consequence is that the measurement gap attenuates cross-cycle improvement: without functional feedback from quantitative outcome data, the cycle's specification-to-failure-to-response-to-consolidation chain operates only on qualitative deployment experience, slowing the rate at which governance architecture can mature and weakening the basis on which standardization choices can be defended against cost-pressure or operational-urgency challenges. The measurement gap is therefore not freestanding but a structural element of the governance story: where the architecture is otherwise complete (as at DSO-A), the gap still attenuates the dynamic refinement through which architecture matures.

Urgency and governance interact. The relationship between governance maturity and urgency is contingent rather than additive. At DSO-A, governance was established before urgency peaked, allowing the organization to convert urgency into deployment volume without sacrificing depth. At DSO-B and DSO-C, urgency and governance development were simultaneous, creating pressure to deploy before governance mechanisms were fully functional. This reflects the fact that governance infrastructure requires sustained investment over multiple years before it becomes operational, consistent with the dynamic governance dimension of Chapter 3 (§3.3.2): architecture accumulates capability through iterative procurement and deployment cycles when functional feedback loops exist, and degrades when they do not. DSOs that begin governance investment late face a structural disadvantage when urgency accelerates.

Contribution to SQ4. This theme directly answers SQ4 by identifying governance architecture as the organizational design characteristic most strongly associated with implementation outcomes, and by specifying which components are most consequential.

7.5.2. Theme 2: Organizational fragmentation operates as a permanent context factor co-present with standardization

Claim. In organizations formed through merger of multiple predecessor utilities, and in large organizations with distributed ordering authority, organizational fragmentation and engineering culture resistance operate as permanent structural features of the standardization environment rather than temporary transition problems. They set the minimum governance demand any program in that environment must meet and can be partially managed through governance design but not eliminated by it. This theme develops engineering culture resistance, introduced as a cross-DSO barrier in Section 7.3.6, as one expression of a deeper fragmentation dynamic that contests the standard itself.

A multi-source construct. Fragmentation is not a single mechanism but a composite of at least three distinguishable sources. *Merger origin* is the most visible: DSO-A absorbed approximately 54 predecessor provincial and municipal utilities; DSO-B carries predecessor lineages whose engineering-tradition reconciliation imposed multi-stakeholder negotiation costs sustained through the MFT structure; DSO-C retains three predecessor lineages with the technically grounded earthed and floating MV-grid architectural split as a continuing source of variation. *Workforce transition* is a second source: continuous rapid hiring replenishes the population of engineers who do not yet share institutional knowledge of exception procedures or specification rationales. *Regional engineering tradition* is a third, observable as residual director authority and the design latitude field engineers were professionally formed to exercise. The observation that fragmentation operates through three distinguishable sources is itself a contribution: it suggests the construct should be treated as compositional rather than as a single moderator.

Triangulation evidence. Organizational fragmentation is independently documented at all three DSOs: DSO-A (approximately 54 predecessor utilities; regional design traditions; distributed director authority), DSO-B (predecessor lineages reconciled through the MFT structure), and DSO-C (three predecessor lineages with the earthed/floating MV-grid split). Engineering culture resistance is independently documented at all three DSOs and at both asset-complexity levels. This satisfies the triangulation threshold for a confirmed cross-case theme.

Fragmentation as a ceiling. Fragmentation operates as a ceiling on achievable depth in two ways. First, it creates heterogeneous design traditions that must be reconciled before a common specification can be accepted, a process that at DSO-A required approximately seven years of multi-stakeholder specification work. This reconciliation cost is not a one-time investment: as long as different regional units retain their own director authority, the ceiling reasserts itself whenever a new specification decision must be made. Second, fragmentation creates distributed ordering authority, so a governance directive from Asset Management cannot bind a director in a different reporting line. DSO-A's approximately 40 annual off-standard walkable station purchases illustrate this ceiling, persisting despite a 97% compliance rate in the configuration-tool-mediated channel precisely because they occur outside it.

Professional resistance as a design constraint. Engineering culture resistance is not irrational behavior that change management can simply overcome. It reflects a legitimate professional identity: field engineers whose competence was formed under site-specific design latitude experience standardization as a devaluation of that competence. The governance implication is to treat resistance as a permanent design constraint rather than a temporary friction. Two responses have shown observed effectiveness. The first is process friction reduction: making the compliant path structurally easier than the non-compliant path, as DSO-A's configuration tool does, reduces the population of engineers for whom resistance generates lower personal cost than compliance. The second is involvement: incorporating field engineers in specification development generates ownership that reduces downstream resistance, as DSO-B's MFT scoring mandate illustrates and DSO-C's pre-pilot resistance-mapping logic operationalizes from a different angle.

Supply chain dimension. Fragmentation also manifests in the supply chain through the resilience-depth trade-off. All three DSOs must balance depth against supply security in a concentrated market with few viable suppliers. Multi-source strategies improve resilience but increase cross-supplier specification governance costs; single-source strategies achieve maximum depth but create concentration risk. This is a structural constraint of the DSO procurement environment.

Contribution to SQ3. This theme answers SQ3 by identifying the most consistently perceived implementation hurdles: not technical design complexity, but organizational and governance barriers grounded in fragmentation-induced governance demand.

7.5.3. Theme 3: Inherent variability prevents complete standardization and must be designed for, not only deviated around

Claim. A structural feature of MV-LV grid asset standardization recurring across all six cases is that complete standardization is not achievable in principle. Inherent variability arising from grid history, site conditions, municipal interface demands, exogenous regulatory and technological discontinuities, and project-type asymmetries imposes a permanent residual variation that no governance investment can eliminate. The two cross-DSO variation-driving barriers of Section 7.3.6, spatial non-conformance and municipal interface friction, are developed here as two of these sources rather than as standalone challenges. The appropriate governance response operates on two levels the case material requires distinguishing. The first is the *design of the standard itself*: anticipated and recurring variation should be absorbed into the standard as bounded variants at the design stage rather than routed repeatedly through an exception process. This couples directly to asset complexity: the more components and interfaces a standard carries, the higher the probability that some component will change for regulatory, production, or supplier reasons, and the more interface-sensitive the design must be to absorb that change without cascading. Designing at the interface level rather than around specific components is therefore a variability-management decision made at the design stage, not a deviation-handling decision made later. The second level is the *deviation pathway*: genuinely unexpected or deliberately discouraged variation is handled through a designed, standardized exception sub-system. Both levels must be planned together, and the distinction between them is itself a finding: much of what the case organizations experience as implementation difficulty originates not in the variability but in design choices that failed to anticipate it, a reading corroborated by the DSO-B reflection in Chapter 8 that most challenges trace back to how the standard was initially designed rather than to the standard concept as such.

Two kinds of inherent variability. The case material supports separating inherent variability by the governance response it should provoke. Some sources push the appropriate *number of variants in the standard itself* upward and should be resolved in design. Different grid voltages requiring different transformer types, and the RMU 3-field versus 4-field distinction DSO-C deliberately preserves, are variant-count drivers: not deviations but parameters the standard must legitimately carry. Predictable municipal demands fall in the same category: if nine of ten municipalities in a service area request a brick-faced enclosure, the economical response is to carry a brick-faced variant in the standard rather than process the same request repeatedly as an exception. Other sources produce variation that cannot be enumerated in advance, one-off site geometries and exogenous regulatory shocks, and these are the proper domain of the deviation pathway. The deviation pathway is therefore for the genuinely unexpected, and for variation that is technically available but should be deliberately discouraged, not for recurring and foreseeable variation that good design should have internalized.

Triangulation evidence. The variability claim is supported by multiple independent sources across all three DSOs, each contributing a different mechanism. *Grid history* is documented most clearly at DSO-C, where the earthed and floating MV-grid split inherited through merger imposes structural variation that cannot be designed away because the legacy network is buried infrastructure; the connection-schema integration challenge, identified by a CMT interviewee as the single most consequential implementation challenge across the entire C.1 trajectory (Int. C-6), is a direct consequence. *Site conditions* (spatial non-conformance, Section 7.3.6) are documented at all three DSOs as a permanent source: brownfield deployment forces accommodation of existing cable routing; inner-city sites force aesthetic and dimensional variants outside the median envelope; flood-prone or peat-soil zones force technical adaptations. DSO-A's municipal aesthetic *menu* and DSO-B's universal peat-soil strain relief are two contrasting design responses, the first internalizing variation as bounded variants, the second eliminating it through deliberate over-engineering. *Municipal interface demands* (Section 7.3.6) are documented universally and add an external authority layer whose preferences a DSO cannot unilaterally override, and which are frequently predictable enough to internalize as variants. *Exogenous regulatory and technological discontinuities* (the SF6-free RMU transition, the Russia–Ukraine supply shock, the forthcoming EU emissions framework) impose specification updates on timelines the regular procurement cycle did not plan for. *Project type asymmetries* appear most clearly in the greenfield-versus-brownfield contrast: greenfield projects allow adoption of the full standard, while brownfield projects necessarily operate at a lower compliance ceiling because the standard cannot bind inherited grid configurations. The pattern is independently observable at all three DSOs across both asset-complexity tiers and satisfies the triangulation threshold. The full set of variation-driving moderators is catalogued in Appendix C.1.3 (code group 10, cross-case moderating factors).

Why this is not merely a list of challenges. The challenges that drive variation could be read as discrete obstacles each requiring its own mitigation. The cross-case material instead supports a stronger claim: these are not independent obstacles but expressions of a single structural property of the standardization environment, namely that the asset population is being standardized inside a context (the live grid, the municipal permitting regime, the supplier base, the regulatory framework) the DSO does not fully control and that imposes irreducible variation. The 100% standardization frontier is therefore not a governance target that better discipline could reach; it is an analytical fiction the architecture should not be designed to chase. Rogers (2003) captures part of this through *reinvention*, the degree to which users modify an innovation during adoption and implementation, treating it as a normal feature of diffusion rather than a failure. The DSO material indicates that reinvention in standardization governance is not just normal but structurally inevitable.

Standardized deviation pathways as the governance response. For the variation that genuinely belongs in an exception process rather than in the standard, the DSOs respond in three characteristic ways that converge on a single design principle. The first is the *bounded variant menu*: rather than allowing project-by-project deviation in unbounded form, DSOs publish a finite catalog of approved variants (DSO-A's station-variant configurations, DSO-C's RMU 3-field versus 4-field distinction, DSO-A's municipal aesthetic menu). This converts an open space of possible deviations into a small finite set that can be specified, costed, and procured in advance, and it is the mechanism through which foreseeable variation is internalized rather than processed as exception. The second is the *formal deviation request process*: where a project legitimately falls outside the bounded menu, an explicit procedure permits adaptation under documented authorization, with the burden of proof on the requester (DSO-A's formal deviation-request process; DSO-C's CMT-approved deviation; DSO-B's justification-required walk-in variants). The third is the *specials category* that absorbs a contained share of demand explicitly outside the standard (DSO-C's specials category capturing approximately 5 to 10% of compact-station demand). All three convert deviation from an uncontrolled exception into a governed sub-process, and they are governed by the same three-tier architecture that governs the standard itself: a normative commitment that deviation is the exception, procedural mechanisms that constrain and document it, and (in DSO-A's case) a structural-tier instrument (the configuration tool's deviation request gate) that operationalizes the burden of proof.

Why this matters analytically. The argument sharpens the central claim of the thesis in two ways. First, it specifies that the governance architecture (Theme 1) is designed not solely to enforce compliance with a single standard but to manage a two-layer system in which the standard and the deviation pathway are governed jointly, with the boundary between them set deliberately at the design stage. Second, it relocates the locus of real governance effort: the most consequential work is often not in forcing compliance with the standard but in designing the standard to internalize foreseeable variation and in governing the residual deviation cases deliberately. This shift, from enforcing the standard to designing for and governing variation, is one of the central findings of this thesis, and it must be made explicit already in the design stage rather than only in the management stage. The Phase 1 consultant interviews flagged the "80/20" pattern, the observation that the final fraction of cases outside the standard envelope consumes disproportionate resources at lower quality (Chapter 3, §3.2.2); the Theme 3 finding is that this pattern arises when the deviation pathway is not itself designed and governed, and when foreseeable variation was not internalized into the standard, not when standardization has gone "too far".

Contribution to SQ3 and SQ4. Theme 3 contributes to SQ3 by adding inherent variability to the structural features the case organizations face independent of their own governance choices, and to SQ4 by extending the governance architecture argument from the single-layer (compliance with the standard) to the two-layer (joint governance of the standard and the deviation pathway, with the boundary set in design). The operational implications appear in Section 7.8 and are translated into prescriptions in Chapter 9.

7.6. Standard-contesting implementation challenges, categorized

This section consolidates the implementation challenges that contest the standard itself, that is, challenges that persist even when legitimate project variation has been accommodated through the design and deviation mechanisms of Theme 3. By the categorization principle of Section 7.1, the variation-driving conditions (spatial non-conformance, municipal interface friction, and the other sources of inherent variability) are not re-cataloged here; they are developed in Theme 3 (Section 7.5.3). The remaining challenges fall into three clusters along the technical-versus-organizational and internal-versus-external dimensions flagged in Chapter 3 (§3.1.3). For each cluster, the discussion identifies the mechanism families (M1–M5, Table 3.1) the challenges attenuate and the governance choices that would activate those mechanisms.

7.6.1. Technical challenges

Inter-asset interface incompatibility arises when the physical interface requirements of a standard asset are not aligned with connected assets. The 630 mm^2 aluminum cable versus distribution station cable-entry incompatibility at DSO-A is the most extensively documented instance. It blocks M1 (design reuse) at the cross-asset level, because design reuse within an asset class becomes operationally infeasible when interface conditions across asset classes are not co-managed, and it weakens M4 (quality consistency) by forcing project-level workarounds. Cross-program interface governance, a function that sits above the individual asset program level and is often unassigned, is the success-factor response.

Specification precision is an ongoing technical governance cost. Supplier interpretation of ambiguous specification language generates products that are technically compliant but operationally unacceptable.

This is documented in A.1 (the compact station water-tightness failure; fuse component discontinuation) and A.2 (cable color specification gap), noted at DSO-B as the primary known deficiency for the next procurement round, and present at DSO-C as incomplete tender specifications producing recurring non-compliance with suppliers who lack the long-term relationship that builds tacit specification knowledge. It blocks M4 most directly and weakens M5 (learning) by preventing systematic capture of specification-failure feedback.

Component-change accommodation recurs across the portfolio and intensifies with asset complexity. When a component within a standardized asset must change, the underlying cause varies (regulatory pressure such as the SF6-free RMU transition, supplier-initiated production change, or supplier substitution) but the governance consequence is common: the standard must absorb the change without cascading into every interfacing component. The more components and interfaces an asset carries, the higher the probability that some component changes within a cycle, so this challenge is most acute for stations and most acute of all for the transportation station. It blocks M1 and weakens M4 when an unanticipated substitution forces project-level redesign, and it connects directly to the design-level argument of Theme 3 (Section 7.5.3): a standard specified at the interface level absorbs such changes as bounded updates, whereas a component-bound standard absorbs them as forced deviations.

Connection schema integration with legacy network architecture surfaces with particular clarity at DSO-C. A standard station placed into an existing network connects to a legacy configuration built under predecessor regional specifications, which cannot be modified because the cables and infrastructure are buried. Resolution requires the connection schema to be made sufficiently flexible and the accompanying work instructions sufficiently detailed to cover the full range of legacy network contexts technicians encounter (Int. C-6). The challenge is largely invisible at DSO-A and DSO-B because their network-architectural inheritance is less heterogeneous than the earthed/floating MV-grid split DSO-C absorbed through merger; it blocks M1 and M3 at deployment.

7.6.2. Organizational and governance challenges

The proof-of-compliance gap is a cross-cutting governance limitation at all three DSOs. DSO-B's first-generation station tender contained requirements for which suppliers declared conformance without being required to demonstrate it through a physical test protocol:

> "A requirement was set, but no burden of proof was demanded to show that it meets that requirement. That was not in the tender and we have had a great many problems with that."
> (Int. B-1, asset management)

DSO-A's compact station water-tightness failure represents the same gap: a specification may be technically complete in its stated requirements while being governance-incomplete in the verification regime needed to give those requirements operational force. The challenge blocks M4 through the verification regime its absence creates and weakens M5 by preventing systematic capture of specification-failure feedback.

Cross-asset interface governance gaps are undocumented responsibilities in all three organizational structures. When standardizing a station forces a consequential decision about cable routing, LV-rack sizing, or transformer capacity, the governance body that manages the station standard is not routinely positioned to manage the knock-on effect on adjacent assets. This gap generates incompatibilities discovered during deployment rather than anticipated in design, and it is the organizational counterpart of the technical inter-asset incompatibility above.

Two organizational issues are not re-developed here because they have already been assigned to the main explanatory themes. Organizational authority fragmentation is treated in Theme 2 as a structural source of internal governance demand rather than as a discrete implementation challenge. The benefit measurement gap is treated in Theme 1 as a structural weakness in governance architecture and returns in the process model as a constraint on cross-cycle improvement. In this section, both are therefore treated only as conditions that intensify the residual challenges described above, not as additional items in the challenge inventory.

7.6.3. Regulatory and institutional challenges

European procurement law tender cycle management is a universal institutional constraint. All three DSOs must manage the risk that procurement cycle transitions introduce specification discontinuity: a new supplier may differ from the previous one in component-level design choices the specification does not explicitly govern. Managing these inter-cycle transitions currently occurs informally rather than through an explicitly designated cross-cycle governance function. DSO-C's deliberate tendering route (Section 7.3.5) shows how governance design within a DSO can navigate the constraint: by securing Tender Board and Board of Directors authorization for a defined period and budget below the European threshold, DSO-C enabled triple-sourcing without continuous re-tendering. The mechanism is asset-class- and DSO-specific and not directly transferable, but it illustrates that the institutional constraint, while binding, admits more design space than it appears to from the outside.

Operating in a supplier-side market is a related external challenge distinct from the procurement-law constraint. Where the component or asset sits in a supplier-dominated rather than buyer-dominated market, the DSO's ability to demand specific specifications, verification protocols, or design changes is structurally limited: a small number of capable suppliers hold bargaining power a single DSO's volume cannot offset. This shapes the design-stage response of Theme 3, that a standard sitting in a supplier-side market should be specified more flexibly to accommodate supplier-initiated change, whereas a standard in a buyer-side market affords more freedom to dictate specifics. The challenge weakens M2 by limiting procurement-scale leverage.

Sector-level standardization limits represent the third institutional challenge. The CAM, jointly adopted by the three large Dutch DSOs since January 2023, indicates that cross-DSO standardization is achievable for sufficiently bounded components. The CAM is governed through a federated three-DSO joint committee, not a single-DSO Asset Management arrangement, and represents a relatively narrow interface object compared to a full station specification. Sector-level alignment on complete station specifications is on DSO-A's strategic roadmap but is regarded as institutionally disproportionate at this stage:

> "If achieving alignment within one organization took seven years, achieving it across the sector would probably take fifteen, absent governance structures for cross-DSO technical coordination that do not presently exist." (Int. A-4, asset management)

This identifies an institutional ceiling on standardization scope: the benefits of cross-organizational harmonization are real, but transaction costs escalate non-linearly with the number of organizations involved, the breadth of specification scope, and the absence of a superordinate governance authority with a binding mandate. The CAM case also illustrates a further constraint of federated governance: the loss of unilateral DSO authority to revise the standard in response to deployment experience, which makes cross-cycle improvement harder to operate at the inter-organizational level than at the intra-organizational level. Together these dynamics attenuate M2 and M5 at the inter-organizational level.

7.6.4. Reconciliation with the validated challenge set

Phase 4 (Chapter 8, §8.2) presented senior practitioners with a consolidated set of fourteen implementation challenges (Appendix E.1.2) for relevance and completeness testing rather than analytical synthesis. All fourteen are addressed somewhere in this chapter: the standard-contesting challenges appear in the three clusters above; the variation-driving challenges (unclear variety policy, exogenous shocks, and the spatial and municipal items) are treated as inherent-variability sources in Theme 3; and the fragmentation-rooted items (regional culture differences, dispersed authority, skill erosion) are treated as sources of organizational fragmentation in Theme 2. Two validated challenges, innovation constraints and skill and knowledge erosion, are case-contingent rather than cross-case structural and were retained in the validated set only because Phase 4 confirmed their practitioner salience; one, consultation-driven decision delays, is on reflection a property of the cross-functional pre-authorization mechanism (Theme 1) rather than a discrete challenge, since the consensus-seeking that slows decisions is the same dynamic that produces downstream legitimacy. The two groupings are therefore substantively consistent, reorganized by analytical mechanism rather than by surface domain.

7.7. A four-stage standardization process model

The cross-case findings developed so far operate at the level of individual case organizations. Lifted to a generic level, they instantiate a process model of internal asset standardization in regulated network-infrastructure organizations. The model complements the descriptive answer to SQ2 by showing how asset standards are implemented and maintained over time, but its main function in this chapter is to locate the SQ3 and SQ4 findings within a recurring procurement-cycle logic. The model is built on the conceptual scaffolding introduced in Chapter 3 and filled with the within-case and cross-case findings of this study. This section presents the model, specifies what physically happens to the standard in each phase and what can go wrong there, states what a good design looks like, shows how organizational design conditions the model at every level, and develops how the standard and its governance architecture improve, or fail to improve, across successive procurement cycles. The cross-cycle dynamic is treated as a property of how phases 2 and 4 iterate, not as a separate cycle running alongside the model.

7.7.1. What the model is

The model is what the standardization and business-process literatures would recognize as a process or phase model of standardization governance. It is normative and cyclical: it describes how a standardization initiative should be structured and managed at any point in time, and it repeats with each procurement cycle. It maps closely onto the business-process management cycle of Reif et al. (2018), which distinguishes process design, implementation, application, and follow-up, and it is consistent with governance models that separate decision-making, rollout, and compliance monitoring (van de Kaa, 2023). It is constructed specifically for *internal* technical/asset standards in regulated asset-intensive organizations; it is not intended to cover de jure sector-level standards (CENELEC, IEC) or market-driven standards-war contexts, where the adoption stage has substantially different dynamics. It also distinguishes three organizational levels, strategic, tactical or program, and operational or project, and treats the strategic adoption decision as a background condition while focusing on the tactical and operational stages where the differentiating empirical work of this study sits.

7.7.2. The four phases and what happens to the standard in each

Across the standardization (van de Kaa, 2023), innovation-implementation (Klein & Sorra, 1996; Rogers, 2003), capital-projects (Choi, Shrestha, Kwak, & Shane, 2020a), and business-process (Reif et al., 2018) literatures, four phases recur with consistent content but varying labels. They are summarized in Figure 7.3 and elaborated below with the physical content each phase imposes on the standard and the communication actions that link the phases.

The four phases are not strictly sequential. Phases 3a and 3b operate concurrently throughout the operational life of the standard, and the chain continues until a new tender reopens phase 2. Two communication actions complete the model. The first is an *update communication* from management & governance to operational use, equivalent to what the diffusion literature calls persuasion, acceptance, or enforcement: the channel through which a new or revised standard reaches the chains that must apply it. The second is a *feedback communication* from operational use back to management and governance: the channel through which deployment experience returns to the specification owner. An impact-and-evaluation activity sits within the management and governance phase, but the case material does not support treating it as a separate phase. In the ideal case each cycle costs less effort than the last, because feedback preserved in one cycle is carried into the development and design phase of the next. The cycle stops improving, and can regress, when the management and governance phase is inappropriately implemented. The conditions under which the model iterates productively are developed in Section 7.7.6.

7.7.3. What a good design looks like

The case material allows the development and design phase (phase 2) to be specified more sharply than the literature anchors alone would, by stating what a good design accomplishes. From both the continuum and layering analysis (Section 7.2.3) and the DSO-B reflection in Chapter 8, phase 2 must address process and enforcement design, not only technical content, and within the technical content

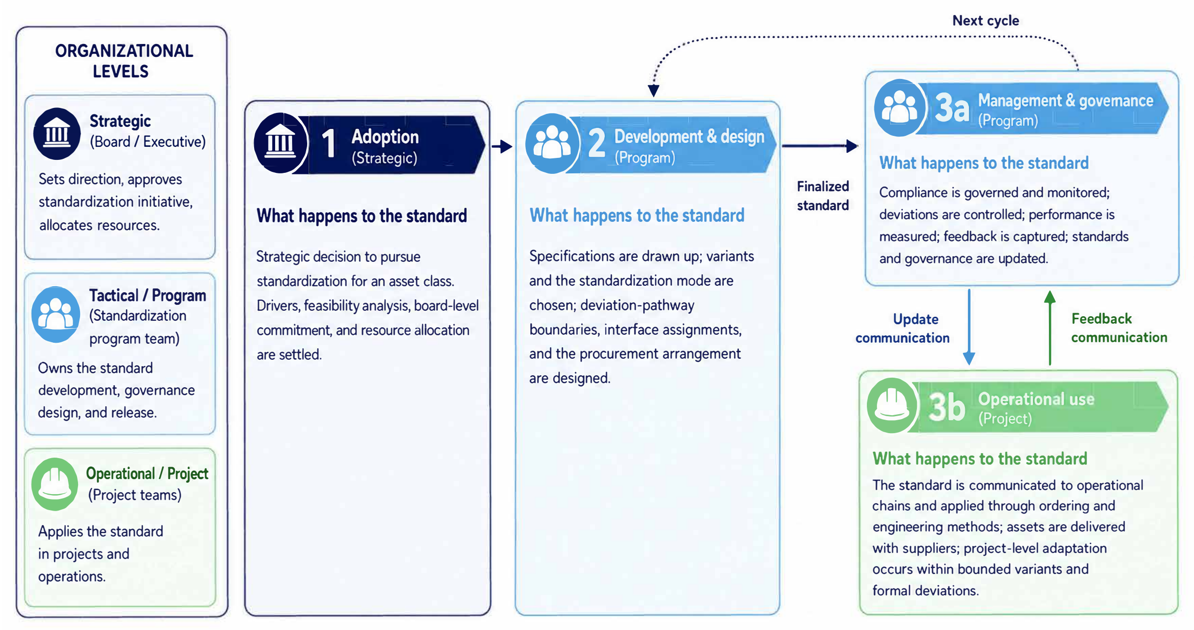


Figure 7.3: Four-stage process model of internal asset standardization in regulated network infrastructure organizations. The model separates strategic adoption, development and design, operational use, and management and governance, and shows how update and feedback communication create cross-cycle improvement.

the design must take a holistic, stakeholder-aware view rather than optimizing solely for technical perfection and supply-chain efficiency. A good design is one that is constructable; that encompasses approximately the 80% of projects falling within the standard envelope, with the remaining roughly 20% deliberately accepted as specials, which means internalizing the foreseeable project variations cataloged in Theme 3 (Section 7.5.3); that defines interfaces durable enough to withstand both internal update requests and externally forced component changes, so the standard does not fracture each time a supplier or regulation changes a component; that is easy to work with, a criterion DSO-C emphasized given its high workforce-growth rate (Chapter 8); that internalizes the predictable demands of municipalities as bounded variants or deliberately routes them to the specials category; and that fits the supplier-market structure of its asset, dictating specifics where the DSO holds buyer-side leverage and remaining flexible where it faces a supplier-side market.

Two contextual factors make this phase easier or harder. The richer the international normative coverage, the lower the asset complexity, and the less fragmented the organization and its mandate, the easier phase 2 becomes; essentially every structural variable developed earlier in this chapter reappears here as a determinant of design difficulty. A further difficulty is the degree of outsourcing: the more specification work is outsourced, the more knowledge sits outside the organization, and the harder it becomes to produce a good design, in the limiting case where a single supplier owns the standard design and feedback does not return to the DSO at all.

7.7.4. Where the empirical bottlenecks sit

The bottlenecks observed across the six programs concentrate in phases 2 and 4 rather than phases 1 and 3. Phase 1 (adoption) is essentially uncontested: the strategic decision to standardize was reached at board level without significant internal resistance, driven by the three convergent drivers of Section 7.3.1. Phase 3b (operational use) is where the symptoms manifest in the field, engineering culture resistance, off-standard ordering, specification interpretation drift, but these manifestations originate in inadequate design and governance choices made in phases 2 and 4 rather than in fundamental operational-stage problems.

Phase 2 (development and design) is the locus of three structural bottlenecks. The first is *specification* *coverage* rather than specification competence: standards are well-engineered in technical content but inadequately scoped in their envelope, edge cases, and deviation pathways, the deviation-pathway argument of Theme 3. The sharper reading the case material supports is that phase 2 must also design the processes and enforcement that will carry the standard, and must design the technical content to internalize foreseeable variation and component change rather than to be technically perfect in isolation. The second bottleneck is *interface assignment*: cross-asset and external interfaces are routinely left unassigned at the design stage and surface as deployment-stage incompatibilities (Section 7.6.2). The third is *procurement-arrangement design*: the choice among single-, dual-, and triple-source arrangements is made at this stage and conditions which mechanism families can be activated downstream.

Phase 3a (management and governance) is the locus of the most consequential bottlenecks. The three-tier governance architecture (Theme 1), the absorption of organizational fragmentation through procedural-tier investment (Theme 2), the governance of the deviation pathway (often called *Request for Deviation*) (Theme 3), and the absent measurement infrastructure all sit here. Phase 3a manages two kinds of change: internal change, which can be deferred to a scheduled update or a new cycle, and external change driven by regulation, supplier substitution, or supplier-initiated component alteration, which is typically time-pressured. Both are easier to absorb when phase 2 design was done well: a component-bound, interface-fragile design forces grave phase 3a adaptations on every externally forced change, whereas an interface-robust design absorbs the same change as a bounded update. Each failure mode cataloged in Section 7.6 therefore has its root cause in phase 2 or phase 3a, with phase 3b functioning as the symptom phase where upstream choices become visible.

7.7.5. Organizational design conditions the model at every level

Organizational design shapes this model at all three levels, which is the sense in which the present study's organizational focus enters the process model. At the strategic level, the location of decision rights (board, asset management, engineering) and the degree of centralization influence how clear and stable the initial commitment is and whether it survives competing priorities. At the tactical or program level, structural choices, a dedicated standards team, clear ownership, cross-functional committees, and defined interfaces with procurement, operations, and projects, determine how effectively standards are designed, governed, and updated; they shape the implementation climate (whether people experience the standard as supported, legitimate, and adaptable) and the quality of the feedback loops. At the operational or project level, the configuration of project organizations, the degree of projectization, the authority of project managers, and the presence of standardization champions shape how consistently the standard is applied, how deviations are handled, and how local learning is captured. Organizational design is in this sense the architecture within which the standardization process runs: it can enable smooth translation from strategic intent through program governance to project use, or create the bottlenecks and fragmentation that undermine the intended benefits. This strategic-tactical-operational mapping is offered as an interpretive lens rather than a formally tested proposition.

7.7.6. Cross-cycle improvement: how the standard and its governance architecture mature

The dynamic question of *how* the standard and its governance architecture change from one cycle to the next is treated here as a property of the process model itself, specifically of how phases 2 and 4 carry information forward into the next phase 2. The case material does not support reading governance maturation as a separate cycle running alongside the process model. What it instead supports is a more modest and more accurate reading. Across the portfolio, governance architecture is established largely as a single substantive design effort during one or two early procurement cycles. DSO-A built the MDT, the core team, and the configuration tool as a coherent arrangement up front; DSO-B is currently running one big formalization initiative that will add the structural tier; DSO-C built the standardization collective as a one-off response to the C.2 complexity mismatch, not as the next step in a continuous governance-evolution sequence. Between these set-piece investments, governance changes incrementally inside phases 2 and 4, release-cycle alignment added to DSO-A's MDT process, the proof-of-compliance gap scoped into DSO-B's next MFT scoring criteria, deviation pathways added at DSO-C as new exception categories surface. The picture is therefore not continuous governance innovation but step-change set-up plus incremental phase-internal refinement. Governance updates ride along inside the same cycle as standard updates; they share the same feedback channels and the same management-and-governance phase.

The conditions under which cross-cycle improvement actually occurs are nonetheless important, because where they fail, the cycle stalls or regresses. Three structural conditions emerge from the case material. First, the architecture must include a functional field feedback loop returning deployment experience to the specification team; the regional-branch ordering authority gap at DSO-C attenuates exactly this channel. Second, the specification team must have the authority and resources to act on feedback; the supra-regional engineering withdrawal in DSO-C's C.2 case shows what happens when this fails mid-cycle. Third, the procurement cycle must be long enough to allow learning to accumulate before the next round begins; where urgency compresses the cycle, the consolidation step is the first casualty. The pattern instantiates the prescriptive logic of Choi, Shrestha, Kwak, and Shane (2020a), who identify discipline to maintain standardization as a critical success factor and recommend that specification changes be permitted only on the next standardization cycle, after the first has completed its lessons-learned phase.

The measurement gap as the most consequential constraint on cross-cycle improvement. The single most consequential constraint on how productively the process model iterates is the measurement gap identified within Theme 1 (Section 7.5.1): without quantitative outcome data flowing back to the specification team, the feedback communication operates only on qualitative deployment experience, and phase 2 redesign proceeds without the data that would allow trade-offs to be defended against cost-pressure or operational-urgency challenges. The standard's quality and the governance architecture are analytically separable but empirically coupled: the same feedback channel carries both. Where the architecture is otherwise complete, as at DSO-A, the measurement gap still attenuates the dynamic refinement through which the standard and its governance arrangements would otherwise mature.

The dynamic-governance dimension and the late-starter disadvantage. Governance maturity is not static but an accumulating organizational capability that improves when the architecture includes the functional feedback loop, consistent with the dynamic governance dimension of Chapter 3 (§3.3.2). DSOs that establish governance before urgency peaks accumulate cycle-on-cycle improvement at a sustainable rate; those that start late must compress multiple learning cycles into shorter timeframes and consistently struggle to complete the consolidation step before the next round begins. The DSO-A versus DSO-B contrast is empirical: DSO-A's program predated peak grid expansion pressure (Section 7.3.4), and the architecture matured through several cycles before peak volume hit; DSO-B has had to build governance during scaling, and the proof-of-compliance gap is the visible cost of compressed cycles.

Institutional and behavioral compliance mechanisms differ in how they survive across cycles. A further dimension of cross-cycle durability concerns which type of compliance mechanism the architecture relies on. The institutional versus behavioral distinction of Chapter 3 (§3.3.3) operationalizes the qualitative difference between the structural tier and the procedural tier. *Institutional* mechanisms operate through system constraints and do not depend on individual behavioral choices. *Behavioral* mechanisms operate through organizational culture, professional norms, and individual compliance. DSO-A's configuration tool is institutional: it makes non-compliance structurally more difficult than compliance at the point of ordering, independently of any engineer's attitude. DSO-B's and DSO-C's enforcement mechanisms are predominantly behavioral, operating through Technical Management gatekeeping at DSO-B and CMT deviation review at DSO-C. Behavioral mechanisms are cheaper to establish but less robust across cycles: they degrade when key personnel change, when team bandwidth is insufficient, or when organizational pressure to accommodate project timelines exceeds the team's capacity for enforcement. Institutional mechanisms are more expensive to establish but provide governance resilience behavioral mechanisms alone cannot match, which is why their absence is the dominant explanation for cycle-on-cycle erosion in the cases that lack them.

Setting up governance is connective tissue, not a separate activity. Setting up and sustaining governance is not a separate activity running alongside the four phases but the connective tissue that makes the phases iterate productively. Governance is established in phase 2, when ownership, cross-functional pre-authorization, deviation rules, and enforcement mechanisms are designed alongside the technical standard, and exercised in phase 3a, when feedback is processed and the standard is revised. Without cross-functional views there is no sound design; without the right channels and stakeholder co-creation there is no acceptance or enforcement in the update communication; without structural ordering channels or a deviation policy there is no controlled application in operational use. The analytical implication is taken up as a theoretical contribution in Chapter 9 (§9.5.1): not a new process model, but an empirically anchored re-allocation of where analytical attention should sit, namely the design and the management-and-governance phases, which sharpens Klein and Sorra (1996)'s adoption-implementation distinction by decomposing implementation into phases 3a and 3b and showing the bottlenecks concentrate upstream of the visible operational symptoms.

7.8. The governance-as-fit framework

The preceding sections have developed the elements of the final framework, primarily addressing SQ4 while consolidating the SQ3 conditions that shape implementation outcomes. Chapter 3 introduced the initial governance demand-capacity logic; the cross-case comparison mapped the six cases onto asset complexity and standardization form; Theme 1 established governance architecture as the primary observed correlate of sustained implementation depth; Theme 2 identified organizational fragmentation as a structural source of internal governance demand; Theme 3 identified inherent variability as an additional demand stream requiring bounded variants and governed deviations; and the four-stage process model showed where these mechanisms operate across procurement cycles. This section therefore does not introduce a new framework. It names and consolidates the framework that has been built across the chapter.

The framework is labeled *governance-as-fit* because the appropriate governance architecture is not universal. It depends on the fit between the governance demand imposed by the asset, organization, and deployment environment, and the governance capacity provided by the three-tier architecture. This formulation preserves the contingency-theory logic, as formalized by Donaldson (2001), introduced in Chapter 1, but specifies it for internal asset standardization in regulated network-infrastructure organizations. Chapter 8 subsequently tests and refines the framework; those Phase 4 refinements are noted here only where they alter the final form of the framework.

7.8.1. Framework logic

The framework has three elements, as represented in Figure 7.4. First, governance demand is composite and consists of two demand streams. Asset complexity and organizational fragmentation jointly define the internal governance demand a program must meet: higher component and interface complexity, stakeholder density, merger-legacy fragmentation, distributed ordering authority, regional engineering traditions, and workforce-growth-related knowledge dilution all increase the governance intensity required to achieve a given implementation depth. Inherent variability adds a second, deployment-environment demand stream. Grid history, site conditions, municipal demands, regulatory discontinuities, and project-type asymmetries require either internalization into the standard as bounded variants or treatment through formal deviation pathways; where neither happens, variation propagates into informal workarounds that erode standardization discipline. Second, governance capacity is provided by the three-tier architecture defined in Chapter 3 and empirically mapped in Section 7.3.3. Relative to fragmentation-induced demand, this capacity is provided through cross-functional pre-authorization, designated specification authority, and structural enforcement; relative to variability-induced demand, it is provided through bounded variant menus, interface-level specifications, and governed deviation pathways. Third, implementation depth depends on whether this capacity is sufficient for the full demand profile. The measurement gap qualifies this relationship dynamically: without systematic adherence, deviation, cost, and performance data, cross-cycle learning depends mainly on qualitative deployment experience, slowing the maturation of both the standard and its governance architecture. The framework therefore explains why similar asset standards can achieve different implementation depth across DSOs, why the same DSO architecture can be sufficient for one asset class but insufficient for another, and why implementation depth can erode over time when the feedback needed for governance maturation remains incomplete.

The C.1/C.2 contrast within DSO-C illustrates the fit logic most clearly. The CMT-based governance model that is functionally in place for distribution stations becomes insufficient for the transportation station because the asset imposes a higher interface, stakeholder, and learning burden. DSO-C's subsequent creation of a separate standardization collective is therefore not an exception to the

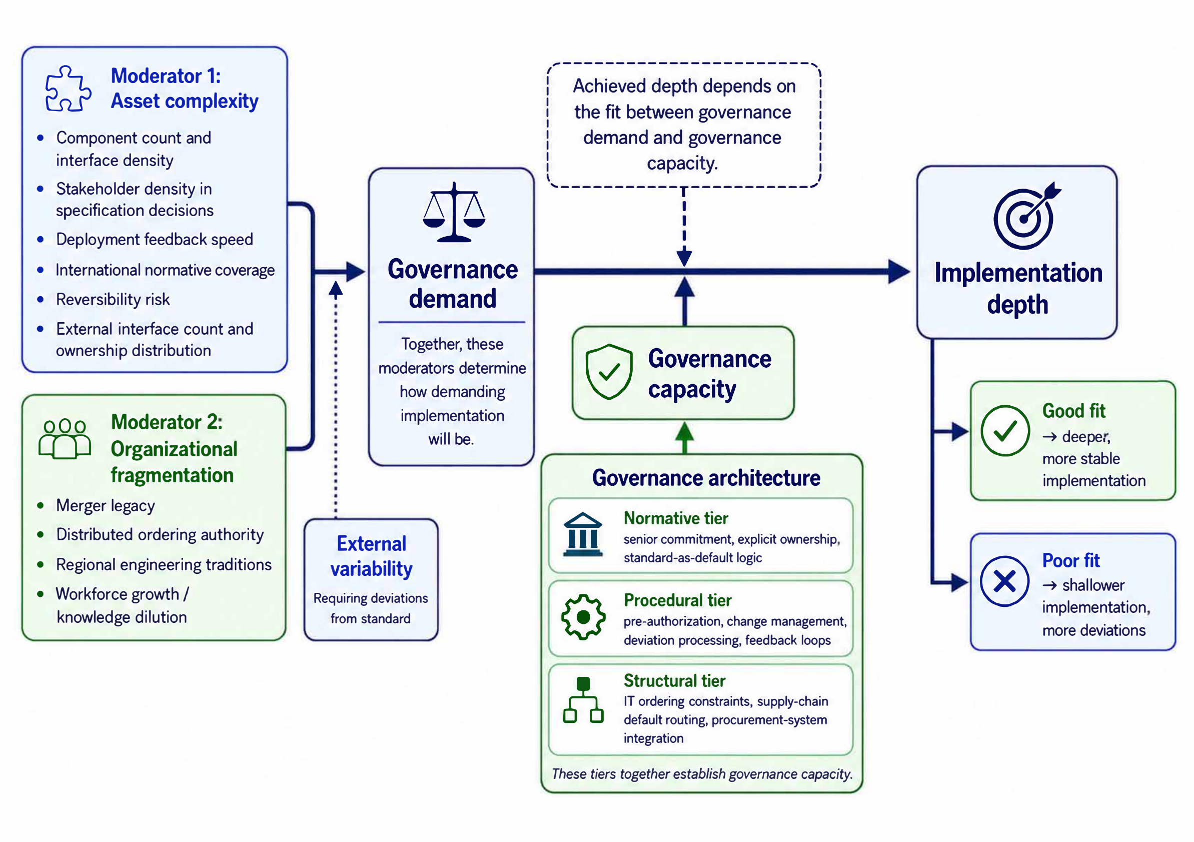


Figure 7.4: Governance demand–capacity fit model for standardization implementation. Asset complexity and organizational fragmentation jointly shape the internal governance demand of a standardization program, while inherent variability adds external demand that must be absorbed through bounded variants and governed deviation pathways. Implementation depth depends on the fit between this composite demand and the governance capacity provided by the normative, procedural, and structural tiers of the governance architecture.

framework, but an empirical illustration of its central claim: governance architecture must be calibrated to the demand profile of the specific standardization program.

7.8.2. From framework to prescription map

Figure 7.5 translates the framework into a prescriptive reference map. The map should be read as a heuristic, not as a deterministic decision rule. Rows represent increasing asset complexity; columns represent increasing organizational fragmentation. Each cell assumes a shared baseline: authoritative standard ownership, a governed deviation pathway, interface-level verifiable specification, and feedback-based release maintenance. The cell text specifies the additional governance modifier that becomes salient under that demand profile.

The prescription map is intentionally conservative. It specifies minimum additional governance requirements rather than an optimal architecture. Programs operating below the prescribed architecture for their profile should be expected to achieve lower implementation depth, weaker deviation discipline, or slower cross-cycle maturation. The evidence-density indicators qualify the strength of the prescription: the semi-complex station profiles are most strongly supported by the case portfolio, whereas the very-complex row is principally extrapolated from the transportation-station boundary case and should be treated as a proposition for further empirical testing.

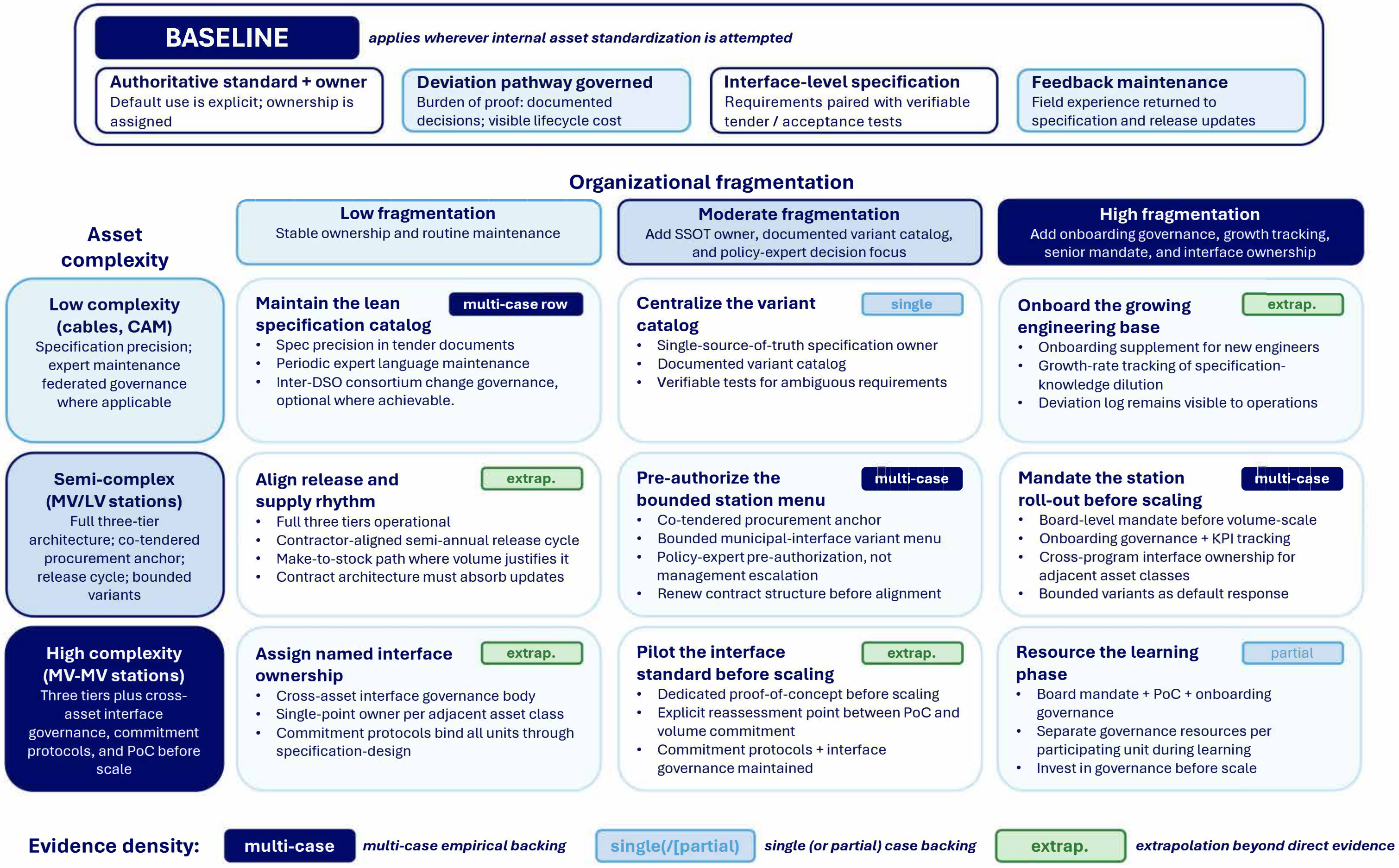
The framework also identifies when standardization should be delayed or narrowed. If governance demand exceeds available capacity, the appropriate response is not to adopt the standard and accept shallow implementation as a transition cost. It is to defer adoption, reduce the standard's scope, or invest in the missing governance tier before scaling. This boundary condition follows directly from the framework logic: standardization is beneficial only when the standard, the deviation pathway, and the supporting governance architecture are designed as a matched system.

7.9. Chapter conclusion

This chapter developed the cross-case argument across six embedded standardization programs in three Dutch DSOs. The central finding is that sustained implementation depth depends less on the technical existence of a standard than on the fit between the governance demand imposed by the asset, organization, and deployment environment, and the governance capacity provided by the standardization architecture. The comparison of A.1, B.1, and C.1 shows that comparable MV-LV station standards can achieve different implementation depth when governance-tier completeness differs. The C.1/C.2 contrast further shows that the same governance architecture can be sufficient for one asset class but insufficient for another when asset complexity and interface burden increase.

The three themes explain this pattern. Governance architecture is the primary observed correlate of sustained implementation depth; organizational fragmentation and professional resistance raise the internal governance demand that architecture must meet; and inherent variability prevents complete standardization in principle, requiring foreseeable variation to be internalized as bounded variants and residual variation to be governed through formal deviation pathways. The four-stage process model locates these findings over the procurement cycle and shows that the main bottlenecks sit in development/design and management/governance rather than in operational use alone. The governance-as-fit framework consolidates these findings into a demand-capacity model and a prescriptive map indicating the minimum additional governance modifiers required under different demand profiles.

The chapter thereby answers SQ3 by explaining the main patterns of convergence and divergence across the six cases, and SQ4 by specifying how organizational structure and governance design condition implementation depth and the barriers encountered. Chapter 8 tests whether these propositions are recognized as valid and practically useful by senior DSO practitioners, after which Chapter 9 positions the framework's theoretical and practical contributions.



BASELINE *applies wherever internal asset standardization is attempted*

Authoritative standard + owner
Default use is explicit; ownership is assigned

Deviation pathway governed
Burden of proof: documented decisions; visible lifecycle cost

Interface-level specification
Requirements paired with verifiable tender / acceptance tests

Feedback maintenance
Field experience returned to specification and release updates

Organizational fragmentation

Asset complexity	**Low fragmentation** Stable ownership and routine maintenance	**Moderate fragmentation** Add SSOT owner, documented variant catalog, and policy-expert decision focus	**High fragmentation** Add onboarding governance, growth tracking, senior mandate, and interface ownership
Low complexity (cables, CAM) Specification precision; expert maintenance federated governance where applicable	**Maintain the lean specification catalog** multi-case row • Spec precision in tender documents • Periodic expert language maintenance • Inter-DSO consortium change governance, optional where achievable.	**Centralize the variant catalog** single • Single-source-of-truth specification owner • Documented variant catalog • Verifiable tests for ambiguous requirements	**Onboard the growing engineering base** extrap. • Onboarding supplement for new engineers • Growth-rate tracking of specification-knowledge dilution • Deviation log remains visible to operations
Semi-complex (MV/LV stations) Full three-tier architecture; co-tendered procurement anchor; release cycle; bounded variants	**Align release and supply rhythm** extrap. • Full three tiers operational • Contractor-aligned semi-annual release cycle • Make-to-stock path where volume justifies it • Contract architecture must absorb updates	**Pre-authorize the bounded station menu** multi-case • Co-tendered procurement anchor • Bounded municipal-interface variant menu • Policy-expert pre-authorization, not management escalation • Renew contract structure before alignment	**Mandate the station roll-out before scaling** multi-case • Board-level mandate before volume-scale • Onboarding governance + KPI tracking • Cross-program interface ownership for adjacent asset classes • Bounded variants as default response
High complexity (MV-MV stations) Three tiers plus cross-asset interface governance, commitment protocols, and PoC before scale	**Assign named interface ownership** extrap. • Cross-asset interface governance body • Single-point owner per adjacent asset class • Commitment protocols bind all units through specification-design	**Pilot the interface standard before scaling** extrap. • Dedicated proof-of-concept before scaling • Explicit reassessment point between PoC and volume commitment • Commitment protocols + interface governance maintained	**Resource the learning phase** partial • Board mandate + PoC + onboarding governance • Separate governance resources per participating unit during learning • Invest in governance before scale

Evidence density: multi-case *multi-case empirical backing* single(/[partial) *single (or partial) case backing* extrap. *extrapolation beyond direct evidence*

Figure 7.5: Governance-as-fit prescription map. The map translates the governance-as-fit framework into a layered 3 × 3 prescriptive heuristic for internal asset standardization programs. All cells inherit a shared baseline of authoritative standard ownership, governed deviation pathways, interface-level verifiable specification, and feedback-based release maintenance. Row modifiers add governance requirements associated with increasing asset complexity, while column modifiers add requirements associated with increasing organizational fragmentation. The nine cells specify additional practice-oriented governance prescriptions for each demand profile. Evidence-density indicators distinguish multi-case empirical backing, single-case or partial empirical backing, and extrapolation beyond direct case evidence.

8

Expert recognition and refinement

8.1. Introduction and purpose

This chapter presents and analyzes the Phase 4 expert validation session, conducted with three senior practitioners, each representing one of the three DSOs studied in Chapters 4–6. The session served three interrelated purposes. First, it tested whether the 14 implementation challenges derived from the within-case data and synthesized in Chapter 7's three-cluster taxonomy of standard-contesting challenges (Section 7.6) are recognized as real and significant by senior practitioners. Second, it established practitioner-weighted priorities across the 10 organizational and governance components identified during the cross-case analysis, clarifying which components practitioners regard as success-critical versus developmental. These components map onto the three-tier governance architecture introduced in Chapter 3 (§3.3.3) and operationalized in Chapter 7 (§7.3.3), so the priority rankings function as a practitioner-side test of which architectural elements are perceived as load-bearing. Third, the session produced direct practitioner testimony on the relationship between governance architecture and standardization success, serving as the principal validation instrument for the governance-as-fit argument of Chapter 7 (§7.8) and grounded in Chapter 3 (§3.3.3). The findings are carried into the governance-as-fit conclusion in Chapter 9, where they have informed the prescriptive conditions for the governance architecture model and the contextual moderators that determine the required intensity of governance investment at different stages of a program's maturity trajectory from Chapter 7.

Participants are anonymized as Interviewee DSO-A, Interviewee DSO-B, and Interviewee DSO-C, consistent with the anonymization protocol applied throughout this study. Where practitioners nuanced, reframed, or contested a finding, those adjustments are incorporated into the analytical account and flagged as refinements to the original proposition.

8.2. Validation of the 14 implementation challenges

8.2.1. Overall recognizability and the permanence proposition

Chapter 3 (§3.2.3) flagged as an analytical possibility, drawn from the industry consultant interviews, that several implementation challenges may be structural features of the operating environment rather than transition friction that disappears once implementation succeeds. The Phase 4 session provides direct empirical confirmation. The first and analytically most consequential practitioner response to the challenge inventory was DSO-C's characterization of all 14 challenges as permanent management responsibilities rather than solvable problems:

> "If you look at these 14 challenges, they are all more or less current. My expectation is that these will never be resolved, but that they will always require continuous attention. They are more 14 points of ongoing concern than things that can truly be solved." (Interviewee DSO-C)

This framing is formalized here as the *permanence proposition*: implementation challenges in MV-LV asset standardization programs are not a temporary transition list to be worked through and resolved but a permanent governance management agenda requiring continuous institutional attention. The appropriate management objective is therefore not challenge elimination but challenge containment through institutional design that makes each challenge continuously manageable at acceptable cost. The proposition refines the cross-case findings in Chapter 7 and is incorporated into the governance-as-fit framework in Chapter 7 (§7.8): the architecture does not converge on a solved state but on a managed equilibrium in which governance infrastructure reduces the frequency and cost of challenge activation without eliminating its structural causes.

DSO-A and DSO-B did not contest this framing. DSO-B explicitly endorsed it, describing all challenges as actively managed within an ongoing transition:

> "We are in the transition, so we do not yet have a real success story where we can already point to a concrete example." (Interviewee DSO-B)

DSO-A offered the most operationally advanced account of addressed challenges but acknowledged that others remained current. The cross-DSO convergence on the permanence proposition is a confirmed refinement to the cross-case analysis rather than a passing observation.

8.2.2. Challenges recognized as successfully addressed

DSO-A: cross-functional alignment and the AM-to-operations communication gap. DSO-A's representative identified the multi-disciplinary team (MDT) structure and the resolution of the Asset Management (AM) to operations communication gap as the two most successfully addressed challenges at their organization. The MDT now includes representation from production chains, the regional construction management function, and contractor management, so specification decisions are pre-authorized by implementation-side participants before reaching procurement:

> "The communication gap between Asset Management and operations has been largely closed, partly because we now have representation from operations in the MDTs: from production chains, from regional branches, from contractor management. Our line with the contractor community through the Changing the Business consultation has also been strengthened. You notice that this is appreciated." (Interviewee DSO-A)

A specific mechanism that resolved contractor friction was the adoption of a semi-annual release cycle to replace the previously continuous document mutation practice, which had allowed specification documents to be updated at any time, generating unpredictable change pressure on contractors. Aligning the release cycle with contractors' own planning and procurement rhythms, combined with dedicated roadshow communication before each release, substantially reduced release-related friction:

> "We had quite a few disputes with the contractor community in the beginning: they kept saying you are changing things again, you are changing requirements again. Now we have aligned the release cycle with their rhythm, and we attend their Changing the Business meetings to hear what is happening. We have a fixed representation there now, and that has really helped." (Interviewee DSO-A)

A precondition for the effectiveness of release-cycle alignment surfaced through a contrasting account from DSO-B. The mechanism is operationally available to DSO-A in part because its underlying contract architecture accommodates specification updates; DSO-B reported the opposite condition:

> "The contracts we have with contractors are based on a specific way of working, set up with the original program of requirements, and they are so tightly closed that when we have a new standard it is very difficult to push it through those contracts. Or we receive excessive prices: it can be done, but you pay three times the prime price." (Interviewee DSO-B)

This qualifies the release-cycle prescription. Aligning the release cycle with contractor planning rhythms reduces change-related friction only when the underlying contract architecture is designed to accommodate change. Where contracts have been tightly specified to a prior operational regime, the mechanism remains useful but is insufficient on its own; contract-architecture renewal becomes a parallel governance investment. This is the chain-governance analogue of the specification-architecture point DSO-B articulates later in the session (§8.2.4): governance mechanisms that look like external constraints often have their root cause in earlier internal design choices.

This mechanism, release cycle alignment as a chain governance instrument, was not identified in the original within-case data at the same level of explicitness. It is treated as a Phase 4 refinement of the chain governance discussion (Section 7.3.3) and is incorporated into the prescriptive framework in Chapter 9 (§9.4.5).

DSO-B: top-down mandate as a compliance accelerator. DSO-B described a recent Board of Directors decision that imposed a key result on the operational organization: modular building is no longer a preference but a performance requirement, currently being translated into an operational program governing how the standard is realized in the field:

> "What our Board of Directors recently established is that certain key results have been imposed on the operational organization: you shall build modularly. By requiring that construction lead times be drastically shortened, they are saying that prefab modular building is the solution. We are now building an operational plan: how do we ensure that the modules that are prescribed are actually realized?" (Interviewee DSO-B)

This corroborates the cross-case finding that normative tier establishment through senior organizational authority is the precondition for effective procedural and structural tier investment (Section 7.5.1).

DSO-C: co-tendering with cross-functional procurement participation. DSO-C identified joint tendering with Supply Chain Management, Procurement, and Production as the governance mechanism that had most successfully generated both compliance and organizational support:

> "The most successful thing for us was tendering jointly with Procurement, SCM, and Production and implementing the chosen standard in such a way that there is support for it. The standard is very easy to apply, and for Production it is genuinely difficult to order and realize something outside it. The level of support for the standard and the actual use of it is very high." (Interviewee DSO-C)

The governance logic is the institutional compliance architecture of Section 7.7.6: making the standard the path of least operational resistance through supply chain integration. DSO-C elaborated on the operational consequence:

> "The standard is a stock item, so you have it within six weeks. If you want a special it still has to be manufactured, so the lead time is at least six months. We make it very convenient for engineers to order the standard, and they pay a price in effort and time if they do not." (Interviewee DSO-C)

This is the friction asymmetry principle of Section 7.7.6 confirmed independently by DSO-C in a different institutional form. Where DSO-B achieves friction asymmetry through procedural barriers on deviation and DSO-A through an IT-enforced configuration tool, DSO-C achieves it through supply chain lead time asymmetry at the point of ordering. The six-week versus six-month asymmetry is also a direct operational signature of DSO-C's upstream production decoupling position, which the cross-case analysis identifies within Theme 1 (Section 7.5.1) as a mechanism-activation moderator: standardization is necessary for upstream movement of the production decoupling point, but the movement itself activates the schedule-control and procurement-scale mechanisms that DSO-C reports in stronger terms than the other two station programs. The cross-DSO corroboration of the friction asymmetry principle across three independent institutional implementations substantially strengthens its status as a generalizable governance finding.

8.2.3. Challenges recognized as currently most urgent

DSO-A: inner-city station variant development. DSO-A's most urgently active challenge is municipal permitting in dense urban environments. The current standard footprint was designed for median site conditions and is insufficient for inner-city deployments where spatial constraints, aesthetic requirements, and planning authority expectations are more demanding:

> "The biggest challenge for us (and I think for others too) is the permitting process, particularly for medium-voltage rooms in inner-city environments. We are working on a new inner-city variant with a number of configurations, and there are active contacts with DSO-C and DSO-B about what is smart and what are good ideas." (Interviewee DSO-A)

This is consistent with the spatial non-conformance barrier of Section 7.3.6, and it specifies the active program response: an inner-city station variant developed through cross-DSO technical consultation. Permit-free placement status does not resolve the challenge, because municipalities retain practical influence over siting and design regardless of formal permitting requirements. The response confirms and extends Theme 3 (Section 7.5.3): rather than processing each inner-city deployment as an exception through the deviation pathway, DSO-A is internalizing the foreseeable municipal-environment variation into the standard itself as a bounded inner-city variant menu, the design-stage variability-absorption response Theme 3 identifies as appropriate for predictable variation, distinct from the deviation pathway reserved for genuinely unexpected variation.

DSO-C: bounded-options menu for municipal aesthetic variation. DSO-C's most urgently active external-interface challenge is structurally parallel to DSO-A's: variability driven by municipal authority over siting and visual design. The DSO-C representative described the source in stronger terms, as a structural feature of Dutch governance ("a design flaw in the Netherlands, that municipalities have final authority") and noting roughly a hundred municipalities each capable of imposing distinct local conditions on compact-station siting. The operational response is a bounded-options menu rather than a per-deployment exception:

> "We try with a standard with options: we have a standard with a limited number of options, and the municipality may choose. The one-million-dollar gamble is that when you give people four options, they say give me the fifth. But for our municipalities that feeling of choice is important." (Interviewee DSO-C)

The DSO-C bounded-options approach and the DSO-A inner-city variant are structurally the same governance response in different formats: foreseeable municipal-interface variability internalized into the standard as a bounded menu of pre-authorized variants rather than processed through the deviation pathway as a per-case exception. The convergence across two DSOs on the same design-stage variability-absorption response (Theme 3, Section 7.5.3) strengthens the analytical status of this prescription. The accompanying observation that a four-option menu often elicits a request for a fifth is a tactical refinement: the bounded-options approach works through structured negotiation, not technical containment alone.

DSO-B: procurement bypass through open ordering channels. DSO-B identified the persistence of procurement bypass routes as its most operationally consequential current compliance challenge. Engineers can order medium- and low-voltage components directly from suppliers at the project level in ways not visible to either Procurement or Asset Management:

> "There is still a back loop in our organization where people can order directly from suppliers at the component level in ways that even Procurement cannot see what is being ordered. That is genuinely remarkable that this is still possible. It is a clear concern: how do we close this?" (Interviewee DSO-B)

This is the exact bypass mechanism documented at DSO-A in Chapter 4, confirmed at DSO-B as current rather than historical. The cross-DSO corroboration establishes it as a sector-level structural vulnerability rather than a case-specific idiosyncrasy. DSO-B's prioritization response is instructive: the primary corrective investment is in governance clarity and cultural alignment rather than technical access restriction:

> "We want to focus our attention on ensuring that we define the standards well together. The human and culture aspect is the most important thing here. I can build very nice reports, but if we do not steer on them and act on them, nothing will change." (Interviewee DSO-B)

DSO-C: rapid workforce growth as a compliance risk multiplier. Chapter 7 (§7.5.2) introduced organizational fragmentation as a multi-source emergent construct, with workforce transition identified alongside merger origin as a parallel source. The Phase 4 session provides the specific operational mechanism, the governance-intensity multiplier of rapid hiring, through which this second source operates. DSO-C identified organizational growth rate as a distinctive compliance challenge that amplifies all other implementation difficulties: hiring approximately 100 new people per month continuously replenishes the population of engineers not yet familiar with exception-handling procedures, standard boundaries, or the rationale behind specific design constraints:

> "One of our challenges is that we hire around a hundred new people every month, and they all arrive without knowledge of how we work. Sometimes someone who has been here three months has to train someone who is just starting. So you are constantly having to give attention to all 14 points on this list." (Interviewee DSO-C)

The onboarding challenge thus operates as a governance intensity multiplier: an architecture adequate for a stable workforce may be inadequate for an organization growing at DSO-C's rate without deliberate onboarding governance supplements. This finding is novel relative to the cross-case analysis and is incorporated into the governance-as-fit framework in Chapter 7 (§7.8) as a dynamic organizational context factor.

8.2.4. Reframing of two challenges

Two challenges from the original 14 were substantively reframed during the session.

Challenge 11: innovation barrier. DSO-B contested the framing of the tender and contract structure as a structural innovation barrier:

> "In the broad sense, I do not recognize innovation as being blocked. If we want to innovate, we can. The current contracts may not provide that space, but before a new product is ready enough to apply, we are certainly several years further along anyway. You quickly move past that contract horizon. Innovation is more a question of risk trade-offs than of structural blockage." (Interviewee DSO-B)

This shifts the locus of the challenge from contract structure to risk appetite and investment cost allocation, both internal organizational choices. The adjusted formulation is that innovation timelines and tender cycle lengths are structurally compatible for most station-type innovations, but the absence of a shared financial mechanism for prototype development keeps the practical threshold for introducing a genuinely new station design high. The challenge is retained in the inventory with this adjusted scope.

Challenge 12: supplier dependency. DSO-B also reframed supplier dependency as a consequence of specification design choices rather than supplier market power:

> "The real question is whether the DSO owns the specification or whether you are always having to negotiate because the supplier is somehow more powerful. That is really about the modularity of how you have designed your station. If your station is designed so that it can handle known types of changes, then the problem does not exist at all: everything is interchangeable. We have partly caused our own constraints by designing stations based on installations rather than modular assemblies." (Interviewee DSO-B)

DSO-A partially confirmed this, noting that the SF6-free RMU supply disruption created operational difficulty but the root cause was the dimensional rigidity of the station design rather than supplier market power. The cross-DSO consensus is that supplier dependency is a consequence of specification architecture choices, specifically insufficient modularity and inadequate dimensional tolerance design, rather than an independent external threat. The challenge is therefore reclassified from the external category to the technical challenges cluster of Section 7.6.1. The reframing is also a direct empirical confirmation of Theme 3's design-stage finding (Section 7.5.3): a standard designed at the interface level rather than around specific supplier components absorbs component change (regulatory, supplier-initiated, or supplier-substitution) as bounded updates rather than forced deviations, the variability-absorption logic DSO-B articulates when describing stations "designed so that they can handle known types of changes". Supplier dependency, on this reading, is not an external constraint but a downstream consequence of design-stage choices that did not anticipate the variability the standard would have to absorb.

8.2.5. Symptom phase versus root-cause phase

DSO-B's reframing of supplier dependency points to a more general observation the session surfaced across multiple challenge discussions. Many of the 14 challenges present as operational problems in the field but originate upstream of operations: in the specification design phase (insufficient envelope coverage, unmapped edge cases, unassigned interfaces, inadequate dimensional tolerances) or in the governance phase (absent compliance architecture, missing proof-of-compliance regimes, unbuilt onboarding infrastructure). Operational-phase root causes that no upstream choice could have addressed are genuinely present but less common than the categorization might suggest: spatial non-conformance in inner-city deployments, regulatory boundary effects of European procurement law, and TenneT/IEC/client-object interface specifications belong here. The remaining challenges, including procurement bypass, off-standard director-authorized orders, supplier non-compliance with ambiguous specifications, the cross-asset interface incompatibility, the benefit measurement gap, release-cycle misalignment, and workforce-growth knowledge dilution, have their root causes in either the specification design or the governance design rather than in operations.

The analytical implication is that the prescriptive recommendations developed in Chapter 9 target the design and governance phases rather than the operational phase. Where design appears as a root cause, it is consistently a coverage failure (an envelope too narrow, interfaces unassigned, edge cases unspecified, deviation paths unmapped) rather than a competence failure (a badly engineered standard). Coverage is itself a governance function: it asks “what does the standard need to specify?” before the engineering question of “how do we specify it?”. Technical engineering competence is not the limiting factor in DSO standardization; standardization governance is, including the governance that scopes the design.

8.3. Validation of organizational and governance components

8.3.1. Priority rankings and rationale

Each participant identified, via written session response, the two governance components they considered most important for standardization success at their organization, followed by a moderated discussion of their rationale. Table 8.1 summarizes the stated priorities and basis for each.

Table 8.1: Expert priorities across the 10 organizational and governance components.

Component	DSO-A	DSO-B	DSO-C
1. Ownership and governance team	Top priority	Top priority (jointly with 10)	Active (via deviation control)
2. Update and change process	Active (release cycle)	Active (catalog transition)	Active (SCM-linked blocking)
3. Deviations and non-compliance	Active (config. tool)	Explicitly mentioned as key enabler	Active (lead time gating)
4. IT tools and process monitoring	Established (config. tool)	Developing	Established (ERP-based)
5. Knowledge management and documentation	Greatest development ambition	Not yet prioritized	Not yet prioritized
6. Horizontal coordination	Top priority	Active (MFT structure)	Active (MDT equivalent)
7. Work allocation by project type	Mentioned	Not prioritized	Not prioritized
8. Tender and procurement governance	Active (dual sourcing)	Most successful mechanism	Most successful mechanism
9. Monitoring, KPIs, and evaluation	Established (compliance metric)	Developing	Limited
10. Culture and mindset	Named as hardest challenge	Top priority (jointly with 1)	Active (via mandate design)

Three cross-DSO patterns emerge from the priority rankings.

First, ownership and culture are the only components prioritized by all three DSOs, albeit at different stages of resolution. DSO-B named them jointly as the two most critical, with an explicit sequencing logic:

> “We are working on everything, but components *Ownership and governance team* and *Culture and mindset* are crucial, and *Culture and mindset* must be supported by *Deviations and non-compliance regulations*.” (Interviewee DSO-B)

The linkage between ownership, deviation governance, and culture reflects the governance argument grounded in Chapter 3 (§3.3.3) and operationalized in Chapter 7 (§7.5.1): ownership and cross-functional authority constitute the normative tier, deviation governance the procedural tier, and cultural embedding the behavioral outcome that follows from those tiers functioning reliably. DSO-B’s formulation is a practitioner restatement of the three-tier architecture model.

Second, *Horizontal coordination* was the most consistently active component across all three organizations. DSO-A named it, alongside *Ownership and governance team*, as the most important success factor:

> "The greatest contribution to standardization success: ownership and governance team, and horizontal coordination." (Interviewee DSO-A)

This corroborates the cross-case finding that cross-functional pre-authorization is the most differentiating structural feature of high-depth programs (Section 7.3.3).

A specific governance design rule emerged through cross-DSO agreement that does not surface in the cross-case analysis as such: substantive specification decisions should be located at policy-expert level, not at management level. DSO-C described the rule explicitly:

> "Decision-making is no issue. You must prevent decisions all being escalated to management, because you write yourself into knots just explaining the problem. Policy experts decide, my employees, they cut the knots. Escalation to the next management level is acceptable when it is unavoidable, but certainly not higher." (Interviewee DSO-C)

DSO-A confirmed the same rule in mechanism terms, describing MDT composition as policy-expert rather than managerial:

> "In the MDTs there are content experts. There are no managers or team leaders in there. They are really the substantive ones, with sufficient knowledge of the subjects that are at stake." (Interviewee DSO-A)

This two-DSO convergence specifies the operational form of the procedural tier: cross-functional pre-authorization works when the authorizing forum is composed of substantive specification authority rather than line management. Management override remains available but is rare and recognized as exceptional; DSO-A described pushback from above as the exception rather than the rule. The rationale is clear: management-level decision-making introduces an explanation overhead that substantive content owners do not incur and tends to dilute decision quality by inserting decision-makers who lack the technical context to weigh the trade-offs. This finding is incorporated into the prescriptive framework as a refinement to the procedural-tier design (Chapter 9, §9.4.1).

Third, *Knowledge management and documentation* is the only component where a clear gap exists between current investment and stated ambition. DSO-A named it as their greatest remaining development ambition; DSO-B and DSO-C did not prioritize it, implying it is not yet a governance investment focus there. This is the Phase 4 confirmation of the measurement-gap sub-finding embedded in Theme 1 of Chapter 7 (§7.5.1): the absence of systematic before-and-after measurement infrastructure is structurally co-present with standardization adoption at all three DSOs and attenuates the cross-cycle improvement of the architecture. Without systematic knowledge management and measurement infrastructure, specification improvements derived from deployment experience are not reliably captured or shared across organizational units and successive procurement cycles, so the process model's phase 2 to phase 3b feedback channel operates only on qualitative deployment experience (Section 7.7.6). The cross-DSO convergence on this gap, despite each DSO's distinct architecture, supports the framing that the absence is structural rather than incidental and that the appropriate prescriptive response sits at the governance-architecture level rather than the program-management level. The pattern is structurally consistent with Choi, Shrestha, Kwak, and Shane (2020a)'s observation in the capital-project literature that four critical success factors combined high impact with low probability of implementation; the session's identification of knowledge management as the only component where ambition outpaces investment across all three DSOs is the DSO-sector parallel of that "high impact, low implementation" diagnostic.

8.3.2. The role of urgency: a two-sided finding

Chapter 3 (§3.2.1) flagged urgency as a condition with ambivalent effects, depending on whether governance infrastructure precedes or accompanies it. The Phase 4 session provides the specific operational mechanism through which this ambivalence operates and refines the cross-case Theme 1 finding (Section 7.5.1). DSO-B articulated urgency not only as a source of governance strain, the framing dominant in the cross-case analysis, but as an active organizational lever that creates political and cultural conditions for adoption:

> “The urgency to build faster means that operations has less time to do its own engineering, and people simply have to use a product catalog and realize from it. You see that we are getting more resources and alignment with all stakeholders because of this urgency. The momentum is here right now. Not the word force: realize. That standardization is actually used.” (Interviewee DSO-B)

This introduces a distinction under-specified in the original cross-case analysis: urgency has opposite effects depending on its sequencing relative to governance infrastructure. When urgency precedes governance infrastructure, it accelerates deployment before specification and oversight mechanisms are in place, increasing deviation rates and specification incompleteness risks; this is the pattern visible in DSO-C’s C.1 program in its earlier phases and in the transportation station case. When urgency arrives after governance infrastructure is established, it creates political momentum for adoption, reduces the space for individual engineering discretion, and makes catalog-based deployment the operationally practical default; DSO-A’s program trajectory exemplifies this.

A third refinement emerged through DSO-C’s articulation of the timing logic that governs cross-functional decision-making under standardization. The horizontal-coordination prescription generates slower decision-making in the short run, by design, and this slower pace can only be absorbed by programmes that begin early enough to accommodate it:

> “You go faster alone, but together you get further. So things taking somewhat longer, half a year or a year, is not a problem if you assume in advance that it will take a year. You just have to start on time.” (Interviewee DSO-C)

This is a temporal complement to the two-sided urgency finding. Urgency converts into adoption acceleration only when governance infrastructure is already established *and* when the programme has been initiated early enough for the inherently slower horizontal-coordination process to have produced its decisions before urgency arrives. Programmes that initiate horizontal coordination only once urgency is acute compress the coordination phase against its natural rhythm and tend to produce decisions of lower durability. The governance-before-scale prescription (Chapter 9, §9.4.1) therefore has a second component: not only must governance infrastructure exist before volume scales, the horizontal-coordination machinery must have been allowed enough calendar time to operate on its own pace before scaling pressure binds.

This two-sided urgency finding is incorporated into the governance-as-fit framework in Chapter 9 as a sequencing condition: the effect of urgency on implementation depth is positive when governance infrastructure is already established and negative when urgency precedes it. The governance-before-scale sequencing prescription follows directly (Section 9.4.1).

8.3.3. Governance as the foundation: direct practitioner testimony

The session’s closing synthesis produced the strongest direct validation evidence for the governance-as-fit argument of Chapter 7 (§7.8), grounded in Chapter 3 (§3.3.3). DSO-A’s formulation is the most explicit:

> “My experience is that the biggest problem, when something did not work, was always the governance. And my experience is also: if you do not have that in order, it is the foundation on which everything else has to be built. If you have discussions about who owns what and what the roles, tasks, and responsibilities are, you lose enormous amounts of time and energy without creating clarity. That applies to standardization too: if you do not lay the governance foundation first, it becomes very difficult to organize anything else.” (Interviewee DSO-A)

When the session facilitator restated this as a proposition and asked for confirmation, the following exchange took place:

> “So in a sense, is governance even more important than the quality of the standard itself? Because if you have the governance in place, you can always improve the quality.” (Session facilitator)

> "Governance is a very important foundation. It is the bedrock on which you build." (Interviewee DSO-A)

The epistemic weight of this testimony is reinforced by its evidential basis. The DSO-A interviewee identified Internal Audit experience as the source of the observation, a sustained organizational vantage point from which the recurring root cause of programme failures was diagnostically reviewed. The statement is therefore not a programme-level opinion but a cross-programme empirical pattern recognized by a participant whose function was to identify such patterns.

This exchange is the session's primary validation output. The argument is not that specification quality is unimportant but that it is a governable and improvable artifact within a functioning governance architecture, whereas a high-quality specification without governance infrastructure provides no guarantee of implementation depth. That is the precise structure of the governance-as-fit argument (Section 7.8).

DSO-B reinforced this by identifying cultural change as the endpoint of a governance-enabled transformation rather than its prerequisite:

> "People keep saying that every situation is different and that it has to be flexible. Breaking through that narrative is the real cultural change that we as DSOs find hardest. It happens even within Asset Management: even there people find it hard not to work with a custom solution. But culture change follows from governance being so strong that people genuinely cannot go around it anymore, and they understand why they should not." (Interviewee DSO-B)

The DSO-B interviewee specified the institutional precondition for this cultural transition explicitly:

> "We need to ensure that both management and the standardization teams have such power in the organization that they have real mandate and authority. That they are the body around which nobody can emotionally go anymore. Then at a certain moment you can also enforce much more, and steer and manage on it more deliberately. But the human side will be a factor, because people have to learn to step out of their own free engineering role." (Interviewee DSO-B)

Mandate strength is therefore positioned not as one governance input among several but as the precondition that determines whether cultural compliance becomes available at all. This anticipates the senior-mandate prescription elevated in Chapter 9 (§9.4.1) and provides the practitioner rationale for treating board-level commitment as the most effective accelerator of governance-architecture establishment.

This is consistent with the behavioral-to-institutional compliance transition argument (Section 7.7.6): cultural change is not a prerequisite for governance effectiveness but an outcome of institutional governance mechanisms becoming sufficiently robust that behavioral compliance becomes the default. The cultural narrative DSO-B identifies as hardest to break ("every situation is different") is structurally consistent with the resistance pattern Gibb and Isack (2001) document in a different sector and decade; the cross-sector recurrence supports treating engineering culture resistance as a structural feature of internally developed standardization rather than a transition-stage artifact.

8.4. What the expert session adds to the cross-case analysis

The expert validation session contributes five analytically distinct additions to the cross-case argument of Chapter 7, summarized in Table 8.2 and elaborated below.

The *permanence proposition* and the *two-sided urgency finding* have the most direct implications for the theoretical framework. The permanence proposition reframes the governance success criterion: the question is not whether challenges are solved but whether the architecture keeps their frequency and cost at an organizationally acceptable level. The two-sided urgency finding introduces a sequencing condition not derivable from the cross-case data alone, which observed urgency primarily as a source of governance strain rather than as a potential compliance accelerator.

The *friction asymmetry principle* moves from a finding corroborated by two cases (DSO-A and DSO-B, via

Table 8.2: Phase 4 additions to the cross-case analytical framework.

Addition	Core content	Implication for synthesis
Permanence proposition	Challenges are permanent; success criterion is containment capacity, not resolution	Reframes governance objective from problem elimination to continuous management
Friction asymmetry (cross-DSO)	Three DSOs confirm institutional compliance mechanism independently through different implementations	Elevates friction asymmetry to a generalizable governance prescription
Release cycle alignment	Semi-annual releases aligned to contractor planning rhythms reduce chain friction	Adds a specific replicable chain governance mechanism
Two-sided urgency	Urgency accelerates adoption when governance is pre-established; worsens compliance when urgency precedes governance	Introduces governance-before-scale as a sequencing prescription
Growth rate moderator	Organizational growth rate increases required governance maintenance intensity	Adds a dynamic contextual moderator to the governance-as-fit framework

different mechanisms) to one corroborated by all three DSOs independently. This convergence elevates it from a cross-case pattern to a generalizable governance prescription applicable beyond the Dutch DSO context.

The *release cycle alignment* mechanism is a novel, replicable addition not present in the original within-case data at equivalent explicitness. It confirms cross-case Theme 2's characterization of engineering culture resistance as manageable through governance design rather than culture change alone. The session also surfaced a precondition for its effectiveness: it operates well only when the underlying contract architecture with implementation partners accommodates specification change, a condition not uniformly met across the three DSOs (Section 8.2.2).

The *growth rate moderator* is the most novel contribution relative to both the cross-case analysis and the theoretical framework literature. It bridges standardization governance theory and workforce management by identifying rapid workforce expansion as a governance intensity multiplier not captured by the static fragmentation baseline used in the governance-as-fit framework, and is incorporated as a dynamic modifier of the organizational fragmentation moderator (Chapter 7, §7.5.2).

8.5. Chapter conclusion

This chapter has presented the Phase 4 expert validation session and established its analytical relationship to the cross-case propositions of Chapter 7. The session achieved its three stated purposes. The 14 implementation challenges were broadly validated as recognizable across all three organizations, with two challenges substantively reframed in ways that deepen rather than contradict the original analysis. The 10 organizational and governance components were prioritized consistently, with ownership and governance structure, horizontal coordination, and culture identified as the most consequential, mapping directly onto the three-tier governance architecture model introduced in Chapter 3 (§3.3.3) and operationalized in Chapter 7 (§7.3.3). The closing synthesis produced direct and unprompted practitioner testimony that governance architecture is the foundational prerequisite for standardization success, confirming the study's central theoretical claim.

Five additions to the analytical framework were derived from the session. The two-sided urgency finding and the growth-rate governance-intensity moderator are the most novel relative to what the within-case and cross-case analyses produced independently. Both are incorporated into the governance-as-fit framework in Chapter 7, where they inform the prescriptive conditions for the governance architecture model and the contextual moderators that determine the required intensity of governance investment at different stages of a program's maturity trajectory. The session also surfaced a useful distinction between the operational phase in which a challenge manifests and the design or governance phase in which its root cause originates (Section 8.2.5), which directly motivates the design-and-governance focus of the prescriptive content in Chapter 9.

9

Discussion and conclusion

9.1. Introduction

This chapter synthesizes the preceding chapters into a structured answer to the main research question and its four sub-questions, presents the study's primary theoretical output as a governance-as-fit framework for asset standardization governance, translates that framework into practical prescriptions for DSO program managers, and positions the contributions within the three theoretical conversations identified in Chapter 1 (§1.3.1). It proceeds in eight sections. Section 9.2 answers the sub-questions and the main research question. Section 9.3 summarizes the governance-as-fit framework developed in Chapter 7 and refined by the expert validation in Chapter 8. Section 9.4 translates the framework into seven prescriptions organized around the decision points a program manager faces. Section 9.5 states the contributions to the three pre-specified streams and a compact set of additional contributions to adjacent literatures. Section 9.6 states the limitations. Section 9.7 offers methodological hindsight and a reflection on the MOT curriculum. Section 9.8 sets out the future research agenda, and Section 9.9 closes the thesis.

The chapter assumes the empirical derivation already developed in Chapter 7. Framework components are stated here in their consolidated form; the case material from which they were inductively constructed is reported in Chapters 4–6 and synthesized in Chapter 7. The chapter therefore discusses and positions rather than re-derives.

9.2. Answering the research questions

9.2.1. SQ1: mechanisms and contextual factors in the literature

The existing literature identifies asset standardization as a multi-level, design-and-process construct whose effects on project and operational performance are reported to be positive in engineering-intensive, capital-intensive contexts where assets are long-lived and safety-critical (Bayzidi et al., 2025; Choi, Shrestha, Kwak, & Shane, 2020a; Gibb, 2001). The systematic review in Chapter 3 (§3.1.4) synthesized the mechanisms into five families: design reuse (M1), procurement scale economies (M2), schedule control (M3), quality consistency (M4), and learning and portfolio improvement (M5), each conditional on activating factors documented in Chapter 3 (§3.1.5). The literature also identified a consistent set of enabling factors and challenges, of which stakeholder alignment, engineering culture resistance, organizational ownership clarity, and supply chain structure were most frequently reported. A critical gap is the near-total absence of empirical work on standardization governance in regulated network infrastructure: the 21 core articles identified address construction, industrial facilities, and nuclear contexts, none of which shares the regulatory architecture, procurement regime, or stakeholder environment of a Dutch DSO. This gap motivated the empirical design and is the foundation of the contribution claims in Section 9.5.

9.2.2. SQ2: standardization forms and perceived outcomes across the six cases

All six programs achieved meaningful standardization depth relative to their pre-program baselines, confirming the basic feasibility of asset standardization in the Dutch DSO context under energy-transition volume conditions, while displaying substantial variation in achieved depth and in the form standardization takes. The within-case analyses (Chapters 4–6) and the cross-case positioning in Chapter 7 (§7.3.2, §7.2.2) jointly support a three-part characterization.

First, the form of standardization is positioned along the three-axis continuum (variant reduction, prefabrication level, customer-order decoupling point) developed in Chapter 3 (§3.3.3) and applied to the six cases in Chapter 7 (§7.2.2). Variant reduction is the common standardization mode and the axis along which depth differentiates most clearly, whereas prefabrication and pre-assembly are near-universal. Modular architecture is not a graded differentiator across the portfolio. Demand-driven modular catalogs are only partially visible in case A.1's configuration-tool logic, and the transportation station (C.2) appears modular mainly because of on-site block assembly and interface decomposition. The dominant empirical pattern is instead bounded article-number consolidation.

Second, standardization in the DSO context takes the form of a nested layering of product, process, and organizational standardization, in which product standardization holds only where process standardization accompanies it and process standardization holds only where organizational standardization (the three-tier governance architecture) accompanies it. This reading is developed in Chapter 7 (§7.2.3) and is consistent with Aapaoja and Haapasalo (2014) and Gibb (2001).

Third, perceived outcomes across the six cases align with literature predictions: procurement cost reduction through volume consolidation, schedule predictability through reduced per-project design work, and quality predictability through repeated validated configurations. However, the absence of systematic before-and-after measurement infrastructure at all three DSOs means these outcomes are reported as practitioner perceptions rather than verified quantitative findings. This measurement absence is itself a substantive finding, taken up in Section 9.6.5.

9.2.3. SQ3: patterns of convergence and divergence across DSOs

The three station programs face structurally similar challenges that they manage to different degrees of success. The cross-case analysis (Chapter 7, §7.3) established that engineering culture resistance, spatial non-conformance, municipal interface friction, procurement regime management under European public procurement law, and supply chain concentration trade-offs are all present at all three DSOs. This indicates that variance in achieved depth cannot be attributed to differences in the challenge environment. The primary differentiating variable is governance architecture, and the within-DSO C.1/C.2 contrast independently corroborates this by showing that the same organization achieves adequate depth at C.1 and inadequate depth at C.2 under an unchanged governance model, the difference explained by the higher governance demand of the transportation station asset category.

Two convergent sector-level findings extend this answer. First, the benefit measurement gap is structural and universal at all three DSOs, a sub-finding of Theme 1 (Chapter 7, §7.5.1). Second, cross-asset interface governance is an undocumented responsibility at all three organizations.

9.2.4. SQ4: organizational structure and governance design

The answer to SQ4 integrates the three cross-case themes from Chapter 7 with the five Phase 4 refinements from Chapter 8. Theme 1 identifies governance architecture as the primary observed correlate of implementation depth: the three-tier construct of normative commitment, procedural cross-functional alignment, and structural compliance enforcement is the organizational design characteristic most strongly associated with sustained depth. Asset complexity and urgency shape the governance demand that must be met but do not determine whether it is met. Theme 2 identifies organizational fragmentation as an emergent multi-source construct (merger origin, workforce transition, regional engineering tradition) that is a structural co-determinant of governance demand alongside asset complexity. Theme 3 identifies inherent variability arising from grid history, site conditions, municipal interface demands, exogenous regulatory and technological discontinuities, and project-type asymmetries as a third structural context factor that prevents complete standardization in principle and requires governance design at two levels: foreseeable variation internalized into the standard at the design stage, and standardized deviation pathways for the residual unexpected variation (Chapter 7, §7.5.3).

The three themes form a system (Chapter 7, §7.8.1): fragmentation sets the internal governance demand; inherent variability sets the external governance demand; governance architecture is the capacity that must meet both demand streams and that matures across procurement cycles through the process-model dynamic of Chapter 7 (§7.7.6). The Phase 4 refinements (permanence proposition, friction asymmetry across three institutional implementations, release cycle alignment, two-sided urgency, growth-rate moderator) sharpen the system without altering its structure.

9.2.5. Main research question

The main research question asks how organizational structure and governance design shape the implementation of asset standards by Dutch DSOs in LV/MV grid construction projects.

Dutch DSOs implement asset standards through a combination of internally defined product specifications, deviation procedures, and procurement-anchored governance arrangements, achieving meaningful variant reduction across the portfolio and varying levels of upstream movement on the customer-order decoupling axis (SQ2). The implementation barriers that recur across organizations are not fundamentally different in kind (SQ3) but are managed to different degrees of success through governance architectures of varying completeness (SQ4). Sustained implementation depth requires a three-tier governance architecture, calibrated to the asset complexity profile and the organizational fragmentation baseline, accommodating for inherent (external) variability, through the demand–capacity logic of Chapter 3 (§3.3.3). Standards deliver their intended perceived benefits under conditions in which this architecture is established before volume scaling begins. The sequencing principle of governance-before-scale is the single most operationally consequential finding the study produces.

9.3. Main finding: governance-as-fit

The main finding of this thesis is that implementation depth in internal asset standardization is best explained by *governance-as-fit*: the match between the governance demand created by the asset and organizational context, and the governance capacity supplied by the standardization program's governance architecture. The framework itself was developed in Chapter 7 (§7.8) and validated and refined in Chapter 8. It is therefore summarized here rather than introduced as a new construct.

The governance demand side consists of three conditions. Asset complexity determines how much coordination, interface management, and lifecycle control the standard requires. Organizational fragmentation determines how difficult it is to make a single standard authoritative across engineering traditions, regional practices, and distributed decision rights. Inherent variability determines how large the legitimate non-standard envelope remains even after the standard has been well designed. These conditions do not undermine standardization in themselves; they determine the intensity and form of governance required for standardization to reach depth.

The governance capacity side is the three-tier governance architecture. The normative tier makes the standard authoritative; the procedural tier converts authority into cross-functional decision routines, release cycles, deviation adjudication, and feedback loops; and the structural tier makes the standard the path of least operational resistance. Chapter 8 confirms and sharpens this architecture through the permanence proposition, the friction-asymmetry principle, release-cycle alignment, the two-sided urgency finding, and the growth-rate moderator.

The core implication is that governance architecture is not a universal maturity ladder. A configuration that is sufficient for a low-complexity and low-fragmentation profile can be insufficient for a semi-complex or very complex asset, or for the same asset under higher fragmentation. This is why the C.1/C.2 contrast is theoretically decisive: within the same DSO, the governance architecture that delivered adequate depth for a compact-station program did not deliver adequate depth for the transportation-station program. The difference was not whether standardization was desirable, but whether the governance capacity fitted the demand profile.

The governance-as-fit prescription map in Chapter 7 (Figure 7.5) translates this logic into a practical reference. Every profile inherits the same core architecture: all three governance tiers, a governed deviation pathway, interface-level verifiable specifications, and co-tendered commitment with procurement, supply chain management, and operations. The cells then add modifiers for increasing asset complexity and organizational fragmentation. The map is intentionally presented as a prescriptive heuristic rather than a deterministic algorithm, because only some cells are strongly evidenced across multiple cases while others are single-case projections or extrapolations requiring future empirical testing.

The framework also provides the boundary condition for the thesis's practical recommendations. Standardization is not unconditionally beneficial. Where asset complexity, contextual misfit, organizational fragmentation, or premature urgency push governance demand beyond available governance capacity, the appropriate response is not to scale the standard and accept shallow implementation as transition cost. It is to defer adoption, narrow the standardization envelope, or invest in governance capacity before scaling. The recommendations in Section 9.4 therefore translate governance-as-fit into program-management prescriptions rather than treating standardization as a one-size-fits-all improvement strategy.

9.4. Practical prescriptions for DSO program managers

The framework, proposed in Chapter 7 and summarized in Figure 7.5 produces seven prescriptions organized around the decision points a program manager faces across the lifecycle of a standardization program, from pre-initiation commitment through specification design and execution to long-run sustainability and lifecycle adaptation. They are applicable to Dutch DSOs operating under comparable institutional conditions; generalizability beyond this scope requires the empirical testing of Section 9.8.

9.4.1. Before initiation: establish governance infrastructure first

The single most consequential governance investment a DSO can make is establishing the normative and procedural tiers before beginning volume-scale deployment. The minimum viable pre-deployment architecture for a semi-complex asset program consists of a named ownership body with formal specification authority, a cross-functional team that must reach documented agreement before any specification is finalized, a formal deviation-request process that places the burden of proof on the requester, and a release cycle plan aligned to the implementation chain's planning horizon. Senior organizational commitment at Board of Directors level is the most effective accelerator and should be sought before program execution begins rather than retrospectively when compliance problems emerge. Practitioner testimony from DSO-C articulates the sequencing logic directly: "in my view you should conceive the standard in advance and then develop and design; but we have not had that phase, so we are learning while we are developing." Programs that skip the pre-deployment governance phase do not eliminate it; they incur it during execution at higher cost.

The deviation-request process is most effective when the default response of the technical-governance body is to push back rather than grant: the requester must demonstrate that standard alternatives have been exhausted before a waiver is considered, and the decision on whether the deviation is genuinely necessary is made by a separate higher layer. This two-stage configuration, observed independently at DSO-B and DSO-C, channels the substantive burden of proof onto the requester while preserving adjudicative authority for cases where deviation is technically warranted.

9.4.2. During execution: prefer institutional to behavioral compliance mechanisms

Behavioral compliance mechanisms (team-based deviation review, manager approval gates, professional norm reinforcement) are valuable but structurally insufficient as primary instruments. They degrade under management turnover, peak workload, and organizational pressure in ways institutional mechanisms do not. The structural tier should therefore be established as early as operationally feasible. The friction asymmetry principle provides the design logic: make standard configurations structurally easier to order than non-standard ones, placing the burden of extra effort on the deviation. For programs where IT-mediated ordering constraints are not yet available, supply chain lead-time asymmetry through procurement integration achieves comparable compliance effects, on the precondition that supplier relationships are sufficiently integrated to prevent value capture from offsetting the lead-time gradient (Lyons & Roulstone, 2018).

9.4.3. Anchor the standard procurement-side: co-tendering across asset management, procurement, supply chain, and operations

A specific institutional compliance mechanism warrants its own treatment because the cross-case evidence positions it as disproportionately consequential. The DSO-C program achieves approximately 90 per cent compliance on the compact-station portfolio through a tendering route in which the standard is jointly tendered by asset management, procurement, supply chain management, and the operations production chain, rather than specified by asset management alone and handed to the other functions for implementation. Expert validation participants from DSO-C named this the single most consequential governance design choice in their program (Chapter 8, §8.2.2). It is structurally distinct from cross-functional pre-authorization at the specification stage (§9.4.1) because it shifts ownership to the implementation chain at the moment of procurement commitment, not afterwards: production chains that co-tendered the standard treat it as their own object, whereas chains that received a finished specification treat it as an external imposition they negotiate against. It is also distinct from the behavioral mechanisms §9.4.2 cautions against, because it embeds compliance in the procurement architecture itself rather than relying on team-based review or manager approval. The DSO-B experience indicates the inverse: standards specified by asset management without procurement-side co-ownership are visibly bypassed in operational execution, which the DSO-B program names as its largest current implementation challenge. The prescription is therefore not merely to involve procurement and operations in specification authoring but to share tendering authority with them at the moment of commitment.

9.4.4. Design the standard for change: interface-level specifications and verifiable test protocols

The specification architecture of a standard shapes the cost of absorbing the changes it will inevitably encounter. Two design principles, both validated independently in the case material, convert frequent disruption into bounded update.

The first is *interface-level design*. A standard specified around the components of a single supplier or supplier generation absorbs every component change as a forced costly deviation; a standard specified at the level of the functional interfaces between components absorbs the same change as a bounded specification update. The Phase 4 reframing of supplier dependency formalizes this: dependence on a single supplier or supplier generation is largely a consequence of specification architecture rather than an externally imposed market constraint, and is therefore addressable through specification design (Blind, 2004) (Chapter 8, §8.2.2). The cross-case evidence indicates that two-supplier qualification is the minimum operating margin and three suppliers is the more robust target, with the SF_6 phase-out at DSO-A demonstrating that single-supplier dependence converts an exogenous regulatory discontinuity into a delivery-blocking event in ways that interface-level multi-supplier qualification prevents. European public procurement law sets an institutional floor under this condition: regulated DSOs cannot consolidate to a single supplier even where doing so would simplify specification management, because procurement-law constraints on competition require multi-supplier qualification to be preserved as an enduring feature of the operating environment. The appropriate response is precision specification and tactical regional allocation, not supplier reduction; supplier-induced variability is not a governance failure but a structural condition that specification design must accommodate.

The second principle is *verifiability of specification requirements*. The cross-case material contains two structurally parallel failures of specifications that were technically correct but operationally unenforceable: the watertightness failure at DSO-A in 2024 originated in first-generation tender language that stated a requirement without an accompanying physical test protocol, allowing suppliers to self-declare compliance against an unverified specification (Chapter 4, §4.2.2); and the cable-color ambiguity at DSO-B, where "grey" as a tender specification accommodated multiple RAL gradations, produced compliant deliveries that nonetheless required field workaround. The prescription that follows is that every specification requirement should be paired with a verifiable test or acceptance protocol within the tender document. A requirement without an associated proof-of-compliance procedure has no operational force; it is a documented expectation rather than an enforceable commitment. The DSO-B reframing captures the principle in operational form: "if the standard is designed so that it can absorb the kinds of changes it will face, the problem doesn't even exist" (Chapter 8, §8.2.2). Interface-level design and proof-of-compliance protocols are complementary: the first reduces the frequency at which deviations are required, the second ensures that deviations that do occur are caught at the procurement gate rather than at field installation.

9.4.5. Manage the chain: release cycle alignment, contractor governance, and external interface asymmetry

Contractor friction is a predictable feature of any standardization program involving external implementation partners, and the cross-case material indicates it is often where compliance breaks down rather than within the DSO itself. Contractors operate across multiple DSO programs with their own qualification processes and procurement rhythms; specification changes that arrive at irregular intervals impose a recurring cost the contractor absorbs incompletely, producing the partial-implementation pattern observed across the cases. The DSO-A experience indicates that two low-cost, high-return investments resolve most of it: a fixed release cycle (semi-annual in DSO-A's case) communicated in advance and aligned to the contractor planning horizon, and representation of a fixed DSO contact in the contractor community's change-management forum. Together these convert the contractor interface from a recurring source of friction into a governed exchange. The same logic applies to the AM-to-operations interface internal to the DSO.

A boundary condition warrants attention. Internal DSO governance architecture interacts with external counterparties whose capacity is outside DSO control. Steekelenburg (2024) documents systematic asymmetry in DSO-municipality collaboration capacity, with larger municipalities better resourced than smaller ones to engage substantively. Even structurally complete three-tier arrangements at the DSO side therefore encounter a capacity-asymmetric external interface the DSO cannot unilaterally compensate for; recommendations directed at internal governance must be paired with sector-level coordination on external-counterparty engagement.

9.4.6. Sustain the program: measurement infrastructure, knowledge management, and cross-program interface coverage

Long-term sustainability rests on three frequently deferred but structurally critical governance investments. The first is *measurement infrastructure*: programs that cannot demonstrate their performance outcomes in measurable terms are structurally vulnerable to resource diversion during budget cycles. Establishing compliance rate tracking, variant reduction measurement, and project-level schedule and cost tracking as standard program governance activities converts the benefit measurement gap from a vulnerability into a governance asset and restores the cross-cycle improvement dynamic where it has stalled. Practitioner testimony from DSO-B indicates the gap is not only an infrastructure absence but an accountability absence: "what I find strange is that nobody at our leadership level has asked us to evaluate this, not at all", locating the gap as much in the program-management interface as in the analytical toolkit. A related prescription follows: program-level standardization KPIs should be reported by segment (greenfield versus brownfield, asset-class, and complexity tier) rather than as a single portfolio-wide depth percentage, because blanket portfolio-wide targets are structurally unrealistic given the greenfield-brownfield asymmetry developed in Theme 3 (Chapter 7, §7.5.3) and risk producing perverse incentives at the segment boundary. The second investment is *specification traceability and knowledge management*: every specification requirement should exist as a discrete, documented decision with a recorded rationale, so that reasoning is accessible to newly hired engineers and successive specification managers. This is most consequential under high growth-rate fragmentation, where rapid hiring continuously replenishes the population of engineers unfamiliar with specification rationales.

The third investment is *cross-program interface coverage*. For asset programs high on the external-interface-count dimension of the asset complexity construct, governance must extend beyond the program's own scope. Three components are implicated: interface specification authority must be assigned in advance for every adjacent asset class; interface change management must be synchronized across adjacent asset classes; and interface escalation paths must be documented before the program scales. The transportation station case illustrates each tier of interface ownership (TenneT-side external interface, DSO-internal cross-function interface, asset-class-internal interface). The within-DSO systems-of-systems observation recurring across the case interviews (one program's interfaces shape another program's design space) is, on this reading, the operational signature of a high-interface-count asset program operating without cross-program interface coverage.

9.4.7. Plan for lifecycle adaptation and recognize the limits of consortium governance

Governance architecture should be designed for adaptation across the program lifecycle rather than for permanence. The current architecture is calibrated to a high-demand regime where structural-tier investment is amortized over many deployments; under a future lower-demand regime, that fixed cost may amortize over fewer projects and some structural mechanisms may become harder to justify economically. This does not imply a return to bespoke delivery. It implies reassessing the program's position on the standardization continuum: variant reduction should generally be retained, while make-to-stock and full pre-assembly positions may need to be reconsidered where volume no longer supports them. The same logic applies to modularization. In the DSO context, modular flexibility should not be treated as a goal in itself. The successful programs in this study primarily follow article-number consolidation rather than modular option proliferation. Programs should therefore use modular decomposition selectively, for example where very-high asset complexity or interface ownership makes it necessary, but should avoid rebuilding broad option catalogs that recreate the variant-management burden the standard was meant to remove. Explicit reassessment points should be built in after governance maturation, at demand-regime transitions, and when the supplier base or regulatory environment changes.

A specific organizational design pattern emerges from the cross-case material as one means of operating the lifecycle-adaptation prescription concretely. The three activity types the architecture must accommodate, namely operating the frozen standard for current production, running incremental improvement cycles between procurement rounds, and exploring next-generation variants, are best served by being organizationally decoupled rather than carried by the same team and budget. DSO-A's distinction between current-tender governance and a designated innovation lot in the next tender, and DSO-C's distinction between *verbetertrajecten* (improvement tracks) and *innovatieprojecten* (innovation projects), are practitioner-named versions of this decoupling. Organizational separation prevents improvement cycles from being absorbed into operational firefighting and prevents exploratory innovation from destabilizing operational specification stability, while preserving a defined transition protocol for moving validated innovations into the operational specification at the next tender boundary.

A second component concerns sector-level extension. The CAM case (Chapter 7, §7.4.1) indicates that cross-DSO standardization is institutionally achievable through consortium governance for bounded asset categories. The consortium form has structural limits: federated arrangements lose unilateral DSO authority to revise the standard in response to deployment experience, making cross-cycle improvement harder to operate at the inter-organizational level. As one senior practitioner observed, "if achieving alignment within one organization took seven years, achieving it across the sector would probably take fifteen" (Int. A-1). Extending consortium governance to more complex asset categories would require a sector-level specification authority with binding mandate, an institutional design that does not currently exist in the Dutch DSO sector. The prescription is therefore not to expand consortium governance reflexively but to recognize that voluntary arrangements have a maximum effective scope above which binding mandate structures become necessary.

9.5. Theoretical contributions

Chapter 1 (§1.3.1) identified three primary literature streams the thesis enters: construction industrialization and capital-project standardization; innovation diffusion and implementation theory (Klein and Sorra, Rogers); and contingency theory and organizational design (Donaldson, Shenhar). The contributions are stated below in that order, followed by a compact summary of additional contributions to adjacent literatures the empirical work touches without entering as primary targets.

9.5.1. Contribution to construction industrialization and capital-project standardization

The contribution to this stream is the specification of the institutional architecture required for sustained implementation depth in regulated network infrastructure. The existing literature consistently reports that standardization produces performance benefits and that implementation challenges exist (Choi, Shrestha, Kwak, & Shane, 2020a; Gibb, 2001) but does not theorize the governance architecture required to achieve and sustain those benefits in regulated multi-stakeholder infrastructure contexts. This study specifies the three tiers (normative, procedural, structural) that are individually necessary and jointly sufficient for sustained depth, and indicates empirically that programs with incomplete architectures achieve systematically lower depth than those with complete ones, holding asset complexity constant. Cross-context evidence from Norwegian public-infrastructure programs supports the centrality of the procedural tier: Økland et al. (2018) find that the dominant time savings from standardized building concepts accrue in the planning and stage-gate phases through re-use of tendering documentation and simplified quality assurance, rather than in on-site execution. The pattern is consistent with the three-tier architecture: depth is shaped less by the artifact being standardized than by the procedural infrastructure surrounding its adoption and deployment.

The contribution can be stated more sharply in nested-layers terms: product (asset) standardization in regulated network infrastructure operates as a nested product–process–organizational system in which depth varies primarily with the depth of the surrounding process and organizational layers rather than with the design quality of the asset standard itself. The permanence proposition (Chapter 8, §8.2.1) adds that the appropriate evaluation criterion is whether the architecture keeps challenge frequency and cost at an organizationally acceptable level, not whether challenges have been resolved. The benefit measurement gap (Chapter 7, §7.5.1) adds that measurement infrastructure is itself a governance dimension requiring explicit institutional design. Its cross-sector recurrence reinforces this: Gibb and Isack (2001) report from 59 UK construction clients that few had meaningful means of measuring project success and that most reported benefits were qualitative and unsubstantiated; Shrestha et al. (2020) report a related upstream finding that the formal feasibility-analysis CSF (requiring NPV and life-cycle benefit quantification before adoption) was the least-accomplished of fifteen standardization CSFs across 43 capital projects. The gap operates symmetrically across the standardization cycle, and the framework's prescriptions on measurement infrastructure address both ends.

A second contribution to this literature concerns the relationship between standardization and modularization. Construction-industrialization literature often treats standardization and modularization as complementary requirements for industrialized delivery. The DSO evidence qualifies this assumption. In a captive-customer, regulated network-infrastructure context, the dominant strategy is not demand-driven modular variety but article-number consolidation: cases converge on small bounded sets of approved variants, while residual project variation is absorbed through site-side adaptation, bounded variant menus, specials categories, and governed deviation pathways. This does not mean modularity is irrelevant. Rather, its function changes. For semi-complex assets, modular option catalogs risk re-importing the variant proliferation that standardization is intended to reduce. For very-complex assets, such as the transportation station, block decomposition and interface-level modularity may be necessary for assembly and supplier coordination, but this is not the same as a customer-facing modular variety strategy. The contribution is therefore to decouple asset standardization from modularization as a universal joint requirement: in the DSO setting, article-number standardization can partially substitute for modular architecture where demand-side variety has no commercial value and make-to-stock economics penalize large configuration spaces.

A third element is the four-stage standardization process model developed in Chapter 7 (§7.7). The model synthesizes elements from standardization theory (van de Kaa, 2023), capital projects (Choi, Shrestha, Kwak, & Shane, 2020a; Gibb, 2001), and the business-process management literature (Reif et al., 2018) into four phases: (1) adoption, (2) development and design, (3) operational use, and (4) management and governance. The model itself is a synthesis rather than an invention; the contribution sits in the empirical overlay the cross-case material supports, which specifies that the bottleneck distribution is asymmetric: bottlenecks concentrate in phases 2 and 3a, while phase 1 is essentially uncontested and phase 3b primarily exhibits symptoms whose root causes originate upstream. The contribution is therefore not a new process model but an empirically anchored claim about where analytical attention should sit for internal asset standardization in regulated infrastructure.

A fourth element concerns inherent variability and standardized deviation pathways. The Theme 3 finding (Chapter 7, §7.5.3) is that asset standardization operates against an irreducible residual variability no governance investment can eliminate. The construction-standardization literature has tended to treat such residual variation as friction to be minimized (Choi, Shrestha, Kwak, & Shane, 2020a) or as the "approximately 20%" of cases outside the standard envelope (Gibb & Isack, 2001), without theorizing the deviation pathway as a governance object in its own right. The contribution this study advances is two-layer: the same three-tier architecture must be deployed twice, once to govern the standard and once to govern the standardized deviation pathway that absorbs the irreducible residual, with the boundary between standard-internalized and exception-routed variation set deliberately at the design stage. The strongest-depth programs (DSO-A's configuration tool, DSO-C's article-number consolidation with a bounded specials category) operate the two layers jointly. Production delivery strategy operates as a mechanism-activation moderator within this argument: the cross-case evidence supports the analytical separation of implementation depth from production delivery strategy as two empirically distinct continua, with M1 and M4 activating at the specification level regardless of CODP position while M2 and M3 reach their theoretical maxima only when production decoupling has moved upstream of the customer order (Wikner & Rudberg, 2005). The move from engineer-to-order toward make-to-stock that the regulated DSO setting instantiates is an under-addressed direction of CODP movement.

9.5.2. Contribution to innovation diffusion and implementation theory

The three-tier governance architecture sharpens Klein and Sorra (1996)'s implementation framework. The adoption–implementation distinction was pre-specified as analytical scaffolding (Chapter 1, §1.3.1); the parallel between the three tiers and their composite implementation-climate construct is recognized in hindsight rather than derived. The contribution is that the architecture disaggregates implementation climate into three structurally distinct tiers that fail and recover independently rather than as a single bundle: the normative tier can hold while the procedural tier is underdeveloped, and both can hold while the structural tier is absent. This specifies the substrate-level heterogeneity of implementation climate as a governance variable rather than a culture variable. The contribution is to construct space, not path-coefficient testing, which the qualitative, small-N design cannot support.

A second extension articulates how the model decomposes by organizational level. For internal technical standards in DSOs, choice and diffusion (in the sense of Rogers, 2003) operate primarily at the strategic level, where the board-level adoption decision is settled; development, design, and acceptance or enforcement operate at the tactical or program level as the implementation of that prior adoption; and operational use and its visible impacts manifest at the project level. The strategic-tactical-operational decomposition therefore extends the adoption–implementation distinction by giving it an explicit organizational-level structure rather than leaving implementation as a single composite process. The cross-cycle improvement dynamic (Chapter 7, §7.7.6) adds the dynamic dimension Klein and Sorra's static path model does not theorize: the standard and its governance architecture co-evolve across procurement cycles through the phase 2 and phase 3a channels of the process model, and the measurement gap is the most consequential structural constraint on how productively that maturation runs.

9.5.3. Contribution to contingency theory and organizational design

Contingency theory has been applied extensively to manufacturing, construction, and project management (Donaldson, 2001; Shenhar, 2001), but its application to the governance of regulated network infrastructure standardization programs is underdeveloped. The contribution operates through three extensions. The first identifies asset complexity and organizational fragmentation as joint moderators of governance architecture requirements through the demand-capacity model. The within-DSO C.1/C.2 contrast indicates that the same architecture can be simultaneously adequate for a moderate-complexity asset and inadequate for a very complex one within the same organizational context, supporting the dual-moderator framing. The second introduces organizational growth rate as a contingency variable that modulates governance maintenance investment requirements, bridging standardization governance theory and workforce governance theory in a way not previously theorized. The third is dynamic-fit reasoning: the cross-cycle improvement dynamic provides a dynamic extension of contingency theory largely absent from the static fit models dominant in the existing organizational- design literature. Shenhar (2001) provides the closer methodological precedent within project-management contingency theory: his demonstration that appropriate management practice varies with project classical-contingency dimensions, and his treatment of project arrangements as context-conditional, anticipates this dynamic-fit reasoning. The two-sided urgency finding sharpens the dynamic dimension by specifying that the same urgency variable operates in opposite directions depending on its sequencing relative to governance infrastructure.

9.5.4. Additional contributions to adjacent literatures

Two adjacent literatures, identified in Chapter 1 (§1.3.1) as relevant but not as primary contribution targets, are touched by the empirical work and warrant brief mention.

Infrastructure governance and energy transition. The empirical material indicates that policy-driven urgency interacts with internal standardization governance in DSOs at a meso level largely absent from existing system-level transition analyses, which tend to focus on either macro-policy dynamics or micro-technological substitution. Transition-driven urgency strengthens governance investment when architecture is sufficiently developed but exacerbates deviation and implementation fatigue when capacity lags the demanded pace of change. The persistence of engineering culture resistance and merger-origin fragmentation over time, rather than as temporary transition friction, is consistent with Markard (2011)'s account of infrastructure sector transformation as a reconfiguration of sector-level routines and institutional arrangements rather than a sequence of discrete technological substitutions. The CAM case further illustrates how transition pressures are mediated through governance design by highlighting federated cross-DSO standardization as a distinct governance form that operates alongside, rather than within, individual DSOs' internal architectures.

Classical standardization theory. In contrast to the market-adoption standards of the smart-grid and information-system literature (Van de Kaa et al., 2021; van de Kaa, 2023) and the external-standards focus of classical standardization theory (Blind, 2004), internal DSO asset standards are owner-created living catalogs maintained through organizational authority. Their institutional dynamics are accordingly those of organizational governance rather than standards-war diffusion. This positioning establishes the boundary between this thesis and the standards-formation literature, and identifies the under-theorized space of internal, organizationally maintained standards in regulated infrastructure as one where the institutional-theoretic vocabulary of compliance basis (along the lines of Scott (2014)) may extend, an extension taken up as a future research direction in Section 9.8 rather than claimed as a contribution here.

9.6. Limitations

9.6.1. Scope and analytic generalizability

This study covers three Dutch DSOs and six embedded cases within a single national regulatory context. The analytical generalization it produces (Yin, 2018) applies to Dutch DSOs and, by theoretical extension, to regulated network infrastructure organizations in comparable institutional environments. Transfer is most defensible to regulated network infrastructure DSOs in comparable European procurement-law contexts, to organizations formed through merger of multiple predecessor utilities, and to asset categories falling within the low to semi-complex range. Transfer is least defensible to deregulated infrastructure organizations, to organizations without significant merger fragmentation, and to very-high-complexity asset categories where the within-portfolio evidence base is limited to a single case. The framework requires empirical validation before application to DSOs in other national regulatory regimes or to other infrastructure sectors.

9.6.2. Internal validity and triangulation

A two-source triangulation standard was applied throughout: a finding was treated as a cross-case pattern only when independently corroborated by evidence from at least two cases or two interviewees in different organizational positions. The study did not employ inter-coder reliability testing, so the analysis relies on within-coder consistency rather than inter-coder agreement. The expert validation session provides a partial counterweight: the cross-case findings were tested for recognizability by senior practitioners not involved in the within-case interviews.

A further reflection concerns the composition of the SLR corpus. The Choi, Shrestha, and related papers that account for a substantial share of the systematic factor inventory are peer-reviewed publications in established construction-management journals; their epistemic status as scholarly outputs is solid.

What is narrower is the corroboration base behind them: a number of these publications are outputs of the Construction Industry Institute's research team RT-UMM-01 on facility standardization in capital projects, and they draw on a shared empirical foundation of CII-member surveys and workshops. Independent replication by research teams outside this program is limited. The empirical phases therefore treat the SLR-derived factor inventory as a well-grounded candidate list of sensitizing concepts rather than an externally validated set of causal determinants, and the Phase 1 consultant interviews function in part as a cross-check against a different empirical base.

9.6.3. Phase-design, instrument, and data-source limitations

Several further methodological limitations affect different phases of the design. First, the Phase 1 expert interviews were conducted with five consultants drawn from a single consulting firm's utilities and operations practice. This homogeneity may have introduced shared analytical conventions into the Phase 1 sensitizing concepts; the empirical phases drew exclusively on DSO practitioner data with the cross-case framework constructed inductively from that data, which mitigates but does not eliminate the risk. Second, the 14-challenge inventory presented to expert participants in Phase 4 (Appendix E.1.2) reflects the analytical state at the point of session preparation rather than the final cross-case formulation. Continued analytical work consolidated some working challenges into single categorical entries and re-organized the inventory into four clusters; the session should accordingly be read as confirming the substantive content of the cross-case findings rather than the precise structural enumeration. Third, the cross-case analysis uses comparison matrices in the tradition of Miles and Huberman (1994); the matrices are presented in the cross-case appendix material rather than embedded in the narrative, which keeps the analytical line in the body intact at the cost of placing the scaffolding one appendix step away. Fourth, document analysis was substantially less developed than initially planned. Documents functioned contextually rather than as a co-equal analytical source, and quantitative performance indicators were available sparingly; triangulation was therefore primarily within the interview corpus rather than across data-source types. The structural absence of systematic before-and-after KPI infrastructure is itself a finding (the measurement gap, Theme 1) and is the underlying reason quantitative triangulation could not be operated more strongly. Fifth, across all three DSOs the operating governance machinery depends substantially on one or two key individuals who carry both the specification knowledge and the informal organizational authority to enforce it; this concentration of capability is not currently captured in the framework as a governance design variable and would warrant explicit treatment in further work on the institutional resilience of internally governed standards, as a boundary-spanning role pattern.

9.6.4. Data asymmetry and case complexity imbalance

Interview depth and documentary access varied across the six cases. The portfolio is also imbalanced on the asset complexity dimension: one very-complex case, three semi-complex, and two lower-complexity. The very-complex tier is represented by a single case, meaning the framework's prescriptions for very-complex assets rest on within-case evidence rather than cross-case triangulation, and should accordingly be treated as more provisional than its claims about semi-complex and low-complexity assets. The within-DSO C.1/C.2 contrast that drives the demand-capacity argument arises within DSO-C only and cannot be cross-validated against equivalent within-DSO contrasts at DSO-A or DSO-B.

9.6.5. Temporal snapshot and the measurement gap as limitation

All data reflects a specific moment in rapidly evolving programs. The full governance effects of DSO-B's board-level modular mandate and DSO-C's co-tendering program were not yet fully observable at the time of data collection. The benefit measurement gap, also a substantive finding (Theme 1, Chapter 7, §7.5.1), is simultaneously a limitation of the evidentiary basis: the absence of systematic outcome measurement at the case organizations is what prevents the study from quantitatively verifying the perceived benefits. The framework's governance mechanism logic does not depend on quantitative outcome data, but its prescriptive claims rest on practitioner perception and corroboration rather than verified outcome data.

9.7. Reflection

This section complements the introductory positioning of the thesis within the Management of Technology (MOT) program (Chapter 1, §1.6.1) with a backward-looking reflection on the research process, on the MOT curriculum as it shaped this work, and on what an interdisciplinary topic of this kind implies for the MOT program itself.

9.7.1. Methodological hindsight

Three case-design choices would be made differently with the framework now in hand. First, the portfolio would be balanced more deliberately on the asset-complexity dimension, with at least one transportation-station-equivalent very-complex case at DSO-A or DSO-B in addition to the C.2 case at DSO-C. The within-DSO C.1/C.2 contrast was an unanticipated analytical opportunity rather than a designed feature of the case selection; future designs should build it in deliberately. More fundamentally, with the governance-as-fit framework now explicit, alternative case selection would not only balance asset complexity but also deliberately sample programs with contrasting governance architectures (for example, presence versus absence of structural-tier enforcement). This would turn what became an *ex post* explanatory dimension into an *ex ante* sampling axis and strengthen the link between case design and the theoretical propositions.

Second, the within-case data collection would have included explicit attempts to elicit existing KPI data even where systematic measurement was absent, to provide partial quantitative triangulation. Relatedly, the study leans more heavily on interview data than originally intended. With more time, I would invest earlier in negotiating access to internal KPI dashboards, project evaluations, and governance documentation, and add limited observation of specification or program meetings. Even given the measurement gap documented in Section 9.6.5, this would have allowed richer documentary and (where feasible) quantitative triangulation, reducing the current dependence on practitioner perception for assessing mechanism activation.

Third, the Phase 1 consultant panel was drawn from a single consulting practice; a diversified Phase 1 design including DSO internal strategy staff, Netbeheer Nederland representatives, and at least one contractor-side respondent would have surfaced sector-level dynamics this thesis addresses only indirectly.

While these alternatives would have strengthened the design, I also value the exploratory and open-ended character of the approach actually taken. Working with a relatively broad, qualitative design made it possible to surface and connect dimensions that were not specified *ex ante* and to locate where the analytical weight of the findings is justified. In that sense, the design contributed directly to developing a structured view of the standardization landscape at Dutch DSOs and to articulating the explanatory relationship between implementation depth and the underlying organizational characteristics and governance design.

9.7.2. Contribution of the MOT curriculum to this thesis

The MOT curriculum provided most of the analytical and practical tools used in this thesis. Research Methods (MOT2313) supplied the methodological vocabulary for the comparative case-study design, the systematic literature review protocol, and the qualitative content-analysis approach. Inter- and Intra-organizational Decision-making (MOT1452) offered the conceptual frame for distinguishing strategic, tactical, and operational decision layers, which underpins the three-tier governance architecture and the role-typology used in the case chapters. Leadership and Technology Management (MOT121A) introduced organizational culture and broader implementation-climate thinking, applied to several lenses in analysis. Integration Moment (MOT1003) provided practical experience in interviewing industry experts, translating their concerns into analytical categories, and formulating grounded recommendations, which directly informed the design and conduct of the Phase 1 and Phase 2 interviews. Finally, Technology, Strategy and Entrepreneurship (MOT1435) gave an early understanding of how innovations and standards diffuse within and across firms, allowing me to connect DSO asset standards to the wider innovation and standardization literatures rather than treating them as a purely technical design problem.

9.7.3. Implications for the MOT program

The substantive object of this thesis sits at the intersection of three literatures: construction industrialization and capital-project standardization, innovation diffusion and implementation theory, and contingency theory and organizational design. The second is of particular curricular interest, since the program often focuses on innovation in organizations. Two implications follow.

The first is that the MOT program's analytical strength, treating technological artifacts as embedded in organizational and institutional arrangements, transfers sufficiently to regulated infrastructure contexts usually addressed in other studies or programs. The adoption-implementation distinction, the three-tier governance architecture, and the demand-capacity logic developed here would not have emerged from a purely technical or purely regulatory framing. The second is that the MOT curriculum could strengthen its treatment of organizational transition dynamics in regulated sectors. The case organizations are neither start-ups nor commercial incumbents responding to disruptive entrants; they are regulated-monopoly infrastructure operators executing a societal mandate under tariff oversight. The transition-management dynamics in such organizations, particularly the interaction between regulatory incentives, workforce composition, and merger-origin fragmentation, differ structurally from those covered by commercial-strategy curricula.

9.8. Future research agenda

Five directions for future research follow from the study's findings and limitations. Each is stated with a testable proposition.

9.8.1. Longitudinal governance maturity tracking

The most direct extension is a longitudinal follow-up tracking the same three DSOs over three to five years to test whether governance architecture investments made during the 2021–2025 period produce measurable compliance depth improvements in subsequent procurement cycles. *Proposition:* programs that establish all three governance tiers before peak deployment volume will achieve statistically higher compliance rates in their second and third procurement cycles than programs that establish only the normative tier. A related avenue is whether the level of standardization currently optimal for high-volume grid expansion remains optimal once transition-driven demand normalizes: the high-fixed-cost, low-marginal-cost economics of the standardized supply chain may transition from advantage to overhead as project volumes decline.

The cross-cycle improvement dynamic (Chapter 7, §7.7.6) is structurally a stage process and could be tested as such. A longitudinal design with quarterly or semi-annual observation of specification updates, deviation-request volumes, and field-feedback flows across two to three procurement cycles would parameterize how fast governance architecture matures, and would allow direct comparison with the Klein-Sorra implementation path model and the Rogers innovation-decision sequence in a regulated-infrastructure setting where stage-model contributions are currently absent.

9.8.2. Cross-national comparative extension

Testing the framework in other European DSO contexts (Germany, Belgium, the United Kingdom) would establish the boundary conditions of the governance-as-fit argument. *Proposition:* organizational fragmentation, operationalized as the number of predecessor utilities consolidated into the current DSO, will be a comparably strong predictor of governance architecture completeness as asset complexity across national regulatory contexts, with the two moderators operating jointly rather than in dominance.

9.8.3. Quantitative operationalization of governance architecture components

The three-tier architecture is currently specified at the qualitative level. Developing quantitative operationalizations for each tier, for example a cross-functional team representation index for the procedural tier and an ordering compliance rate for the structural tier, would enable hypothesis testing in larger samples. *Proposition:* in a sample of 20 or more standardization programs in network infrastructure organizations, the presence of IT-mediated ordering enforcement will account for a statistically significant portion of variance in compliance rates, identifying the structural tier as one of the most significant governance determinants of implementation depth. A complementary direction examines whether the institutional-theoretic vocabulary of compliance basis (in the sense of Scott (2014)) extends meaningfully to the internal organizationally-maintained-standard setting that classical standardization theory (Blind, 2004) does not address, by treating the procedural tier as a candidate fourth basis of compliance distinct from regulative, normative, and cultural-cognitive ones. This is a future-research extension, not a contribution claimed by the present study.

9.8.4. Sector-level standardization governance

The CAM case indicates that cross-DSO standardization through consortium governance is achievable for bounded, low-complexity components. Future research should examine what governance architecture is required to extend cross-DSO standardization to semi-complex and very-complex assets, including the institutional design questions of mandate structure, specification authority allocation, and procurement coordination. *Proposition:* cross-DSO standardization transaction costs scale super-linearly with specification scope and the number of participating organizations, implying a maximum effective scope for voluntary consortium governance above which binding mandate structures become institutionally necessary. A further avenue concerns the interaction between internal DSO governance architecture and the external municipal interface: Steekelenburg (2024) examines the latter in isolation, and future research could integrate the two by studying how internal architecture choices condition, and are conditioned by, the capacity of external counterparties.

9.8.5. Onboarding governance and post-transition lifecycle

The growth-rate finding is novel relative to both the standardization literature and the contingency theory literature. A dedicated study of how compliance architecture must adapt during periods of rapid workforce expansion would develop this finding into a testable theoretical contribution. *Proposition:* in organizations hiring more than 50 new engineers per month, structural-tier mechanisms will maintain compliance rates closer to program targets than behavioral mechanisms, with the gap between institutional and behavioral mechanisms increasing monotonically with hiring rate. A related direction concerns the long-run lifecycle question raised in Section 9.4.7: whether DSO grid expansion can move toward a fully industrialized production-line mode comparable to that observed in some Asian utility contexts is a policy-relevant question this thesis cannot answer, because productization requires quantitative production-economics analysis that the measurement gap precludes, the comparator operates under institutional conditions structurally absent from the Dutch context, and productization mixes asset standardization with modularization, prefabrication, and supply-chain industrialization in ways the thesis has deliberately kept analytically separate. Future research could pursue this along three directions: quantitative production-economics modeling of standardization scale effects under explicit cost-of-capital and labor-scarcity assumptions; comparative cross-national institutional analysis examining which features of production-line utility models transfer to liberalized European regulatory environments; and supply-chain capacity studies examining whether the Dutch and broader European manufacturing base could absorb the demand profile a production-line DSO model would imply.

9.9. Concluding statement

This study set out to understand how Dutch DSOs implement asset standards in LV/MV grid construction projects, what implementation barriers arise during that process, and how organizational structure and governance design shape those barriers and the conditions under which standards deliver their intended benefits. The answer is architecturally precise: sustained implementation depth requires a three-tier governance architecture, composed of normative commitment, cross-functional procedural alignment, and structural enforcement, calibrated to the complexity of the asset and the fragmentation of the organization, and established before volume scaling begins. The energy transition imposes a deployment urgency that governance systems, once in place, can convert into compliance momentum; without that foundation, the same urgency produces deeper non-compliance and weaker benefit realization than would have occurred at lower volume.

The study contributes to the three pre-specified literature streams identified in Chapter 1, and touches two adjacent literatures. To *construction industrialization and capital-project standardization* it contributes the institutional architecture required for sustained implementation depth in regulated network infrastructure, formalizes the nested product-process-organizational system in which depth is realized, re-allocates the bottleneck distribution across a four-stage process model into the design and management-and-governance phases, and extends the standardization-and-deviation argument by specifying that the same three-tier architecture must govern both the standard and the standardized deviation pathway. To *innovation diffusion and implementation theory* it contributes a substrate-level disaggregation of Klein and Sorra's implementation climate into three structurally distinct tiers that fail and recover independently, together with an organizational-level decomposition of the adoption-implementation sequence into strategic, tactical, and operational layers. To *contingency theory and organizational design* it contributes a dual-moderator structure (asset complexity and organizational fragmentation), introduces organizational growth rate as a novel contingency variable, and extends static contingency reasoning into dynamic-fit reasoning through the cross-cycle improvement dynamic. Touching adjacent literatures, the work shows how transition-driven urgency interacts with internal governance capacity in DSOs at a meso level largely absent from system-level transition analyses, and identifies the under-theorized space of internal, organizationally maintained standards in regulated infrastructure as a setting where the institutional-theoretic vocabulary of compliance basis may extend.

The DSOs that invest in governance architecture first, treat it as the foundational infrastructure of their standardization programs, and recognize the boundary conditions under which standardization adoption should be deferred or rescoped rather than pursued universally will build faster, deviate less, sustain their programs longer, and be better positioned to extend standardization across the asset portfolio as the grid expansion demands of the coming decade intensify.

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A

Additional methodology

A.1. Use of generative AI tools

During this MSc thesis I used a generative AI assistant selectively as a writing and thinking aid. I mainly employed it as a sparring partner to test the clarity of my ideas and formulations, for example by asking whether paragraphs clearly conveyed the intended argument and requesting suggestions for making definitions or research gap statements more precise. I also used it to help reformulate my own draft text for conciseness and coherence, especially in the introduction, theory, and discussion chapters, always starting from material I had written myself. In addition, I used the tool to propose alternative phrasings for complex sentences, to improve the flow between sections, and to standardize terminology across the thesis. Occasionally, I asked for feedback on the logical structure of sections (e.g. whether the order of contributions or research questions was clear) and then adjusted my outline accordingly. Finally, in the late stages of writing, I used the assistant for light language editing, such as improving readability, consistency of tense, and minor grammar issues. All substantive research design choices, empirical analyses, and theoretical contributions were developed by me; AI support was limited to improving the articulation and presentation of ideas that I had already formulated.

B
Phase 1 additional material

B.1. Phase 1 research materials

B.1.1. PRISMA screening protocol and full-text eligibility audit log

This appendix documents the screening protocol and the per-record disposition of studies that passed abstract screening and entered full-text eligibility assessment. The corresponding aggregate counts are reported in the PRISMA 2020 flow diagram (Figure 2.1 in Chapter 2).

Screening criteria. Database identification yielded 1,481 records from Scopus and Dimensions across the search blocks. Basic formal criteria reduced the corpus to 1,165 records: journal article, conference paper, or peer-reviewed review; English or Chinese language; publication year 1990 or later; and subject classification within engineering, energy, business, environmental science, social sciences, decision sciences, or materials science. Abstract screening against the substantive inclusion criterion reduced the pool to 106 records. The inclusion criterion was that the paper substantively addresses standardization of components, products, or designs within a larger project, industry, or capital-project improvement context, including joint treatments of standardization with prefabrication, design, component, product, DfMA, production-based delivery, modular integrated construction, or facility design standardization in construction. Abstract-stage exclusion criteria were: standardization treated only at the level of technical specifications without organizational or project context; only process, quality, safety, or decision-making standardization without component- or product-level standardization; global, ISO, or international regulatory standards; contract standardization; standardized work breakdown structures; and standardization of bids or contractor selection. A full-text audit was then conducted on the 106 records: 21 were included in the synthesis sample (Table B.2), 56 were excluded after full-text reading (Table B.1), and 29 could not be retrieved within the access window. The three counts reconcile with the corresponding boxes of the PRISMA diagram.

Scope of the audit log. The audit-log table in this appendix covers the full-text assessment stage in full. Abstract-stage exclusions are reported at the aggregate level in the PRISMA flow diagram; per-record reasons at abstract stage were not retained in the working data. The abstract-screening protocol is the one stated above. The six canonical full-text exclusion categories and their counts are: standardization not central to the paper (16); adjacent concept of modularization, prefabrication, modular integrated construction, or DfMA (16); too technical or specification-level focus (11); no project context (7); out of scope due to publication quality, duplicate, or format (3); and wrong type of standard (3). Table B.1 clusters the 56 excluded studies by exclusion category, listing the included studies and the not-retrieved studies in separate panels.

Table B.1: Full-text eligibility audit log for the systematic literature review. Article IDs correspond to the record numbering used during screening; full bibliographic references for the 21 included studies appear in Table B.2.

Stage / Reason	Article IDs
Included studies (n = 21): full-text criteria satisfied	
Included in synthesis sample	18, 19, 22, 28, 33, 34, 36, 38, 40, 41, 44, 46, 47, 50, 52, 60, 61, 79, 83, 93, 100
Excluded at full text (n = 56): criteria not met, clustered by canonical reason	

continued on next page

Table B.1 continued from previous page

Stage / Reason	**Article IDs**
Standardization not central to the paper (n = 16)	3, 4, 6, 8, 13, 14, 21, 27, 31, 45, 63, 64, 66, 89, 95, 101
Adjacent concept: modularization, prefabrication, modular integrated construction, or DfMA (n = 16)	11, 26, 29, 43, 62, 67, 69, 71, 72, 73, 74, 82, 84, 87, 88, 104
Too technical: specification-level focus (n = 11)	16, 17, 32, 35, 59, 70, 81, 86, 92, 94, 103
No project context (n = 7)	75, 76, 77, 85, 98, 99, 105
Out of scope: publication quality, duplicate, or format (n = 3)	9, 25, 102
Wrong type of standard: external regulatory or ISO rather than internal asset (n = 3)	24, 51, 53
Not retrieved (n = 29): full text unobtainable within screening window	
Access constraint, not a substantive exclusion	1, 2, 5, 7, 10, 12, 15, 20, 23, 30, 37, 39, 42, 48, 49, 54, 55, 56, 57, 58, 65, 68, 78, 80, 90, 91, 96, 97, 106

B.1.2. Studies included in the synthesis sample

Table B.2 reports the 21 studies retained at full-text eligibility and forming the synthesis sample.

Table B.2: The 21 studies retained at full-text eligibility and forming the synthesis sample of the systematic literature review.

#	Short ref.	Title	Context	Type of standard
1	Y. Li et al. (2023)	Business model innovation in the construction industry: emerging business model archetypes from bathpod modularization	Construction; bathpod manufacturers; UK/European	Modularized and standardized bathroom pods and off-site production systems
2	Aapaoja and Haapasalo (2014)	The challenges of standardization of products and processes in construction	General construction; examples Nordic	Standardization of products (components) and project/process methods
3	Gibb and Isack (2001)	Client drivers for construction projects: implications for standardization	UK construction across building types	Standard and non-standard components, products, and processes
4	Choi, Shrestha, Kwak, and Shane (2020a)	Critical success factors and enablers for facility design standardization of capital projects	Industrial capital projects (e.g. energy, oil & gas)	Facility design standardization
5	Mehta (2024)	Design one, build many (D1BM) concepts in engineering, procurement, and construction (EPC)	EPC capital projects	Design-one-build-many program standardization
6	Kumaraswamy and Chan (1995)	Determinants of construction duration	General construction	Standardization as a duration determinant
7	Silka and Butyrin (2021)	Development of a system of standard designs in industrial construction	Industrial construction; Russian context	System of standard designs
8	Zuo and Yang (2024)	Digital technology of construction monitoring and quality control of prefabricated buildings	Prefabricated buildings	Digital and information standardization for prefab
9	Bayzidi et al. (2025)	The effects of BIM maturity levels on modularization and standardization in the construction industry	Construction; BIM-mature firms	Four-level standardization scale; modularization grades
10	Robinson et al. (2011)	Efficiencies in design and manufacturing for construction using shipping containers	Construction; container modular	Container-based modular standardization
11	Choi et al. (2022)	Exploring the benefits and trade-offs of design standardization in capital projects	Capital projects	Design standardization
12	Choi, Shrestha, Shane, and Kwak (2020)	Facility design standardization decision-making model for industrial facilities and capital projects	Industrial capital projects	Facility design standardization decision model
13	Choi, Shrestha, Kwak, and Shane (2023)	Facility design standardization work process and optimization in capital projects	Capital projects	Facility design standardization work process
14	Ivanovski and Repin (2001)	High voltage distribution lines, which are going through cities	Power transmission infrastructure; urban contexts	Standard high-voltage line design

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Table B.2 continued from previous page

#	Short ref.	Title	Context	Type of standard
15	Shrestha et al. (2020)	How design standardization CSFs can impact project performance of capital projects	Capital projects	Design standardization CSFs
16	Choi, Shrestha, Kwak, and Shane (2020b)	Innovative technologies and management approaches for facility design standardization and modularization of capital projects	Capital projects	Facility design standardization technologies and management
17	Choi, Kwak, and Chi (2023)	Key tasks for facility standardization work process in capital projects	Capital projects	Standardization work process tasks (extension)
18	Lyons and Roulstone (2018)	Production learning in a small modular reactor supply chain	Small modular reactors; nuclear supply chain	Modular reactor production standardization
19	Shrestha et al. (2021)	Recipes for standardized capital projects' performance success	Capital projects	Configurational analysis of CSF combinations
20	Økland et al. (2018)	Shortening lead-time from project initiation to delivery: a study of quick school and prison projects	Public-sector construction; Norway	Standard concept reuse for quick delivery
21	Gibb (2001)	Standardization and pre-assembly: distinguishing myth from reality using case study research	Construction case studies; UK	Standardization and pre-assembly across project types

B.1.3. Phase 1 industry consultant interview overview

Table B.3 summarizes the five Phase 1 industry consultant interviews. Roles are reported at the level of the consulting engagement; participants worked across multiple Dutch DSO clients, and role attribution reflects the nature of their work on standardization rather than a single specific organization. Interviews were conducted in Dutch, each approximately one hour, and audio-recorded with informed consent.

Table B.3: Phase 1 industry consultant interviews. Identifier `Int. I.1-5` is the anonymized identifier used throughout the thesis. Interviews were conducted in Dutch, each approximately one hour, and audio-recorded with informed consent.

ID	Engagement role	Standardization-relevant experience	Years	Date
Int. I.1	Consultant	Asset-management transformation and technical-standardization roll-out at one major Dutch DSO.	around 2	19 Jan 2026
Int. I.2	Consultant	Organizational design standardization and program design at two major Dutch DSOs.	2–3	19 Jan 2026
Int. I.3	Consulting program manager	Operating-model alignment and tactical standardization at major Dutch DSOs; design of cross-functional standardization teams.	8–10	20 Jan 2026
Int. I.4	Consulting manager	Systems engineering and digital information standardization across two Dutch DSOs.	around 6	21 Jan 2026
Int. I.5	Senior consulting manager	Organizational design standardization and program design at one Dutch DSO.	2–5	22 Jan 2026

B.1.4. Phase 1 industry consultant interview guide

The interview guide captures the consistent structure and the canonical question formulations that recurred across all five sessions, expressed in English rather than the Dutch in which the interviews were conducted. Each interview opened with a brief researcher introduction explaining the bridge purpose of the conversation: to translate insights from construction-sector and capital-project standardization literature into the Dutch DSO context in advance of the empirical case study phase. Interviews ran approximately one hour and were audio-recorded with consent.

Opening and orientation (approximately 5 minutes)

- Brief researcher introduction: research goal, current state of the literature review, and explicit statement of the bridge purpose (translating SLR insights into the Dutch DSO context).
- Confirm consent for recording, anonymity protocol, and use of the material in the thesis.
- Outline of the four to five thematic blocks for the session.

Block 1: Definition of standardization in the DSO context

- Could you briefly describe your professional experience with technical and asset standardization at Dutch DSOs, including the duration and scope of that experience?
- How do you define technical asset standardization, system standardization, or product standardization in the DSO setting?
- Are there situations where one of these forms exists without the others, or do they typically appear together?
- How do standardization, modularization, and prefabrication relate to each other in your experience? Are they distinct, or inherently linked?

Block 2: Effects of standardization (positive and negative)

- In your experience, what positive effects do DSOs realize or expect to realize from technical asset standardization? Examples are welcomed across cost, time, quality, safety, sustainability, and any further dimensions you wish to introduce.
- For each positive effect mentioned, what is the underlying mechanism? Why does standardization produce this effect?
- What negative effects, downsides, or trade-offs of standardization have you observed in DSO contexts?
- Are some negative effects one-time transition costs and others permanent inherent costs of the standardized approach?
- Where in the DSO value chain (asset management, procurement, construction operations, maintenance) do effects predominantly materialize?

Block 3: Underlying success factors

- What organizational, cultural, technological, or contextual factors determine whether standardization succeeds or fails in practice at DSOs?
- Probes by category if not raised spontaneously: organizational and governance factors, cultural and behavioral factors, technological and digital factors, environmental and regulatory factors, stakeholder and supplier factors.
- Are there factors whose strong presence makes standardization measurably more difficult, rather than easier?
- What conditions must be in place at DSOs for standardization programs to succeed?

Block 4: Implementation challenges in practice

- Building on the success factors discussion, what are the largest implementation challenges DSOs encounter in practice? These are typically symptoms of underlying factor configurations rather than independent issues.
- Could you describe one or two concrete situations from your own experience where standardization implementation went significantly off-track, and what you understood the root cause to be?
- Where in the DSO organization do the most serious implementation challenges typically arise?

Block 5: Tips and orientation for the case study phase

- I will be conducting case studies at three DSOs with focus on distribution station programs at all three and on cable and transport-distribution-station programs at two of them. Do you have specific tips, themes, or warning signs I should explicitly probe in those case interviews?
- Reflecting on the themes we have discussed (effects, success factors, implementation challenges), is there anything analytically important that we have not yet covered and that you would want to add before we close?

Closing

- Thank the participant.
- Confirm that follow-up questions by email may be sent if specific points need clarification during analysis.
- Confirm anonymity protocol and how the material will be used.

B.1.5. Systematic literature review codebook

The Phase 1 SLR codebook was generated through open coding of the 21 articles retained at full-text eligibility (Table B.2). After cleaning, the codebook contains 60 analytical codes distributed across four code groups, following the categorical structure used in the chapter synthesis.

Code group 1: positive effects Effects associated with asset standardization that practitioners or empirical studies report as beneficial. Organized by KPI dimension.

Table B.4: Systematic literature review codebook, code group 1: positive effects, organized by KPI dimension.

Code	Definition
Cost and efficiency	
Saving costs (general)	Reductions in capital, operational, or lifecycle costs through reuse and procurement scale.
Lower transaction and process costs	Reduced front-end coordination and tendering effort; reused documentation.
Inventory and warehouse efficiency	Smaller and more turnover-efficient inventory through commonality.
Time and schedule	
Shorter schedules and delivery times	Reduced time from design initiation to commissioning.
Schedule predictability and control	More reliable and controllable schedules across projects.
Quality, risk and safety	
Improved quality and fewer errors	Reduced workmanship variability and defect rates.
Controlled risk and increased reliability	Lower technical and project risk through proven designs.
Improved accuracy and project control	Better controllability through standardized documentation and interfaces.
Improved safety	Higher construction and operational safety through familiar components.
Operations, maintenance and learning	
Easier maintenance and operations	Common procedures, simplified field practice.
Quicker repair and less training	Faster fault-finding; reduced retraining for new designs.
Predictable and standardized O&M	Stable maintenance routines and commonality of spares.
Learning effects and experience transfer	Lessons learned propagate across repeated deployments.
Continual improvement of products and components	Iterative refinement of the standard over time.
Sustainability and circularity	
Reduced environmental impact and circularity	Material waste reduction, improved energy efficiency, predictable end-of-life.
Strategic, relational and business-model	
Enabling modularization and prefabrication	Standardization as enabler of modular and off-site approaches.
Standard product platforms and mass production	Platform reuse and mass-production feasibility.
Flexibility and value for money	Value-for-money decisions retained through configurable options.
Uniform demands and procurement benefits	Volume discounts and multi-purchase agreements.
Reduced economic risk and uncertainty	Investment concentrated on proven designs.
Reputation and expectation alignment	Track record builds stakeholder confidence.

Code group 2: negative effects Effects associated with asset standardization that practitioners or empirical studies report as adverse. Organized by KPI dimension.

Table B.5: Systematic literature review codebook, code group 2: negative effects, organized by KPI dimension.

Code	Definition
Cost and efficiency	
Higher upfront and per-unit costs	Higher cost per unit before scale realization; upfront engineering effort.
High transaction and set-up process costs	Sustained governance effort to define and maintain the standard.
Quality, risk and safety	
Design rigidity and loss of flexibility	Conflict between uniformity and project-specific variation.
Poor contextual fit and performance	Uniform designs misfit specific environmental or regulatory conditions.
Operations, maintenance and learning	
Reduced innovation and technological lock-in	Standards delay adoption of newer technologies.
Strategic, relational and business-model	
Exposure to market and regulatory changes	Large standardized investments misalign when policy or markets shift.
Governance and scoping burden	Continuous managerial effort to govern the program scope.

Code group 3: success factors Conditions, choices, or practices that the literature identifies as enablers of standardization implementation. Organized by the six clusters used in §3.1.5.

Table B.6: Systematic literature review codebook, code group 3: success factors, organized by the six implementation-factor clusters.

Code	Definition
Strategic and organizational governance	
Strategic standardization approach	Company-wide approach defining how standards are used across projects.
Management commitment to standardization	Visible senior leadership backing; burden of justification on deviations.
Dedicated standardization team	Designated team for specification and inter-project coordination.
Standardization strategy embraced by all participants	Owners and contractors jointly commit to consistent application.
Recognizing cost of establishing the standard	Explicit recognition of upfront engineering and governance cost.
Scope of standardization	Explicit choice of which systems, packages, or components are in scope.
Extent of standardized units and projects	Anticipated number of deployments; share of portfolio covered.

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Table B.6 continued from previous page

Code	**Definition**
Benefits, trade-off and risk evaluation and communication	Explicit articulation of expected benefits and trade-offs.
Degree or level of standardization	Selecting standardization levels and extent of reuse.
Project planning and early integration	
Early design engagement	Standardization addressed in early design rather than retrofitted.
Early selection of approach	Standardization approach identified early in the program lifecycle.
Early stakeholder engagement and alignment	Parties aligned and committed before specification is finalized.
Early procurement	Procurement involvement before design is final.
Time is needed to plan for standardization	Explicit planning time allocated for standardization development.
Stakeholder collaboration and culture	
Cooperation among stakeholders	Cross-stakeholder cooperation as a structural condition.
Cooperative culture through vertical alignment	Cooperative culture across owner, contractor, and supplier.
Experienced and dedicated project team	Team experience and capability related to standardization.
Stability of project team	Staff continuity across project phases.
Processes, learning and change management	
Formal lessons-learned and feedback process	Structured channel from deployment to specification update.
Discipline and value-based change control	Discipline to keep the standard intact; value-based change evaluation.
Rigorous management of change process	Formal change-management process across the standard's lifecycle.
Feasibility analysis of standardization	Feasibility analysis as a step before program commitment.
Effective processes create a basis for product use	Standardized products require repeatable processes around them.
Client, context and regulatory fit	
Type and location of project	Suitability of standardization varies with project type and site.
Compatibility of location, infrastructure and design	Compatibility of standard design with regional infrastructure.
Design adequate for environmental regulations	Standard design meets the environmental regulatory envelope.
Legal and regulatory compliance with material sourcing	Sourcing restrictions addressed during specification.
Technical design and constructability	
Constructability of standardization	Buildability of standardized designs under realistic site conditions.
Interfaces more important than components	Specification at the interface level to keep components interchangeable.
Modularization	Modular construction of the asset class with standard interfaces.
Pre-assembly	Off-site fabrication and assembly as a deployment mode.
Basic engineering design data and criteria	BEDD repository anchoring consistent specification.
Technology maturity and digital enablement	
Technology maturity	Sufficient maturity of technology included in the standard.

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Table B.6 continued from previous page

Code	Definition
Technology scalability and interchangeability	Standard accommodates a range of sizes and capacities.
Supplier and vendor involvement	Suppliers and vendors involved in specification work.
Digital and information standardization	Information standards complementing physical asset standards.

Code group 4: implementation challenges Conditions or dynamics that the literature identifies as obstacles to standardization implementation. Organized by the same six clusters as the success factors, plus an additional technical-design and digital-enablement cluster where the literature reports challenges without a clear paired success factor.

Table B.7: Systematic literature review codebook, code group 4: implementation challenges.

Code	Definition
Strategic and organizational governance	
Lack of standardization management and enforcement	No standardization management or enforcement system in place.
Lack of understanding of value and risks	Stakeholders cannot articulate why the standard matters.
Contracting and risk allocation misaligned	Tender and contract structures push risk in directions that undermine the standard.
Supplier dependency and concentration	Reliance on few suppliers; vulnerability to disruption.
Project planning and early integration	
Lack of early procurement	Procurement engaged after specification is final.
Shortened lead time reduces alignment	Schedule compression generates downstream resistance.
Stakeholder collaboration and culture	
Insufficient stakeholder alignment	Open communication absent; late-stage resistance.
Change of leadership, team or O&M	Personnel turnover; tacit knowledge fails to transfer.
Cultural resistance and preference for customization	Field actors prefer bespoke or familiar configurations.
Processes, learning and change management	
Lack of standard methods and feedback	No standard methods; absent feedback loops in production.
Design and processes not supporting standard products	Ordering pathways for standard items absent or burdensome.
Scope and design changes undermining standardization	Mid-program changes erode the standard envelope.
Client, context and regulatory fit	
Regional and regulatory variation	Regulatory and infrastructural variation across jurisdictions.
Project type and site constraints	Brownfield, urban, or refurbishment contexts constrain applicability.
Tension between uniformity and project-specific requirements	Project-specific requirements exceed standard envelope.
Technical design and constructability	

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Table B.7 continued from previous page

Code	Definition
Extensive supplier adaptation needed	Suppliers repeatedly adapt the standard product for project-specific conditions.
High product variety and customized solutions	Surviving variety in the active population undermines volume commitment.
Insufficient design flexibility for future expansion	Standard locks the asset into a configuration unable to accommodate change.
Lack of modularization and stable manufacturing	Standard not designed as modular blocks; manufacturing not stable.
Technology maturity and digital enablement	
Lack of accessible designs for engineers	Engineers cannot easily find, interpret, or order the current standard.
Lack of digital and information standardization	Documentation and configuration data not in a common digital substrate.

B.1.6. Industry consultant codebook

The Phase 1 consultant codebook extends the SLR codebook with codes that emerged inductively from the five industry consultant interviews and were not present in the SLR. All codes from Appendix B.1.5 continue to apply; only the additions are listed here. After cleaning, the consultant phase contributed 22 additional analytical codes, concentrated in the strategic governance, organizational culture, processes, and digital enablement clusters, plus two new effect codes and two new negative-effect codes that surfaced specifically in the DSO setting.

Table B.8: Industry consultant codebook, additions to code group 1 (positive effects) not present in the SLR codebook.

Code	Definition
Strategic, relational and business-model	
Industrialized "production line" way of working	Shift from craft-based per-project delivery to scalable repeatable process.
Reduction of labor bottlenecks	Fewer engineers required per unit; junior staff upskilled through explicit standards.
Strategic grid clarity and future-proof portfolio	Standard building blocks simplify long-term portfolio planning.
Regulatory and permitting facilitation	Predictable standard designs accelerate permit approval.
Stakeholder and community acceptance	Predictable designs and visualization support external-stakeholder co-design.
More room for investment	Lower per-unit costs free capital headroom for new initiatives.

Table B.9: Industry consultant codebook, additions to code group 2 (negative effects) not present in the SLR codebook.

Code	Definition
Cost and efficiency	

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Table B.9 continued from previous page

Code	Definition
Vendor concentration risk	Single-supplier mass failure affects many standardized assets simultaneously.
Operations, maintenance and learning	
Loss of improvisation, innovation and creativity skills	Long-term atrophy of ad hoc problem-solving after prolonged standardization.
Strategic, relational and business-model	
Reduced job satisfaction and staff turnover risk	Repetitive work and felt freedom restriction drive selective attrition.

Table B.10: Industry consultant codebook, additions to code group 3 (success factors) not present in the SLR codebook.

Code	Definition
Strategic and organizational governance	
Only senior specialists in standardization team	Senior specialists (not middle managers) chair standardization teams for legitimacy.
Available resources at tactical level	Sufficient tactical capacity freed from delivery for specification work.
Governance and operating-model alignment	New governance fits existing decision rights rather than parallel structure.
Stakeholder collaboration and culture	
Innovation-embracing culture	Organizational openness to new ways of working alongside the standard.
Organizational cohesion and attachment	Willingness to accommodate for the greater good across functions.
Willingness to change	Users willing to adopt the concept rather than seeing only problems.
Sense of autonomy and creativity	Bounded space for local tailoring defusing perception of restriction.
Processes, learning and change management	
Communication strategy	Accessible self-describing documentation; audience-specific narratives.
Transparent decision framework	Standard packaged with explicit justification of decisions.
Single source of truth for standards	One accessible, authoritative location for the current standard.
Client, context and regulatory fit	
External stakeholder communication and legitimacy	Field staff equipped with consistent narratives for municipalities and clients.
Technology maturity and digital enablement	
Digital infrastructure and IT enablement	Standards stored, searchable, and integrated with project, ERP, and ordering tools.
Human capital and capabilities (new cluster)	
Availability of required technical knowledge	Deep content knowledge available for specification work.

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Table B.10 continued from previous page

Code	Definition
Taking into account skills of existing technical staff	Legacy staff's tacit knowledge captured rather than displaced.
Stakeholder co-creation and end-user involvement	Operational staff included so they contribute and feel ownership.

Table B.11: Industry consultant codebook, additions to code group 4 (implementation challenges) not present in the SLR codebook.

Code	Definition
Strategic and organizational governance	
Complexity of sequencing the implementation roadmap	Foundation must be established before content development.
Lack of long-term ownership	Unclear accountability for sustained standard maintenance after rollout.
Project planning and early integration	
Difficulty prioritizing what to standardize first	Many candidate standards; no shared sequencing logic.
Limited transferability between DSOs and contexts	Direct copy of standards across organizations fails because conditions differ.
Stakeholder collaboration and culture	
Competing internal agendas	Departmental priorities as resistance to centralized routing.
Siloed organization and difficulty of cross-functional alignment	Cross-functional alignment itself is a long-term cultural change.
Processes, learning and change management	
Change in day-to-day work	Major change in routines requiring sustained support.
Insufficient perseverance to sustain new way of working	Organizations struggle to stick to the chosen path under pressure.
Struggle between adherence and accommodating improvements	Tension between current standard and in-project innovation without shared rules.
Technical design and constructability	
Historical fragmentation and variation	Legacy variant populations (merger-origin) take years to rationalize.
Supplier diversity undermining standardization	Multiple suppliers re-introduce variation via supplier-specific tolerances.
Human capital and capabilities	
High initial investment	Significant time/effort from the organization before return materializes.
Struggle of removing important people from operation	Freeing senior specialists from delivery is difficult under capacity pressure.
Workforce transition and loss of tacit knowledge	Aging workforce; tacit knowledge of legacy network at risk in turnover.
"Good enough for now" mindset	Short-term delivery focus crowds out structural investment.

B.2. Phase 1: research findings

B.2.1. Systematic literature review: effects

Tables B.12 and B.13 report the positive and negative effects identified in the systematic literature review, grouped by KPI dimension, with the full multi-mechanism content preserved per effect. The consolidated, mechanism-coded view of these effects is provided by Table 3.1 in Chapter 3.

Table B.12: Positive effects of asset standardization identified in the systematic literature review, organized by KPI dimension and linked to the mechanism through which they operate. The consolidated and mechanism-coded version appears as Table 3.1.

KPI dimension	Effect	Mechanism	Primary sources
Cost and efficiency	Saving costs (general)	Reduced design and engineering efforts; increased reuse of standard components; volume procurement; reduced re-engineering for known configurations.	(Choi, Shrestha, Kwak, & Shane, 2020a; Gibb, 2001; Mehta, 2024)
	Lower transaction and process costs	Tendering documentation reused across follow-on projects; coordination and quality-assurance effort reduced.	(Choi, Shrestha, Kwak, & Shane, 2020a; Gibb & Isack, 2001)
	Inventory and warehouse efficiency	Centralization of parts; smaller warehouse footprint; optimized purchasing through bulk orders against standard items.	(Mehta, 2024; Silka & Butyrin, 2021)
Time and schedule	Shorter schedules and delivery times	Reduced time from design initiation to commissioning; replication of validated designs across sites; pre-positioned standard inventory.	(Choi et al., 2022; Gibb, 2001; Økland et al., 2018)
	Schedule predictability and control	Reliable and controllable schedules; reduced schedule variance through repeated execution of known designs.	(Gibb, 2001; Økland et al., 2018)
Quality, risk and safety	Improved quality and fewer errors	Reduced workmanship variability through repeated assembly procedures; clearer specifications; off-site inspection.	(Aapaoja & Haapasalo, 2014; Gibb, 2001; Mehta, 2024)
	Controlled risk and increased reliability	Use of tried-and-tested standard designs; cumulative trial and testing data informing subsequent releases.	(Choi, Shrestha, Kwak, & Shane, 2020a; Gibb, 2001)
	Improved accuracy and project control	Standardized documentation and interfaces support consistent data and monitoring across projects.	(Choi, Shrestha, Kwak, & Shane, 2020a)
	Improved safety	Reduced exposure through familiarity with standard components and procedures; standardized testing regimes.	(Gibb, 2001; Mehta, 2024)
Operations, maintenance and learning	Easier maintenance and operations	Common operations and maintenance procedures develop around standardized assets; simplified field practices.	(Choi et al., 2022; Ivanovski & Repin, 2001; Økland et al., 2018)

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Table B.12 continued from previous page

KPI dimension	Effect	Mechanism	Primary sources
	Quicker repair and less training	Standardized components and layouts enable quicker fault-finding and repair; reduced retraining for new designs.	(Gibb & Isack, 2001; Økland et al., 2018)
	Predictable and standardized operations and maintenance	Worked-out procedures for installation and exploitation; commonality of spares.	(Choi et al., 2022; Ivanovski & Repin, 2001)
	Learning effects and experience transfer	Lessons learned propagate across projects when the same design is repeatedly applied; productivity through repetition.	(Aapaoja & Haapasalo, 2014; Lyons & Roulstone, 2018)
	Continual improvement of products and components	Iterative refinement of standards over time; improvements feed back into all subsequent projects.	(Lyons & Roulstone, 2018; Silka & Butyrin, 2021)
Sustainability and circularity	Reduced environmental impact and circularity	Lower material waste through reuse; improved energy efficiency of validated designs; predictable end-of-life pathways.	(Lyons & Roulstone, 2018; Silka & Butyrin, 2021)
Strategic, relational and business-model	Enabling modularization and prefabrication	Standardization underpins modular and prefabricated approaches by stabilizing interfaces and component definitions.	(Gibb, 2001; Y. Li et al., 2023; Lyons & Roulstone, 2018)
	Standard product platforms and mass production	Standard units can be copied, expanded, and relocated; platform reuse and mass production become feasible.	(Y. Li et al., 2023; Robinson et al., 2011)
	Flexibility and value for money	Predictability and reuse improve value-for-money decisions while retaining configurable options within the standard.	(Choi et al., 2022)
	Uniform demands and procurement benefits	Volume discounts and multi-purchase agreements; price-list arrangements with suppliers.	(Choi, Shrestha, Kwak, & Shane, 2020a; Gibb & Isack, 2001)
	Reduced economic risk and uncertainty	Concentrated investment on proven designs; explicit recognition and valuation of economic risk in repeated deployments.	(Choi et al., 2022; Mehta, 2024)
	Reputation and expectation alignment	Track record builds confidence with customers, regulators, and field staff; stakeholders know what to expect.	(Gibb, 2001)

Table B.13: Negative effects of asset standardization identified in the systematic literature review, organized by KPI dimension and linked to the mechanism failure mode through which they arise. The consolidated and mechanism-coded version appears as Table 3.1.

KPI dimension	Effect	Mechanism failure mode	Primary sources
Cost and efficiency	Higher upfront and per-unit costs	Standardized concept can be significantly more expensive per unit before scale realization; upfront engineering and alignment effort.	(Choi et al., 2022; Økland et al., 2018)
	High transaction and set-up process costs	Cost and time of assessing market and establishing scope of the initial program; sustained governance effort.	(Choi et al., 2022; Choi, Shrestha, Kwak, & Shane, 2020a)
Quality, risk and safety	Design rigidity and loss of flexibility	Conflict between uniformity and variation; design impotence between maximum standardization and project flexibility.	(Aapaoja & Haapasalo, 2014; Gibb, 2001)
	Poor contextual fit and performance	Uniform designs misfit specific environmental, regulatory, or geographic conditions, reducing realized performance.	(Ivanovski & Repin, 2001)
Operations, maintenance and learning	Reduced innovation and technological lock-in	Standards delay adoption of newer technologies; manufacturers reluctant to modify systems for incremental advancements.	(Ivanovski & Repin, 2001; Mehta, 2024)
Strategic, relational and business-model	Exposure to market and regulatory changes	Large standardized investments may misalign when markets, fiscal policy, or community expectations shift.	(Choi et al., 2022)
	Governance and scoping burden	Continuous managerial effort to define, update, and govern the scope of the standardization program.	(Choi et al., 2022; Choi, Shrestha, Kwak, & Shane, 2020a)

B.2.2. Systematic literature review: factors and challenges

Tables B.14 and B.15 report the success factors and implementation challenges identified in the systematic literature review, grouped by category.

Table B.14: Success factors for asset standardization identified in the systematic literature review, grouped by category.

Category	**Factor**	**Aspects**	**Primary sources**
Strategic governance & ownership	Strategic standardization approach	Company-wide approach defining how standards are used across projects; explicit decision rules; portfolio-level prioritization; standardization processes and tailored SOPs.	(Choi, Shrestha, Kwak, & Shane, 2023; Choi, Shrestha, Kwak, & Shane, 2020a, 2020b; Choi, Shrestha, Shane, & Kwak, 2020; Silka & Butyrin, 2021)
	Management commitment to standardization	Visible senior leadership backing, buy-in, ownership assignment; deviation places burden of justification on requester; appropriate responsibility, authority, and supportive culture to enforce and sustain standardization.	(Choi, Shrestha, Kwak, & Shane, 2023; Choi, Shrestha, Kwak, & Shane, 2020b)
	Standardization strategy embraced by all participants	Owners and contractors jointly embrace the goal of standardized designs and consistent key staffing across project phases; commitment supported through vertical alignment.	(Choi, Shrestha, Kwak, & Shane, 2020a; Choi, Shrestha, Shane, & Kwak, 2020)
	Economic evaluation and market analysis	Evaluating whether a standardized approach is economically warranted; assessing market and supplier maturity prior to program commitment; deciding when and where to build.	(Choi, Shrestha, Shane, & Kwak, 2020)
	Degree or level of standardization	Selecting standardization levels (facility, building, component, joint) and the extent of horizontal and vertical reuse.	(Choi, Shrestha, Shane, & Kwak, 2020; Silka & Butyrin, 2021)
	Extent of standardized units and projects	Assessing the expected number of standardized deployments and the share of portfolio covered by the standard; size of the program.	(Choi, Shrestha, Shane, & Kwak, 2020; Økland et al., 2018)
	Having a development plan	Plan identifying drivers, scope, and milestones for the standardization program prior to execution.	(Choi, Shrestha, Shane, & Kwak, 2020)

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Category	Factor	Aspects	Primary sources
	Recognizing cost of establishing the standard	Explicit recognition that the initial standardized design entails higher cost for the first deployment than per-project engineering, and provision for this in the business case.	(Choi, Shrestha, Shane, & Kwak, 2020)
	Scope of standardization	Identifying which portions of the project, systems, packages, equipment, and buildings to include in the standard.	(Choi, Shrestha, Shane, & Kwak, 2020)
	Benefits, trade-off, and risk evaluation and communication	Explicit evaluation and communication of benefits, trade-offs, and sacrificed conventional-execution benefits across stakeholders.	(Choi, Shrestha, Kwak, & Shane, 2020a; Choi, Shrestha, Shane, & Kwak, 2020)
	Benchmark of data of project management team	Benchmark data on project-management team performance to track standardization gains over time and across the portfolio.	(Choi, Shrestha, Shane, & Kwak, 2020)
Project planning & early-phase integration	Early design engagement	Addressing standardization in early design engagement so requirements are embedded before late-stage rework becomes necessary.	(Y. Li et al., 2023)
	Early selection and identification of standardization approach	Early identification of the standardization approach, including which standards apply and which deviations are anticipated.	(Choi, Shrestha, Shane, & Kwak, 2020)
	Early stakeholder engagement and alignment	Ensuring all parties are involved early, aligned, and committed to support the standardization program.	(Choi, Shrestha, Shane, & Kwak, 2020; Mehta, 2024)
	Alignment and approval prior to basic design	Standardization approach approved at concept-stage gate before basic design begins, rather than retrofitted during execution.	(Choi, Shrestha, Kwak, & Shane, 2020a)
	Early procurement	Early procurement involvement so suppliers and vendors are committed before design is finalized.	(Choi, Shrestha, Kwak, & Shane, 2020a)
	Time is needed to plan for standardization	Recognition that additional planning time is required to establish standardization rather than treating it as a routine design step.	(Gibb, 2001)

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Category	**Factor**	**Aspects**	**Primary sources**
Stakeholder collaboration & culture	Cooperation among stakeholders	Cross-stakeholder cooperation as a key condition for implementing standardized designs.	(Choi, Shrestha, Shane, & Kwak, 2020)
	Cooperative culture through vertical alignment	Cooperative culture supporting standardization, with vertical alignment between owner, contractor, and supplier organizations.	(Choi, Shrestha, Shane, & Kwak, 2020)
	Dedicated standardization team	Designated standardization team meeting regularly to discuss field lessons and inter-project coordination; structured release and review cycle.	(Choi, Shrestha, Kwak, & Shane, 2020a; Choi, Shrestha, Shane, & Kwak, 2020)
	Experienced and dedicated project team	Project team experience and capability related to standardization; commitment to staff continuity across phases.	(Choi, Shrestha, Kwak, & Shane, 2020a; Choi, Shrestha, Shane, & Kwak, 2020)
	Stability of project team	Recognition that team changes disrupt standardization and that staffing continuity is a precondition for cumulative learning.	(Choi et al., 2022; Choi, Shrestha, Kwak, & Shane, 2020a)
	Division of responsibility	Clarity over which party (owner, EPC contractor, supplier) holds component-selection authority; component choice can fall to turnkey contractors, overriding owner-defined standards in practice.	(Choi, Shrestha, Shane, & Kwak, 2020; Gibb, 2001)
Processes, learning & change management	Effective processes create a basis for product use	High quality, reasonable costs, and effective product delivery depend on effective repeatable processes.	(Aapaoja & Haapasalo, 2014)
	Formal lessons-learned and feedback process	Lessons reviewed after the first of multiple projects and considered for subsequent deployments; deployment experience returns to the specification team.	(Choi, Shrestha, Kwak, & Shane, 2020a; Choi, Shrestha, Shane, & Kwak, 2020)
	Discipline and value-based change control	Discipline to keep the standardized design intact and resist unnecessary changes; value-based evaluation of proposed changes.	(Choi, Shrestha, Kwak, & Shane, 2020a; Choi, Shrestha, Shane, & Kwak, 2020)

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Category	Factor	Aspects	Primary sources
	Rigorous management of change process	Formal change-management process addressing changes throughout the standard's lifecycle.	(Choi, Shrestha, Shane, & Kwak, 2020)
	Feasibility analysis of standardization	Feasibility analysis as a separate step before committing to standardization program scope.	(Choi, Shrestha, Kwak, & Shane, 2020a)
	Standard design maturity assessment	Maturity assessment performed on the first project to set guidelines for subsequent projects; pilot validation before scale rollout.	(Choi, Shrestha, Shane, & Kwak, 2020)
Context & regulatory fit	Type and location of project	Component standardization works better for greenfield, out-of-town projects than for urban refurbishments.	(Gibb & Isack, 2001)
	Compatibility of location, infrastructure, and design	Evaluating whether standard designs and chosen locations are compatible based on regional infrastructure.	(Choi, Shrestha, Shane, & Kwak, 2020)
	Design adequate for environmental regulations	Standardized design adequate for environmental regulations across the deployment area.	(Choi, Shrestha, Shane, & Kwak, 2020)
	Legal and regulatory compliance with material sourcing	Legal and regulatory restrictions on utilization of materials addressed during specification.	(Choi, Shrestha, Shane, & Kwak, 2020)
Technical design & constructability	Constructability of standardization	Early constructability review to maximize buildability of standardized designs under realistic site conditions.	(Choi, Shrestha, Kwak, & Shane, 2020a; Choi, Shrestha, Shane, & Kwak, 2020)
	Interfaces more important than components	Specification at the interface level so adjacent assets and supplier components remain interchangeable.	(Gibb, 2001)
	Modularization	Linking modular plant construction to the extent of standardization at the modular interface level.	(Lyons & Roulstone, 2018)
	Pre-assembly	Greatest benefit gained when standardization and pre-assembly are linked.	(Gibb, 2001)

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Category	**Factor**	**Aspects**	**Primary sources**
	Basic engineering design data and criteria (BEDD)	Developing BEDD, including the basis of standardization, to achieve and maintain consistent specification across the portfolio.	(Choi, Shrestha, Shane, & Kwak, 2020; Silka & Butyrin, 2021)
	O&M requirements integrated in design	O&M perspectives included in specification work and addressed in BEDD; design considers operational and maintenance requirements rather than only construction.	(Choi, Shrestha, Shane, & Kwak, 2020)
Technology, supplier & digital enablement	Technology maturity	Technology must be sufficiently mature to be included in a standardized design.	(Choi, Shrestha, Kwak, & Shane, 2020a; Choi, Shrestha, Shane, & Kwak, 2020)
	Technology scalability and interchangeability	Technology available in a range of sizes and capacities that the standard can accommodate.	(Choi, Shrestha, Shane, & Kwak, 2020)
	Supplier and vendor involvement	Involving suppliers and vendors in standardization to enable bulk purchasing and informed specification.	(Choi, Shrestha, Kwak, & Shane, 2020a; Choi, Shrestha, Shane, & Kwak, 2020)
	Willingness and capability in establishing long-term contracts	Owner willingness and supplier capability to enter multi-year framework contracts with stable specifications, enabling procurement scale economies.	(Choi, Shrestha, Shane, & Kwak, 2020)
	Digital and information standardization	BIM maturity, ERP integration, and structured data exchange as enablers of consistent standard application.	(Bayzidi et al., 2025; Choi et al., 2022)

Table B.15: Implementation challenges of asset standardization identified in the systematic literature review, grouped by category.

Category	Challenge	Aspects	Primary sources
Strategic governance & ownership	Lack of standardization management and strategy enforcement system	Lack of a proper standardization management and strategy enforcement system; standards exist on paper without consistent enforcement.	(Choi, Shrestha, Kwak, & Shane, 2020a)
	Lack of understanding of value and risks of standardization	The value of standard products and components is not understood; benefits and risks of standardization are not legible to internal stakeholders.	(Aapaoja & Haapasalo, 2014; Choi et al., 2022)
	Contracting and risk allocation misaligned with standardization	Contracts for design-one-build-many projects must address risk allocation patterns that diverge from per-project contracts.	(Mehta, 2024)
	Supplier dependency and collaboration issues	Change of supplier identified as a recurring issue; reliance on a small number of suppliers increases program fragility.	(Choi, Shrestha, Shane, & Kwak, 2020; Mehta, 2024)
Project planning & early-phase integration	Lack of early procurement	Lack of early procurement explicitly identified as a barrier to implementing standardized designs at scale.	(Choi, Shrestha, Kwak, & Shane, 2020a)
	Shortened lead time reduces alignment	Lead-time reductions create urgency and a risk of stakeholders feeling unheard, causing downstream resistance.	(Økland et al., 2018)
Stakeholder collaboration & culture	Insufficient early stakeholder engagement and alignment	Open communication among stakeholders identified as important; absence of early alignment generates late-stage resistance.	(Choi, Shrestha, Shane, & Kwak, 2020; Y. Li et al., 2023)
	Change of leadership, project team, or O&M team	Change of leadership noted as a challenge in maintaining standardization; tacit knowledge does not transfer with personnel changes.	(Choi, Shrestha, Shane, & Kwak, 2020)
	Cultural resistance and preference for customization	Local stakeholders advocate for traditional site-built alternatives; preference for customization undermines volume commitment.	(Aapaoja & Haapasalo, 2014; Økland et al., 2018)
Processes, learning & change management	Lack of standard methods and feedback	No standard methods and routines in use; absence of feedback loops in production.	(Aapaoja & Haapasalo, 2014)

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Category	Challenge	Aspects	Primary sources
	Design and processes not supporting standard products	Current design processes do not support using standard products and components; ordering pathways for standard items absent.	(Aapaoja & Haapasalo, 2014)
	Scope and design changes undermining standardization	Change of scope and change of design reported as implementation issues; standard erodes through ad hoc deviation.	(Choi, Shrestha, Shane, & Kwak, 2020)
Context & regulatory fit	Regional and regulatory variation	Implementation of standardized designs in different regions identified as a recurring source of misfit.	(Choi, Shrestha, Shane, & Kwak, 2020; Mehta, 2024)
	Project type and site constraints for standard products	More difficult to use standard products on refurbishment and renovation projects, in dense urban contexts, or under existing footprints.	(Gibb & Isack, 2001)
	Tension between uniform design and project-specific requirements	Conflict between uniformity and variation; project-specific requirements recurrently exceed standard envelope.	(Aapaoja & Haapasalo, 2014; Gibb, 2001)
Technical design & constructability	Extensive supplier adaptations needed beyond standard product	Supplier-required adaptations in standardized extension projects can be substantial; specification becomes effectively bespoke at the margin.	(Økland et al., 2018)
	High product variety and customized solutions	"Unique" products difficult to bring under standardization; surviving variety undermines volume commitment.	(Aapaoja & Haapasalo, 2014)
	Insufficient design flexibility to accommodate future expansion	Standard offers advantages but designs must remain flexible to meet emerging project requirements over the asset lifecycle.	(Mehta, 2024)
	Lack of modularization and stable manufacturing model	Manufacturer initially favored a more efficient Made-to-Forecast model but was forced into Made-to-Order under variant pressure.	(Robinson et al., 2011)
Technology maturity & digital enablement	Lack of easy available or understandable designs for engineers	Design engineers may avoid standard designs if they are not easily retrievable or interpretable in available systems.	(Aapaoja & Haapasalo, 2014)

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Category	Challenge	Aspects	Primary sources
	Lack of digital and information standardization	For design-one-build-many concepts, no ready-made commercial solution to manage standard documentation across deployments.	(Mehta, 2024)

B.2.3. Per-paper coverage matrix

Table B.16 records which of the 21 included systematic-literature-review papers contributed which content to the synthesis. The matrix is provided as an audit-trail artefact: each synthesized effect, factor, and challenge in Chapter 3 can be traced back to one or more rows of this table.

Table B.16: Per-paper coverage of effects, success factors, and implementation challenges across the 21 papers included in the systematic literature review. Full bibliographic details and type-of-standard descriptions are in Table B.2.

#	Short reference	Effects contributed	Factors and challenges contributed
1	Y. Li et al. (2023)	Modularization enables factory production; standard product platforms; circularity through modular reuse.	Early design engagement; open communication; insufficient stakeholder alignment.
2	Aapaoja and Haapasalo (2014)	Lower transaction costs; improved quality and fewer errors; learning effects through repetition; reduced training.	Effective repeatable processes underpin product use; cultural preference for customization; lack of standard methods and feedback; design impotence between uniformity and variation.
3	Gibb and Isack (2001)	Lower costs; shorter delivery and construction times; fewer quality problems; reduced training; uniform demands and procurement benefits.	New-build out-of-town fit; planning constraints; contractor turnkey override of standardization (division of responsibility).
4	Choi, Shrestha, Kwak, and Shane (2020a)	Cost and schedule savings; safety and quality benefits via dedicated team and lessons-learned.	Strategic standardization approach; alignment and approval prior to basic design; early procurement; constructability review; team and O&M continuity; regional implementation.
5	Mehta (2024)	Cost savings (engineering and economies of scale); shorter schedules; quality and safety; inventory benefits.	Early collaboration across design, procurement, and construction; supplier reliance; absence of database replication tools; site specificity and lock-in.
6	Kumaraswamy and Chan (1995)	Empirical association of standardization (and prefabrication) with shorter construction duration; productivity gains as duration determinant.	Anchors schedule-control mechanism M3 statistically; contributes to learning-effects mechanism M5 via productivity-through-repetition finding.
7	Silka and Butyrin (2021)	30% material cost reduction; 50–80% warehousing reduction; 13% faster completion; continual improvement through iterative refinement.	Multi-level design organization (facility to equipment); BEDD development; system of standard designs.
8	Zuo and Yang (2024)	Earthquake-resistant quality; error reduction; factory production enabled.	Regional and climate adaptability of standards; digital monitoring enabler.
9	Bayzidi et al. (2025)	Digital coordination supports standardization levels and modularization grades.	BIM maturity; AI/Lean integration; digital and information standardization as enabler.
10	Robinson et al. (2011)	Efficient made-to-order via parametric models; standardization-enabled mass production.	Parametric design; lack of stable manufacturing model under variant pressure.
11	Choi et al. (2022)	Cost and schedule savings; efficiency and predictability; flexibility and value for money; reduced economic risk.	Modularization tandem; supplier collaboration; customization culture; absence of quantification; data management; exposure to market and regulatory changes.

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#	Short reference	Effects contributed	Factors and challenges contributed
12	Choi, Shrestha, Shane, and Kwak (2020)	Cost savings (design and procurement); learning curves; safety.	Technology maturity; market analysis; project complexity; team instability; division of responsibility; O&M integrated in design; standard design maturity assessment; willingness and capability in long-term contracts; benchmark of project-management team data.
13	Choi, Shrestha, Kwak, and Shane (2023)	— (work-process focused; does not contribute new effect content).	Management commitment to standardization; BEDD-anchored work process.
14	Ivanovski and Repin (2001)	Mass production; standardized installation and exploitation; reduced training.	Climatic and geographic variations as a source of misfit; standardization restrained innovation; poor climate fit as failure mode.
15	Shrestha et al. (2020)	Positive association between number of accomplished design-standardization CSFs and project performance across 41 capital projects.	Empirical evidence that the CSF inventory matters; risk-mechanism anchor through historical-data argument.
16	Choi, Shrestha, Kwak, and Shane (2020b)	Technology- and management-enabled standardization (BIM, parametric design, modular construction tools, lessons-learned systems) producing schedule and cost predictability.	Digital and information standardization as a precondition; technology vendor involvement and lifecycle support; lessons-learned systems; management-approach inventory (PMIs).
17	Choi, Kwak, and Chi (2023)	Lessons-learned capture and continual improvement contributions.	Key standardization-work-process tasks: BEDD validation; cross-functional alignment; specification governance.
18	Lyons and Roulstone (2018)	Reduced subsequent design costs; learning curves through production repetition.	Extent of modularization; local-conditions variability; modular interface specification.
19	Shrestha et al. (2021)	Configurational recipes for cost and schedule success.	Five CSFs (Discipline; O&M Considerations; Define Standardization Approach; Applied Knowledge of Standardization; Benefits & Trade-off Recognition) identified as necessary conditions across configurations.
20	Økland et al. (2018)	Shorter lead times (1 year planning, 1 year construction); learning and QA efficiency; higher per-unit cost as trade-off; predictable schedule.	Repetition; document reuse; stakeholder resistance (feeling unheard); supplier adaptations beyond the standard.
21	Gibb (2001)	Cost and schedule savings; continual improvement; safety and productivity.	Interface focus and pre-assembly; planning time needed; design impotence between uniformity and variation.

B.2.4. Industry consultant interviews: effects

Tables B.17 and B.18 report the positive and negative effects identified in the five Phase 1 industry-consultant interviews, grouped by KPI dimension, with the mechanism through which each effect operates and the interview source attribution (`Int. I.1-5`).

Table B.17: Positive effects of asset standardization identified in the Phase 1 industry-consultant interviews, organized by KPI dimension. The consolidated and mechanism-merged version is integrated into Table 3.1.

KPI dimension	**Effect**	**Mechanism**	**Source**
Cost and efficiency	Saving costs (general)	Lower total cost of ownership via standardized designs and easier portfolio management; bulk procurement economies of scale.	Int. I.2–4
	Lower transaction and process costs	Reduced internal coordination waste, fewer meetings and dependencies; less manual asset registration and data entry; reduced process friction across supply chain.	Int. I.3–4
	Uniform demands and procurement benefits	Bulk and forecast purchasing reduces unit costs by 10–50%; clear specifications enable formal tendering and quality audits; long-term contracts increase supplier reliability.	Int. I.2–4
	Inventory and warehouse efficiency	Standard materials available on call-off contracts; reduced need for custom on-demand production.	Int. I.2, I.4–5
Time and schedule	Shorter schedules and delivery times	Faster construction and assembly from known, repeatable standards; prefabrication reduces on-site assembly time; reduced site disruption; forecast-based supply avoids multi-year lead times; reusable templates accelerate design.	Int. I.1, I.4–5
	Schedule predictability and control	Forecast-based asset delivery prevents long delays; clear scope and portfolio planning enable accurate timelines; asset management can plan operations against certainty of component availability.	Int. I.1, I.4
Quality, risk and safety	Improved quality and fewer errors	Quality requirements defined upfront in standards; repeated familiar processes reduce human error; formal quality audits with bulk procurement contracts; standardized testing procedures; standards-populated asset data reduces manual errors.	Int. I.1, I.3–4
	Improved safety	Standardization prevents operational shortcuts that would violate safety requirements; safety standards enforced by governance for long-term asset integrity.	Int. I.1, I.3–4

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KPI dimension	**Effect**	**Mechanism**	**Source**
Operations, maintenance and learning	Easier maintenance and operations	Interchangeable components with standard instructions; technicians perform familiar tasks with fewer unique situations; standardized maintenance procedures reduce cognitive load.	Int. I.3–5
	Predictable and standardized operations and maintenance	Standardized failure patterns enable predictive maintenance; risk-based asset management forecasts component replacements by location; component lifecycle data visible across portfolio.	Int. I.4–5
	Continual improvement of products and components	Feedback loops embedded into each phase of standardized processes; improvements disseminated via periodic releases of refined standards.	Int. I.4
	Learning effects and experience transfer	Repetition and familiarity build proficiency; knowledge crystallizes; explicit knowledge capture in standards accelerates onboarding.	Int. I.1, I.3
Sustainability and circularity	Reduced environmental impact and circularity	Sustainable design variants can be integrated into standards (e.g., sedum roofs); standardized end-of-life pathways.	Int. I.4
Strategic, relational and business-model	Reduction of labor bottlenecks	Fewer engineers required per unit (65–70% reduction versus bespoke); reduced engineering hours for design analysis; junior staff upskilled quickly via explicit knowledge; lower expertise required for routine operations.	Int. I.3–4
	Employee satisfaction and work culture	Clarity on tasks and expectations reduces frustration; workers estimate effort and complete work faster; centralized issue resolution reduces being “stuck”.	Int. I.1
	Regulatory and permitting facilitation	Predictable standard designs speed permit approvals; solid baseline for permitting; pre-defined spatial specifications simplify site search; faster asset registration; early engagement with municipalities via 3D models.	Int. I.1, I.3–4
	Stakeholder and community acceptance	Early visualization via 3D models enables community co-design; reduced on-site disruption; predictable timelines support customer forecasting for grid connections; aligned expectations with external stakeholders.	Int. I.4

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KPI dimension	Effect	Mechanism	Source
	Reputation and expectation alignment	Signaling efficiency improvements to regulators and public; commitment to reducing queue times in energy transition; clear communication of standard portfolio to external partners.	Int. I.3–4
	Strategic grid clarity and future-proof portfolio	Standard building blocks simplify long-term portfolio planning; functional requirements defined upfront for multidisciplinary alignment; consolidation of voltage levels reduces future complexity; consistent baseline enables predictable future deployments.	Int. I.4
	Industrialized "production line" way of working	Shift from bespoke craft-based delivery to scalable, repetitive process across the program portfolio.	Int. I.4
	Standard product platforms and mass production	Reusable assets deployable across multiple projects; reproducibility via standardized design and copy-paste deployment.	Int. I.1, I.4
	More room for investment	Lower net costs and benchmarking gains enable higher capital-expenditure headroom for new initiatives.	Int. I.4

Table B.18: Negative effects of asset standardization identified in the Phase 1 industry-consultant interviews, organized by KPI dimension. The consolidated version is integrated into Table 3.1.

KPI dimension	Effect	Mechanism failure mode	Source
Cost and efficiency	Higher costs	Upfront investment required for one to two years before return on investment is realized; cost of establishing standard design and initial scoping.	Int. I.4
	High transaction and setup process costs	Time and cost of assessing market needs and defining standardization scope; initial project scoping delays benefits realization.	Int. I.3
	Vendor concentration risk	Single-supplier mass failure affects widespread standardized assets simultaneously; multi-supplier strategy required for resilience.	Int. I.4
	Governance and scoping burden	Diverting 10–20 FTEs of senior staff from delivery to standards work; need for senior cross-functional coordinators who are scarce; short-term resource trade-offs strain operations.	Int. I.3–4
Quality, risk and safety	Poor contextual fit and performance	Standards inapplicable to indoor or historic urban sites ("80/20" rule); bespoke 20% cases require disproportionate time and money at lower quality; spatial constraints prevent prefab deployment.	Int. I.4
	Exposure to market and regulatory changes	Rigid designs vulnerable to policy, community, or market shifts; standard envelope locked in before all change vectors are known.	Int. I.3
Operations, maintenance and learning	Loss of improvisation, innovation, and creativity skills	Long-term atrophy of ad hoc problem-solving after prolonged standardization; erosion of creative capacity through repetitive standard work.	Int. I.2, I.5
Strategic, relational and business-model	Design rigidity and loss of flexibility	Deviation requires justification perceived as restrictive; limits on alternative or innovative solutions for unique needs; "blue" or control-heavy culture stifles perceived freedom.	Int. I.2–3, I.5

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KPI dimension	**Effect**	**Mechanism failure mode**	**Source**
	Reduced job satisfaction and staff turnover risk	Repetitive work seen as boring across technical and non-technical roles; felt freedom restriction reduces work enjoyment; major mindset shift prompts exits and knowledge loss.	Int. I.1, I.4
	Reduced innovation and technological lock-in	Reluctance to adopt new technology that would deviate from standards; restrained R&D due to standardization inertia.	Int. I.2, I.5

B.2.5. Industry consultant interviews: factors and challenges

Tables B.19 and B.20 report the success factors and implementation challenges identified in the five Phase 1 industry-consultant interviews, grouped by category.

Table B.19: Success factors for asset standardization identified in the Phase 1 industry-consultant interviews, grouped by category.

Category	Factor	Aspects	Source
Strategic and organizational governance	Management commitment to standardization	Senior leadership visibly backs the standardization concept and "brings it to the organization"; policy-makers consistently communicate the seriousness of the new way of working.	Int. I.2–5
	Strategic standardization approach	KPIs along the whole value chain (e.g., at investment-proposal stage, deployment, and operations); end-to-end adherence and deviation tracking.	Int. I.3–5
	Dedicated standardization team	Multi-disciplinary team manages each standard with representatives across functions; structured release and review cycle.	Int. I.2–5
	Only senior specialists in the standardization team	Senior specialists rather than middle managers chair standardization teams; technical authority creates legitimacy in their home departments.	Int. I.3
	Governance and operating-model alignment	Standardization embedded in an organizational structure and operating model that supports it; new governance fits existing decision rights rather than layered as parallel structure.	Int. I.2–3, I.5
Stakeholder collaboration and culture	Innovation-embracing culture	Organizational maturity and "hechting tussen mensen" (interpersonal bonding) influence how openly the new way of working is taken up.	Int. I.1
	Organizational cohesion and attachment	Strong bonding and willingness to "in-schikken" (accommodate) for the greater good supports cross-functional alignment on the standard.	Int. I.4
	Willingness to change	Users must be willing to adopt the concept; otherwise they see only problems and not the benefits.	Int. I.1, I.4
	Sense of autonomy and creativity / freedom for limited tailoring	Overly detailed, "blueprint" approaches risk being perceived as restrictive; controlled space for local tailoring defuses cultural resistance.	Int. I.2–5
Processes, learning and change management	Communication strategy	Accessible, self-describing documentation and clear communication explain why standards matter to different audiences.	Int. I.2–5
	Transparent decision framework	Standards package with explicit justification of decisions, so changes can be traced and contested through formal channels.	Int. I.3

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Category	Factor	Aspects	Source
	Single source of truth for standards	One accessible, authoritative location for the current standard replaces scattered versions in e-mails and local laptops.	Int. I.1, I.3–5
	Formal lessons-learned and feedback process	Feedback loops where technicians and managers submit improvement suggestions bundled into periodic standard releases.	Int. I.2–5
	Benefits, trade-off, and risk evaluation and communication	Explicit articulation of what benefits and trade-offs the standard delivers for different stakeholder audiences.	Int. I.2–5
	Rigorous management of change process	“Change factory” equips people to carry the transformation; controlled release and deviation management.	Int. I.3, I.5
Client, context and regulatory fit	External stakeholder communication and legitimacy	Staff who interact with municipalities and local governments are equipped with consistent narratives and visual material.	Int. I.4
Technical design and constructability	Interface-focused system design	Asset standards aligned so that interfaces between components are stable; component substitution does not propagate across the system.	Int. I.1, I.3
	Constructability of standardization	Standards easy to use and applicable in practice; constructability tested before scale rollout.	Int. I.4
Technology maturity and digital enablement	Digital infrastructure and IT enablement	Organizational and software architecture to store standards, link to project management and ERP, and integrate with ordering tools.	Int. I.1, I.3–5
	Digital and information standardization	Standardization content linked with digital workflows so that suggestions, approvals, and deviations route through the same system.	Int. I.1
Human capital and capabilities	Availability of required technical knowledge	Minimal technical basis: deep content knowledge available for specification work even when delivery capacity is stretched.	Int. I.1, I.3–5
	Availability of tactical-level resources for setting standards	Sufficient tactical resources is critical; organizations struggle when they cannot free senior specialists from delivery duties.	Int. I.3
	Taking into account skills of existing technical staff	Standardization considers legacy staff who know the grid by heart; their tacit knowledge is captured rather than displaced.	Int. I.1, I.4

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Category	**Factor**	**Aspects**	**Source**
	Stakeholder co-creation and end-user involvement	Operational staff and other end-users included in multi-disciplinary teams so they can contribute and feel ownership of the standard.	Int. I.4–5

Table B.20: Implementation challenges of asset standardization identified in the Phase 1 industry-consultant interviews, grouped by category.

Category	Challenge	Aspects	Source
Strategic and organizational governance	Complexity of sequencing the implementation roadmap	Foundation must be established first (processes, systems, team formation) before content development; difficulty calibrating sequencing under simultaneous delivery pressure.	Int. I.2–5
	Lack of long-term ownership for continuous development	Governance and responsibilities not clearly defined; unclear who is accountable for sustained standard maintenance after initial rollout.	Int. I.2–3, I.5
	Lack of standardization management and strategy enforcement system	Lack of structure in the asset-management department; absent enforcement allows day-to-day deviation to accumulate.	Int. I.1–2, I.5
Project planning and early-phase integration	Difficulty prioritizing what to standardize first	Many candidate standards exist; no shared logic for sequencing which standards to develop and deploy first.	Int. I.2–5
	Limited transferability of standards between DSOs and contexts	Initial expectation to copy from one DSO to another one-to-one fails because organizational and contextual conditions differ.	Int. I.2
Stakeholder collaboration and culture	Competing internal agendas around standardization	Creating a “standardization factory” means everything must route through it; competing departmental priorities surface as resistance to that routing.	Int. I.2
	Cultural resistance and preference for customization	Dutch “polder model” culture requires extensive discussion and consensus-building; preference for bespoke solutions persists in some teams.	Int. I.1–5
	Siloed organization and difficulty of cross-functional alignment	Departments accustomed to operating independently struggle to align under a single specification authority; cross-functional alignment is itself a long-term cultural change.	Int. I.1–5
	Supplier dependency and collaboration issues	Existing supplier contracts must be broken when specifications change; collaboration with new suppliers requires governance arrangements that take time to develop.	Int. I.4
	Supplier diversity undermining standardization	Multiple suppliers means less standardization because supplier-specific tolerances re-introduce variation into the active product population.	Int. I.4

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Category	**Challenge**	**Aspects**	**Source**
Processes, learning and change management	Change in day-to-day work	Major change in people's daily work and executive-level self-organization; day-to-day routines change in ways that require sustained support.	Int. I.1–5
	Insufficient perseverance to sustain the new way of working	Organizations struggle to stick to the chosen path and not deviate from the process under operational pressure.	Int. I.3, I.5
	Struggle between adhering to standard and accommodating improvements	Tension between adhering to the current standard and accommodating in-project improvements or innovations; no shared rule for when to deviate.	Int. I.2–3, I.5
Client, context and regulatory fit	Project type and site constraints for standard products	Greenfield versus brownfield: existing situations where things must be fitted into legacy infrastructure constrain standard applicability.	Int. I.1–4
	Scope and design changes undermining standardization	Realization-side pressure ("we have a batch of cables here, we need to proceed") overrides specification governance in the moment.	Int. I.2–5
Technical design and constructability	Historical fragmentation and variation	Legacy variant populations (e.g., six different power transformers from merger-origin) take years to rationalize.	Int. I.4
	Tension between uniform design and project-specific requirements	Regional managers historically controlled areas and could determine much; uniform design conflicts with this autonomy.	Int. I.4–5
Technology maturity and digital enablement	Lack of digital and information standardization	Standardization of documentation describing components is where it most often goes wrong; data and information are fragmented across systems.	Int. I.1, I.4–5
Human capital and capabilities	High initial investment	Significant time and effort from the organization to bring multi-disciplinary teams together; payoff lags investment.	Int. I.4
	Struggle of removing important people from operation for standard creation	Freeing 10–15–20 FTEs of senior specialists is difficult when delivery capacity is already stretched.	Int. I.3–4
	Workforce transition and loss of tacit system knowledge	Aging workforce; tacit knowledge of legacy network design risks being lost in workforce turnover before it is captured in the standard.	Int. I.1, I.3–5

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Table B.20 continued from previous page

Category	Challenge	Aspects	Source
	Short-termism / “good enough for now” mindset	Large parts of operations initially say “we do not really believe in standardization”; short-term delivery focus crowds out structural investment.	Int. I.3, I.5

C

Phase 2 additional material

C.1. Phase 2 research materials

C.1.1. Phase 2 case interview overview

Table C.1 consolidates the fifteen Phase 2 case interviews conducted across the three DSOs and six embedded cases. Each interview is identified by the anonymized identifier used throughout the within-case chapters (`Int. A-1`...`Int. C-6`). Roles are reported as anonymized functional descriptions sufficient to locate the respondent within the strategic–tactical–operational role typology discussed in Chapter 2 (§2.3.3), while preserving participant anonymity in accordance with the consent arrangements and the HREC-approved data management plan. Interview dates are reported at month granularity for methodological rigor while maintaining the anonymization commitment to participants. The case-coverage column indicates which of the embedded cases each interview substantively addressed, based on the within-case analytical use of each transcript; many respondents discussed more than one case where their role spanned multiple asset programs.

Table C.1: Phase 2 case interviews across the three DSOs and six embedded cases. Role descriptions are anonymized functional summaries; identifying details have been suppressed in line with the HREC-approved data management plan. The strategic / tactical / operational column maps each respondent to the role typology defined in §2.3.3. All interviews were conducted in Dutch and lasted approximately 60–90 minutes.

ID	Org.	Anonymized role description	Level	Date	Cases addressed
Int. A-1	DSO-A	Asset and product management lead, distribution-network components	Strategic / tactical	4 Feb 2026	A.1, A.2
Int. A-2	DSO-A	Policy advisor, technical policy within asset management	Tactical / operational	18 Feb 2026	A.1, A.2
Int. A-3	DSO-A	Operational installation responsible (OIV); network operational safety and field installation authority	Operational	18 Feb 2026	A.1, A.2
Int. A-4	DSO-A	Production program technical manager	Operational	9 Mar 2026	A.1, A.2
Int. B-1	DSO-B	Systems specialist, asset management	Tactical / operational	12 Feb 2026	B.1
Int. B-2	DSO-B	Component innovation and management team lead; asset-management policy and innovation	Strategic / tactical	17 Feb 2026	B.1, B.2
Int. B-3	DSO-B	Asset specialist, LV and public-lighting components; asset-management policy and innovation	Tactical / operational	24 Feb 2026	B.2
Int. B-4	DSO-B	Specialist technical management, commercial-project chain	Operational	9 Mar 2026	B.1
Int. B-5	DSO-B	Operational lead, public charge-point connection module deployment	Operational	25 Mar 2026	B.2
Int. C-1	DSO-C	Program manager, MV transport program (TVRS)	Strategic / tactical	19 Feb 2026	C.2
Int. C-2	DSO-C	Policy expert, station design (asset-management policy experts unit)	Tactical / operational	19 Feb 2026	C.2 (C.1 touched upon)
Int. C-3	DSO-C	Technical lead, TVRS program	Tactical / operational	23 Feb 2026	C.2
Int. C-4	DSO-C	Senior policy expert components, standardization unit	Tactical	4 Mar 2026	C.1
Int. C-5	DSO-C	Regional engineer, infrastructure construction	Operational	16 Mar 2026	C.1 (C.2 touched upon)
Int. C-6	DSO-C	Operational installation responsible (OIV) and contract-management team member	Operational / tactical	17 Mar 2026	C.1

C.1.2. Case interview guide

This appendix presents the semi-structured interview guide used in the case study interviews on internal asset standardization at Dutch distribution system operators (DSOs). The guide was designed to elicit comparable accounts from different organizational roles while allowing probes tailored to the specific asset and program. Interviews focused on the mechanisms through which standardization operates in projects, perceived effects (positive and negative), implementation challenges, and contextual conditions.

Interview structure and general instructions **Estimated duration:** 60 minutes.
Respondent identifier: `[ROLE]-[DSO]-[ASSET]-[ProgramID]`.

Interviewer notes.

- Begin with 2–3 minutes of rapport building.
- Always ask for concrete project examples, including metrics and timelines where available, to link mechanisms and outcomes to specific contexts.
- Use the same core questions for all cases; adapt follow-up probes to the respondent's role and asset.
- When two assets are discussed in one interview, make explicit comparisons under each main heading.
- Emphasize that respondents should answer from the perspective of their current role.

0. Introduction (ca. 5 minutes)

1. Thank the interviewee, briefly explain the study (asset standardization in grid expansion under the energy transition and the limited academic evidence), confirm the planned end time, consent, and audio recording.
2. **Role and involvement**
   "Could you describe your role in relation to `[ASSET]` projects and standards at `[DSO]`? How long have you been in this role, and how are you involved in using or developing this standard?"
3. **Definition of the standardized asset**
   "How would you define the standard `[ASSET]` in your organization? What does this concept entail, and would you classify it as a technical, product, component, asset, or system standard?"

1. Program and project overview (ca. 15 minutes)

1. **Standard and program set-up (adoption)**
   "Could you outline your DSO's standardization program for `[ASSET]`? Why and how was it initiated?"
2. **Current standard and program (tactical implementation)**
   "How is the standard currently governed and maintained? How has it developed since the start?"
3. **Typical project and variability (operational implementation)**
   "Could you walk me through one recent project using the `[ASSET]` standard from start to finish? What were the main phases?"

2. Experienced changes and effects (ca. 15 minutes)

1. **Changes in day-to-day practice**
   "Compared to the situation before standardization, which activities or project phases now run differently because of the standard?"
2. **Perceived positive effects**
   "From your perspective, what are the main positive effects of working with this standard—for you, for projects, and for the organization?"

3. **Perceived negative effects and limitations**
   "And what disadvantages or limitations do you experience when working with this standard?"

3. Challenges and underlying factors (ca. 15 minutes)

1. **Implementation challenges**
   "What are the main challenges or bottlenecks you see in implementing or using this standard, and what are their consequences?"
2. **Handling challenges (mitigation)**
   "How do you and your colleagues deal with these challenges in practice?"
3. **Underlying organizational, process, and contextual factors**
   "Looking at these challenges, what do you see as their main causes? Which organizational, process-related, or contextual factors underlie them?"

4. Contexts, conditions, and lessons (ca. 5–10 minutes) This block was emphasized particularly with more experienced and program-level respondents.

1. **Where does the standard work well or less well?**

2. **Conditions and success factors**

5. Strategic and cross-asset questions (program / strategic roles) These questions were asked only to respondents with program-wide or strategic responsibilities.

1. **Strategic overview and future**
   "From a strategic perspective, how does the `[ASSET]` standardization program fit within your DSO's broader objectives (acceleration, cost, reliability, etc.)?"
2. **Technical complexity and comparative leverage**
   "If you compare `[more complex asset]` to `[less complex asset]`, where do you see that standardization yields the greatest benefit, and why?"
3. **Optional clarifications if time allows**
   - Relationship between standardization, modularization, and pre-assembly.
   - Definitions of system, asset, component, and technical standardization (using a grid structure illustration if needed).
   - Degrees of standardization (e.g. percentage of projects using the standard, scope of complementary process standardization).
   - Comparisons with other countries (differences in workforce culture, regulation, polder model, grid congestion).

6. Closing (ca. 3–5 minutes)

1. **Summary and final input**
   "In summary, it sounds like the main points are `[2-3 key points summarized by interviewer]`. Does that match your experience? Is there anything important about `[ASSET]` standardization that we have not discussed?"
2. Thank the interviewee, explain next steps (transcription, analysis, optional feedback of results).
3. Immediately after the interview, the researcher recorded brief notes on key themes, data quality, and relevant non-verbal observations.

C.1.3. DSO within-case codebook

The Phase 3 DSO codebook extends both prior layers with codes that emerged from the within-case analysis of the six embedded cases. Two classes of addition appear in this layer. The first comprises analytical codes for effects, success factors, and challenges that practitioners in the case organizations raised but that were not present in the prior two layers; these extend the existing four code groups. The second comprises five case-specific situational categories that capture the narrative structure of within-case analysis but do not appear in the cross-sectional SLR or consultant material: case context, program timeline, organizational actors, project phases, and the situation around the standard. A final cross-case category captures moderating factors developed during cross-case synthesis in Chapter 7. All codes from Appendices B.1.5 and B.1.6 continue to apply. After cleaning, the Phase 3 codebook contributes 86 additional analytical codes.

Table C.2: DSO within-case codebook, code group 1 (positive effects) developed during cross-case synthesis.

Code	Definition
Cost and efficiency	
Ability to hold inventory of standard assets	Standard variants can be stock-held rather than project-allocated.
Reduced specific inventory	Lower project-specific inventory through commonality.
Quality, risk and safety	
Traceability of mistakes	Errors can be traced through documented and consistent designs.
Compliance-based dispute resolution	Contested deliveries referred to agreed specification rather than re-negotiated.
Operations, maintenance and learning	
Reduced skill threshold for routine work	Procedural compliance substitutes for engineering judgment at project level.
Workforce uniformity in equipment exposure	Field staff encounter only the standard variants; reduced exotic exceptions.
Strategic, relational and business-model	
Process standardization potential	Project and work processes can be standardized around the standard asset.
Smart-solution enablement	Standardization as platform for downstream digital or automated solutions.
Order-decoupling-point shift	Move from engineer-to-order toward make-to-stock production logic.

Table C.3: DSO within-case codebook, code group 2 (negative effects) developed during cross-case synthesis.

Code	Definition
Quality, risk and safety	
Forcing suboptimal adjacent components	Standard for one asset forces suboptimal choices on connected assets.
Forcing suboptimal network design	Standard envelope leads to suboptimal grid-level configurations.
Systemic risk of scaling	Concentration of technical risk when many assets share a single design.

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Table C.3 continued from previous page

Code	Definition
Operations, maintenance and learning	
Out-of-standard inventory residual	Legacy non-standard stock complicates the transition period.
Organizational ability loss	Reduced internal capability to design non-standard or innovative solutions.
Strategic, relational and business-model	
Contractor loss of freedom	Restriction of contractor autonomy and solution space.
Municipal loss of freedom and objections	Municipal resistance to standardized aesthetics or layouts.
Cost of standard components	Standardized solutions perceived as more expensive in some contexts.

Table C.4: DSO within-case codebook, code group 3 (success factors) developed during cross-case synthesis.

Code	Definition
Strategic and organizational governance	
Minimal decision-makers with mandate	Compact core team with clear authority for specification decisions.
Traceability and transparency	Documented rationale and history of changes, variants, and deviations.
Operational separation and demarcation	Clear demarcation of which unit decides on which specification element.
Stakeholder collaboration and culture	
Mechanic and field involvement	Operational field staff involved in design feedback loops.
Regional staff and municipality involvement	Regional units and municipalities involved early in the design cycle.
Processes, learning and change management	
Standard request and deviation process	Clear procedures for requesting non-standard solutions and handling exceptions.
Closing alternative paths	Ordering and design pathways outside the standard are structurally closed.
Cross-functional collaboration team (MFT/CMT)	Structured collaboration team across engineering, operations, and procurement.
Technical design and constructability	
Tactically well-designed standard	Standard is robust, widely applicable, and aligned with external norms.
Variability options accommodating stakeholders	Designed-in tolerance for legitimate local variation.
Pre-certified interfaces with external assets	Interfaces with client assets pre-certified to avoid project-level redesign.
Technology maturity and digital enablement	
Supporting IT tools	Ordering and configuration tools steering users toward standard variants.
Supplier relationships (new cluster)	

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Table C.4 continued from previous page

Code	**Definition**
Supplier dual-sourcing	Two qualified suppliers per critical component for resilience.
Supplier dedicated to region or project	Region- or project-specific supplier assignment for accountability.
Consistent specifications across suppliers	Same specifications enforced across all qualified suppliers.
Adherence to external norms	
Adherence to international norms	Internal standard anchored to IEC, NEN, or sector norms.

Table C.5: DSO within-case codebook, code group 4 (implementation challenges) developed during cross-case synthesis.

Code	**Definition**
Strategic and organizational governance	
Authority dispersion and demarcation issues	Overlapping mandates between programs, departments, and regions.
Fragmented ownership of the standard	No single integrally responsible owner across the lifecycle.
Tactical roadmap and prioritization issues	Difficulty sequencing governance investments under time pressure.
Stakeholder collaboration and culture	
Consensus-heavy decision-making (polder model)	Slow specification decisions due to extensive consensus-building.
Regional cultural differences and resistance	Regional units maintain distinct practices or resist central standards.
People skills and resistance to circumventing the standard	Field staff find or accept alternative paths outside the standard.
Processes, learning and change management	
Process circumvention in execution	Operational staff find ordering or design paths outside the standard.
Misalignment of internal processes	Project, procurement, and asset-management processes not aligned with the standard.
Tender and contract constraints	Contract durations and public-procurement rules complicate iterative development.
Lack of benefit measurement infrastructure	Absence of systematic before–after KPIs to evidence standardization effects.
Client, context and regulatory fit	
External regulatory constraints	Permits and objection procedures affecting specification options.
Municipal demands and spatial constraints	Local spatial and aesthetic requirements shaping standard applicability.
Technical design and constructability	
Configurational optimum versus standardization	Site-specific optimum technically achievable but precluded by the standard.
Innovation versus standard tension	Innovative solutions held back by adherence to current standard.

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Table C.5 continued from previous page

Code	Definition
Interface complexity with adjacent components	Standard for one asset must coexist with non-standard adjacent assets.
Supplier relationships and supply chain	
Supplier stopping component production	Supplier-side discontinuation forces specification updates.
Supplier power and dependency	Power asymmetry between DSO and a small qualified supplier set.
Suppliers causing inevitable variants	Supplier-specific tolerances reintroduce variation despite specification.
Permits and external stakeholders	
Municipality denying or delaying permit requests	Permit denial forces design or location deviation.
Inhabitant objections (size and noise)	Local objections to standard footprint or operational signature.

Code group 5: case context (new) Codes capturing the organizational, regulatory, and grid-design context in which each case program operates. Used to construct the "DSO context" and "historical background" sections of the within-case chapters.

Table C.6: DSO within-case codebook, code group 5 (case context) developed during cross-case synthesis.

Code	Definition
Organizational adoption driver	Strategic rationale that triggered the program's adoption.
Regulatory context: tenders determine approach	Public-procurement rules shape the standardization approach.
Net design influencing standard choices	Grid topology and architecture constraining specification options.
Grid load increase	Demand growth shaping the urgency and scope of standardization.
Quality concerns triggering the program	Quality issues in the legacy population motivating the program.
Labor capacity constraint	Workforce scarcity as a substantive program driver.
Project-allocated stock and scarcity	Inventory pre-commitment creating de facto rationing.

Code group 6: program timeline and key moments (new) Codes capturing the sequential evolution of the standardization program. Used to construct the "Timeline and key milestones" section of each case chapter.

Table C.7: DSO within-case codebook, code group 6 (program timeline) developed during cross-case synthesis.

Code	Definition
Program set-up moment	Initial program initiation and scoping.
Specification set-up	First-time specification development phase.

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Table C.7 continued from previous page

Code	Definition
Tender preparation and award	Procurement cycle from market reflection to award.
Pilot and proof of concept	Pilot deployment validating the standard before scaling.
Standard update or release cycle	Periodic update of the active specification.
Variant addition or phase-out	Adding or retiring a specific variant from the active set.
Rationalization moment	Active-set reduction from many variants to few.
Dual-sourcing introduction	Move from single to dual qualified supplier.
Future tender or specification update	Anticipated next-cycle changes.
Audit and KPI evaluation moment	Audit or evaluation event in the program timeline.

Code group 7: organizational actors and governance roles (new) Codes capturing the organizational units, governance roles, and external actors involved in each program. Used to construct the "Actors and governance structure" section of each case chapter.

Table C.8: DSO within-case codebook, code group 7 (actors) developed during cross-case synthesis.

Code	Definition
Asset Management (AM) unit	The asset-management function responsible for specification ownership.
AM standardization sub-unit	Within-AM unit responsible for the standardization program.
Multi-disciplinary or cross-functional team	MFT / CMT structure for specification decisions.
Operational installation responsible (OIV)	Operational authority for installed-asset safety.
Net specialist or net architect	Grid-design function shaping standard integration.
Tender board and executive board	Senior governance body authorizing tender and program scope.
Supplier and vendor	External supplier of the standard component.
Contractor	External party executing the project work.
Municipality and external stakeholder	Local authority or external party affecting deployment.
Regional branch and operations	Decentralized operational unit responsible for deployment.

Code group 8: project phases and operational steps (new) Codes capturing the project lifecycle from initiation to commissioning, used to locate where in the project work the standard takes effect.

Table C.9: DSO within-case codebook, code group 8 (project phases) developed during cross-case synthesis.

Code	Definition
Initiation and location choice	Project initiation; selection of placement.
Engineering and project design	Project-level engineering using the standard.
Permits and municipality discussion	Permit application and local authority engagement.
Ordering and procurement	Component or asset ordering through the standardized channel.
Production and supplier instructions	Supplier production work to standardized specification.
Transportation and logistics	Logistics from production to deployment site.

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Table C.9 continued from previous page

Code	Definition
Placement and construction	On-site placement and civil works.
Connection and commissioning	Asset connection and operational hand-over.
Maintenance, inspection and repair	Operational lifecycle activities after commissioning.

Code group 9: state of the standard (new) Codes capturing the before, current, and future state of the standard and its application. Used to construct the "Standard and program setup" and "Current state" descriptive passages in the within-case chapters.

Table C.10: DSO within-case codebook, code group 9 (standard state) developed during cross-case synthesis.

Code	Definition
Before: technical and design options	Legacy variant population and design rules before the program.
Before: situation and context	Organizational and market conditions before the program.
Before: way of working	Project- and operational-level practice before the standard.
Current: technical and design specifications	Current active standard variant set.
Current: governance processes	Current governance and change-management arrangements.
Current: way of working	Current project- and operational-level practice with the standard.
Current: in numbers	Active-variant counts, deployment counts, compliance rates.
Future: technical and design options	Anticipated future variant set.
Future: way of working	Anticipated future operational state.

Code group 10: cross-case moderating factors (new) Codes developed for cross-case synthesis (Chapter 7) capturing factors that operate above the within-case level and that condition the relationship between governance architecture and implementation depth. These codes underpin the governance-as-fit framework developed in Chapter 9.

Table C.11: DSO within-case codebook, code group 10 (moderating factors) developed during cross-case synthesis.

Code	Definition
Asset complexity	
Number of components in the asset	Component count internal to the standardized asset.
Number of interfaces	Count of interfaces between the standard and adjacent assets.
Functional homogeneity	Whether one function maps to one configuration, or many.
Reversibility risk	Lock-in once designs are deployed at scale.
Stakeholder density in specification	Number of internal and external parties involved in specification decisions.
Organizational fragmentation	
Size and merger-origin fragmentation	Large organizational scale and residual diversity from past mergers.
Regional culture and attitude differences	Variation across regions in norms and standardization openness.

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Table C.11 continued from previous page

Code	Definition
Historical grid design and legacy	Existing grid configurations constraining standard applicability.
Growth rate and workforce dynamics	Hiring rates introducing staff unfamiliar with governance rules.
Supplier and supply chain	
Supplier landscape and number	Number and capability profile of qualified suppliers.
Supplier capability and flexibility	Supplier capacity to coordinate compatible changes.
International and national norm coverage	Degree to which external norms pre-structure component choices.
Volume and project type	
Volume and asset mix	Number and mix of assets shaping payoff of standardization.
Greenfield versus brownfield share	Share of deployments in legacy versus new contexts.
External and regulatory context	
External regulatory constraints	Laws and permitting regimes affecting specification options.
Municipal demands and spatial constraints	Local spatial and aesthetic requirements affecting deployment.
Stakeholder power and bargaining position	Relative bargaining power of clients, municipalities, and other actors.
Financial constraints and investment priorities	Budget for governance, innovation, and standard refinement.

C.1.4. Documents and secondary material

This appendix lists the documentary sources consulted in this study, organized by their function rather than by case organization. Two prefix families are distinguished. Sources prefixed `S-` are published or otherwise publicly retrievable secondary sources: those prefixed `S-A`, `S-B`, and `S-C` correspond to publications issued by the three case DSOs (DSO-A, DSO-B, DSO-C); those prefixed `S-NL` are publications by sector-level organizations that do not identify any specific DSO; and those prefixed `S-S` are supplier-issued documents. Sources prefixed `D-` are internal organizational documents that were shared with the researcher on request and are not publicly retrievable; `D-A` and `D-B` denote internal documents provided by DSO-A and DSO-B respectively. DSO-C did not share internal documents, and no `D-C` entries therefore exist.

Consistent with the anonymization strategy described in Section 2.7, the appendix does not link individual sources to specific case organizations, and bibliographic detail beyond that needed to confirm authenticity, currency, and analytical role is omitted. For the internal `D-` documents, original document titles are deliberately not reproduced, because several would be sufficient to identify the issuing organization. The full case-attributed source register, including original titles, is maintained as an internal traceability file outside the thesis during the six-month data-retention window required by the TU Delft Human Research Ethics Committee.

DSO internal documents These documents were shared with the researcher on request and are not publicly retrievable. They were used to corroborate interview-based accounts of organizational structure, specification content, and standardization decision logic, and in a small number of cases to document quantitative design rationale (variant counts, lifecycle-cost and makeability reasoning) that interviews described qualitatively.

DSO-C did not share internal documents; documentary support for the DSO-C cases derives entirely from the publicly retrievable `S-C` sources listed above.

C.2. Phase 2 research findings

Table C.12: DSO secondary public sources consulted as contextual and corroborating material.

ID	Type	Year	Role in analysis
S-A.1	Corporate annual review	2025	Workforce, investment scale, regional coverage
S-A.2	Financial annual report	2025	Investment volumes, output figures, strategic framing
S-A.3	Investment plan	2025	Forward investment trajectory, 2026–2028 horizon
S-A.4	Modular construction program documentation	2020	Standardization rationale, savings targets, safety logic
S-A.5	Compact connection module adoption page	—	Sector-level standardization precedent
S-B.1	Group-level financial annual report	2023	Workforce, investment scale, asset volumes
S-B.2	Group-level financial annual report	2025	Updated investment volumes, output figures, transformer-station installation rate
S-B.3	Press release: framework-contract award for transformer stations	2023	Contract terms, supplier identities, delivery volumes
S-B.4	External government document on organizational history	2021	Mergers, unbundling, public capital-injection context
S-B.5	Joint sector announcement page on compact connection module	2023	National adoption decision, technical specifications
S-B.6	Investment plan	2023	Forward EV charging infrastructure roll-out commitments
S-C.1	Group-level financial annual report	2024	Workforce, investment scale, asset volumes, regional coverage
S-C.2	Group-level financial annual report	2025	Updated investment volumes, deployment figures, capacity added
S-C.3	Investment plan	2023	Forward investment trajectory, network-doubling horizon, labor-scarcity framing
S-C.4	Program news item: first transport-distribution station placement	2025	Pilot site, supply-chain composition, build-time benefit claim
S-C.5	Program web page	—	Standardization program positioning and rationale
S-C.6	Predecessor history page	—	Historical lineage of predecessor regional operators
S-C.7	External trade-press article on program	2025	Independent corroboration of supply-chain consortium architecture
S-C.8	External national news-agency item	2025	Public framing of program launch
S-C.9	External consultancy report mentioning program	2026	Independent external account of standardization rationale

Table C.13: DSO internal documents

ID	Type	Year	Role in analysis
D-A.1	Departmental organization chart (standardization function)	—	Corroboration of specification-authority location and team structure
D-A.2	Internal overview of organizational departments	—	Corroboration of inter-departmental structure and actor landscape
D-A.3	Internal decision document on station variant rationalization	2025	Cross-disciplinary sign-off (MDT composition); documented two-stage scenario appraisal and selected variant-reduction scenario
D-A.4	Internal component specification: distribution cable	2024	Layered requirement structure resting on referenced NEN standards; select-within-a-scaffolding logic
D-A.5	Internal component specification: prefabricated MV–LV substation, with procurement-process overview	2026	Specification content and cross-disciplinary approval; corroboration of procurement-enforcement (payability) pathway
D-B.1	Internal decision document: standard transformer-capacity "unless" rule	2023	Mandatory default-capacity rule and defined exception criteria; lifecycle (total-cost-of-ownership) rationale
D-B.2	Internal policy on distribution-station spatial integration, with makeability-analysis annex	2024	Standard exterior palette and capped non-standard-appearance share; documented makeability assessment across station types
D-B.3	Internal decision deck: variant and land-use minimization (four decisions)	2024	Before/after variant counts across technical, switchgear, transformer, and connection dimensions; de-meshing-to-single-connection-variant link

Table C.14: Sector-level secondary public sources

ID	Type	Year	Role in analysis
S-NL.1	Netbeheer Nederland communication on Climate Agreement	2019	DSO sector response, planning trigger

Table C.15: Supplier-issued secondary public sources

ID	Type	Year	Role in analysis
S-S.1	Supplier press release: framework-contract award	2021	Confirmation of multi-year procurement award
S-S.2	Supplier press release: product quality incident	2024	Confirmation of waterproofing remediation
S-S.3	Supplier press release: framework-contract award (compact stations)	2020	Confirmation of continued supply relationship and contract term

D

Phase 3 additional material

D.1. Phase 3 research materials

D.1.1. Three-axis standardization positioning of the embedded cases

The cross-case analysis in Chapter 7 treats the six embedded cases as occupying distinct positions along three standardization sub-dimensions introduced in Chapter 3 (§3.3.3): variant reduction within an active asset population, the degree of prefabrication under the four-level scale of Gibb (2001), and the location of the customer-order decoupling point at engineering and production levels following Wikner and Rudberg (2005). Table D.1 consolidates the case-level positioning data drawn from the within-case chapters (Chapters 4–6) and serves as an audit-trail artefact for the cross-case argument. The table is referenced explicitly from §7.7 when the four-stage standardization model is mapped onto the six embedded cases. Cross-case comparison along organizational and governance dimensions is presented in narrative form in Chapter 7; the analytical matrices that underpin that narrative are integrated into the chapter rather than reproduced separately here to avoid duplication.

Table D.1: Three-axis positioning of the six embedded cases on standardization sub-dimensions. The variant-reduction axis tracks the rationalization of the active product population. The prefabrication axis follows Gibb (2001) four-level scale. The decoupling axis distinguishes engineering-level and production-level customer-order decoupling points.

Case	Variant-reduction axis	Prefabrication axis (Gibb)	Engineering / production decoupling
A.1 (DSO-A distribution stations)	150 configurable combinations → 6 focus configurations (97% Q4 2025 compliance reported)	Level 3 (system-level prefab)	Engineering: standardized; Production: assemble-to-order under framework contract
A.2 (DSO-A LV/MV cables)	Stable small variant set; type-standardized, length-customized	Level 2 (component-level, prefab plug)	Engineering: fully standardized; Production: make-to-stock with supplier buffer
B.1 (DSO-B MV-LV transformer station)	~100 historical configurations → 3–4 active scheme types (“compact unless”)	Level 3 (modular compact-station prefab)	Engineering: standardized post-MFT; Production: assemble-to-order via TopTeam
B.2 (DSO-B compact connection module)	Single CAM standard across three DSOs	Level 3 (prefab connection module with factory plug)	Engineering: federated standardized; Production: make-to-stock via Connectens
C.1 (DSO-C compact distribution stations)	70+ variants → 3 segment-aligned (~2015) → 2 article-number variants (2023)	Level 3 (CMT-managed compact-station prefab)	Engineering: fully standardized; Production: make-to-stock (~6-week lead time)
C.2 (DSO-C TV(R)S)	Asset class resolved into 4 defined variants (TVS 10/20 kV; TVRS 2 or 3 transformers)	Level 3 in design intent; level 2–3 in execution (still on-site assembled)	Engineering: standardized; Production: assemble-to-order with prefab modules and on-site integration

E

Phase 4 additional material

E.1. Phase 4 research materials

E.1.1. Phase 4 validation session participants overview

Table E.1 summarizes the three senior practitioners who participated in the Phase 4 expert validation session. One practitioner participated from each of the three case DSOs, in accordance with the cross-case validation logic stated in Chapter 2 (§2.5) and reported in Chapter 8 (§8.1). Participants are referred to throughout Chapter 8 as *Interviewee DSO-A*, *Interviewee DSO-B*, and *Interviewee DSO-C*, consistent with the anonymization protocol applied across the thesis. Roles are reported as anonymized functional descriptions sufficient to establish seniority and cross-program responsibility while preserving participant anonymity in line with the HREC-approved data management plan.

Table E.1: Phase 4 expert validation session participants. Anonymized identifiers are used throughout Chapter 8. Roles are anonymized functional descriptions; identifying details have been suppressed in line with the HREC-approved data management plan. The session was conducted in Dutch and lasted approximately two hours.

ID	**Org.**	**Anonymized role description**	**Phase 2 link**	**Date**
Interviewee DSO-A	DSO-A	Senior asset and product management lead with cross-program oversight of distribution-network standardization	Yes (Int. A-1)	May 2026
Interviewee DSO-B	DSO-B	Senior asset-management policy and innovation lead with cross-program oversight of MV-LV and connection-module standardization	Yes (Int. B-2)	May 2026
Interviewee DSO-C	DSO-C	Senior cross-program standardization lead with oversight of compact distribution stations and transport-distribution stations	No	May 2026

E.1.2. Validation session protocol

This appendix describes the protocol used for the expert validation session with senior practitioners from the participating DSOs. The session was designed to assess the recognizability, completeness, and practical relevance of the cross-case findings, and to refine the governance-as-fit framework developed in Chapters 7 and 8.

Purpose and participants The validation session had three objectives:

1. To test whether the implementation challenges and governance components derived from the case studies were recognizable to senior practitioners.
2. To obtain practitioner judgments on the relative importance of these challenges and governance components.
3. To identify missing elements and sharpen the wording of the governance-as-fit framework before final synthesis.

Participants were senior professionals with cross-program responsibilities in asset management, standardization, and grid expansion from the three DSOs included in the case studies. All participants had direct experience with one or more of the standardized asset programs analyzed in the thesis. The participant roster is reported in Table E.1.

Session format The session was organized as a semi-structured group discussion of approximately two hours. It was held in person at a central location and facilitated by the researcher. Key elements were:

- Short presentation of the cross-case findings, focusing on the three overarching themes (governance architecture, organizational fragmentation, inherent variability and standardized deviation pathways) and the associated challenge and governance lists.
- Individual reflection: participants were first asked to read the lists silently, mark items they recognized as important in their own organization, and note any missing elements.
- Plenary discussion: the group then discussed each cluster of items in turn, with the researcher prompting for examples, agreement, disagreement, and refinements.
- Prioritization: participants were invited to indicate which challenges and governance components they considered most consequential for implementation depth.

The session was audio-recorded with consent and summarized in analytic memos immediately afterward.

Materials: fourteen implementation challenges. Participants received a one-page overview of fourteen implementation challenges (Table E.2), grouped into four domains. Each challenge was formulated in neutral language and illustrated with brief examples drawn from the within-case material. The four-domain grouping reflects the session materials as shown to participants; the cross-case analysis subsequently consolidates the challenges into the three-cluster taxonomy of Chapter 7 (§7.6), and two challenges are reframed during the session itself (Chapter 8, §8.2.4).

Table E.2: Fourteen implementation challenges presented to Phase 4 participants, grouped by domain.

#	Challenge	Brief formulation as presented to participants
Operational and implementation challenges		
1	Process circumvention in execution	Project teams and site staff bypass the standard process via alternative procurement routes, direct supplier contacts, or informal agreements.
2	Skill and knowledge erosion	Outsourcing and simplification of tasks reduce the depth of technical knowledge and improvisation skills in the organization.
3	Consultation-driven decision delays	The strongly consultative “polder model” slows down standard-related decision-making and leads to compromise designs.
Organizational challenges		
4	Communication gap between Asset Management and Operations	Specifications are set without systematic feedback from execution, leading to an “ivory tower” perception among operational staff.
5	Unclear ownership of the standard as a whole	No single actor feels integrally responsible for the entire standard; responsibility is fragmented across departments.
6	Regional culture differences and resistance	Merger-origin regional units maintain different technical traditions and identities, generating uneven adoption and resistance.
7	Dispersed authority due to organizational structure	Decision rights over specifications, procurement, and project execution are spread across several layers, complicating coherent governance.
Technical and specification challenges		
8	Specification incompleteness and sequencing	Transition-driven urgency forces DSOs to deploy a standard before the specification cycle is fully complete, creating gaps and frequent revisions.

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Table E.2 continued from previous page.

#	Challenge	Brief formulation as presented to participants
9	Unclear variety policy	The boundary between mandatory conformity and allowed deviation is insufficiently formalized, leading to inconsistent handling of exceptions.
10	Legacy network differences	Historical differences in network architecture and connection schemes make it difficult to apply one standard uniformly.
11	Innovation constraints	Existing standards and tender structures limit the scope for technical innovation and the introduction of improved solutions.
External challenges		
12	Supplier dependence	A concentrated component market gives suppliers substantial bargaining power and limits DSOs' ability to enforce technical changes.
13	Exogenous shocks	Regulatory changes and market developments require frequent adaptations to the standard, often on timelines that are difficult to manage internally.
14	Municipal dependence	DSOs are structurally dependent on municipal permitting and land acquisition, and spatial or aesthetic demands can conflict with standard designs.

Materials: ten governance components. A second slide presented ten organizational and governance components (Table E.3), framed as the main levers through which a DSO can shape implementation depth. For each component, a short guiding question was shown to focus participant response. The numbering is preserved in Chapter 8 (§8.3.1, Table 8.1) and referred to consistently throughout the cross-case discussion.

Table E.3: Ten organizational and governance components presented to Phase 4 participants, with the guiding question shown for each.

#	Component	Guiding question shown to participants
1	Ownership and governance team	Who decides on the standard?
2	Update and change process	How is the standard updated and revised?
3	Deviations and non-compliance	Under what conditions is deviation from the standard allowed, and how is this handled?
4	IT tools and process control	How do systems support and enforce use of the standard in ordering and project execution?
5	Knowledge management and documentation	Where does the "single source of truth" for the standard reside, and how is it maintained?
6	Horizontal coordination	How are decisions about the standard aligned across departments and programs?
7	Work allocation by project type	Which organizational chain is responsible for which types of projects using the standard?
8	Tender and procurement governance	How is the standard translated into procurement specifications, contracts, and supplier management?
9	Monitoring, KPIs, and evaluation	How is standardization success measured and fed back into governance decisions?

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Table E.3 continued from previous page.

#	Component	Guiding question shown to participants
10	Culture and mindset	To what extent do professionals and managers actually want to work with standards, and how is this attitude shaped?

Core questions to participants. For both the list of challenges and the list of governance components, participants were invited to respond to the following core prompts:

1. "Which of these items are clearly recognizable in your organization's experience with standardized assets? Which are less relevant or missing?"
2. "If you had to select three to five items that most strongly limit or enable implementation depth today, which would they be, and why?"
3. "Are there important challenges or governance components that are not yet captured in these lists? How would you formulate them?"
4. "Do any of the formulations need adjustment to better reflect how these issues manifest in your context?"

Participants' comments and rankings were used to refine the wording of the themes, to distinguish organization-specific from cross-organizational patterns, and to calibrate the prescriptive emphasis in the final governance-as-fit framework presented in Chapter 9.