

Integrating Plan for Every Part Analysis with Bill of Materials Readiness to Mitigate Long Lead-Time Risk in New Product Introduction

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Abstract

Long lead-time components can threaten a new-product launch even when the bill of materials appears complete. This paper develops a stage-gated framework joining Plan for Every Part analysis with bill-of-materials and enterprise-system readiness. A shared part-level record combines supply lead time, internal release lag, required build dates, evidence status and criticality. Lead-time slack and a weighted Material Readiness Index support explicit gate decisions and recovery ownership. A composite power-systems launch with 214 bill-of-materials lines demonstrates how timing and data readiness can produce different risk assessments. The example illustrates the decision logic without estimating its effect on launch performance. Buffer values, weights and gate thresholds are design parameters that require calibration and sensitivity analysis. The contribution is a traceable bridge between part-level planning and launch governance, with documented exceptions rather than an assumed readiness guarantee. Multi-program validation should test the relationship between gate assessments and shortage hours, expedite cost and schedule adherence. The framework complements quality planning, process capability and supplier qualification.

Keywords: *new product introduction; Plan for Every Part; bill of materials; ERP master data; lead-time risk; stage-gate; material readiness; supply chain resilience; U.S. manufacturing; power systems manufacturing*

1. Introduction

The commercial value of a new product depends heavily on how quickly and smoothly it moves from approved design to stable production. In practice, many NPI programs reach their pilot or first production build with engineering work largely complete but with material that is missing, late, incorrectly specified in the ERP system, or physically unsuited to the production line. When this happens, the launch slips, expediting costs rise, and the factory absorbs disruption that was predictable months earlier. The cost of such disruption is not trivial: announcements of supply chain glitches have been associated with significant losses in shareholder value (Hendricks & Singhal, 2003). Power systems products are particularly exposed. A typical unit such as a power conversion cabinet, a switchgear or distribution assembly, or a power supply module combines commodity hardware with engineered components that are made to order: custom transformers and inductors, insulated gate bipolar transistor (IGBT) or silicon carbide power modules, film and

electrolytic capacitor banks, molded case breakers and contactors, fabricated copper busbar, sheet metal enclosures and wire harnesses. Several of these categories carry supplier lead times measured in months, and recent component allocation periods have shown that quoted lead times can lengthen sharply and with little warning (Christopher & Peck, 2004; Simchi-Levi et al., 2014). Power electronic devices and converter assemblies are central to modern power systems (Adenuga, 2023; Mohan et al., 2003) and to grid architectures with high renewable penetration (Adenuga, 2022; M. A. Shittu et al., 2025). Design choices such as converter topology directly shape component count and therefore BOM complexity (Tackie et al., 2023), and semiconductor supply in particular has proved vulnerable to disruption and allocation (Gideon, 2025). Battery storage, substation equipment and other power infrastructure add further engineered content to the same supply base (Adaramola et al., 2018; Komi & Ganiu, 2022; M. A. Shittu et al., 2023). Transformer lead times in particular lengthened sharply after 2020 as demand grew faster than manufacturing capacity (McKenna et al., 2024; U.S. Department of Energy, 2022b).

The problem also has a national dimension. Since 2021, U.S. federal policy has treated manufacturing supply chain resilience as a strategic priority. Executive Order 14017 directed reviews of critical supply chains, and the resulting assessments identified fragile, single-source and long lead-time supply for manufactured goods as a vulnerability for both the commercial and the defense industrial base (The White House, 2021; U.S. Department of Defense, 2022). Grid and power conversion equipment, including transformers and power electronics, was singled out as essential to the clean energy transition and as subject to constrained supply (U.S. Department of Energy, 2022a). A parallel assessment of the information and communications technology supply chain reached similar conclusions about concentration and single-source dependence (U.S. Department of Commerce & U.S. Department of Homeland Security, 2022), and analysis of global value chains estimated that disruptions lasting a month or longer now occur every few years on average (Lund et al., 2020). Subsequent legislation, including the CHIPS and Science Act (2022) and the Inflation Reduction Act (2022), added incentives for domestic production and, in some programs, domestic content requirements. Executive Order 14005 strengthened domestic content preferences in federal procurement (Executive Order No. 14005, 2021), and the Infrastructure Investment and Jobs Act (2021) funded grid investment that depends on exactly this class of equipment. These measures respond in part to a long erosion of the domestic industrial base (Pisano & Shih, 2012). Each of these measures raises the number of new products, new suppliers and requalified parts flowing through U.S. factories, and with them the volume of NPI material risk. Supply chain reliability in the energy sector is increasingly treated as a matter of national capability rather than a concern of individual firms (Okonkwo et al., 2024b, 2025). Related work on digital supply chain governance in the energy and infrastructure sectors makes the same case for system-level coordination (Okonkwo et al., 2024a).

Two established practices speak to parts of this problem. **Plan for Every Part (PFEP)**, a lean material-flow tool popularized by Harris, Harris and Wilson (2003), records for each part the information needed to plan its supply, storage and presentation: supplier, location, lead time, usage, packaging, point of use and replenishment method. **BOM and ERP readiness**, rooted in material requirements planning (Jacobs et al., 2011; Ptak & Smith, 2011), concerns whether the product structure, item master records and planning parameters in the ERP system are correct enough to drive purchasing and production. In most organizations PFEP belongs to materials or lean engineering and is completed close to launch, while BOM accuracy belongs to engineering and planning and is checked through engineering change processes. Neither practice, on its own,

is designed to answer the question that matters most in NPI: *for every part, will it physically arrive, correctly specified and correctly planned, before the build that needs it?*

1.1 New product introduction and stage-gate governance

Stage-gate models structure product development as a sequence of work stages separated by decision gates at which a cross-functional group decides whether to continue, redirect or stop the project (Cooper, 1990, 2008). The approach has since been applied well beyond industrial product development, including to portfolio growth and innovation decisions (Agyei, 2021). Risk-based decision frameworks from regulated manufacturing (Aneke & Adesemoye, 2020) and predictive schedule-risk methods for large capital projects (Zhou et al., 2024) show how gate decisions can rest on quantified evidence rather than on status reporting. Their strength is that they make readiness explicit and force decisions at defined points. Studies of development performance emphasize that downstream manufacturing and supply issues should be addressed early, while design choices are still flexible (Brown & Eisenhardt, 1995; Clark & Fujimoto, 1991; Krishnan & Ulrich, 2001; Ulrich et al., 2020; Wheelwright & Clark, 1992). Coordination across the design and manufacturing interface is a central determinant of development outcomes (Adler, 1995), development teams face specific threats to manufacturability (Swink, 1999), and internal and external integration for product development is moderated by uncertainty (Koufteros et al., 2005). Overlapping development activities can shorten time to market, but only when upstream information is released early and reliably (Terwiesch & Loch, 1999). Product architecture links design decisions to process and supply chain consequences (Fixson, 2005; Ulrich, 1995), and lean product development emphasizes front-loading such issues (Morgan & Liker, 2006). Best-practice studies of stage-gate processes stress clear, visible gate criteria (Cooper et al., 2002), and graded readiness scales such as technology readiness levels (Mankins, 1995) and maturity models such as the capability maturity model (Paulk et al., 1993) offer precedents for the staged readiness assessment proposed here. Industry quality frameworks such as Advanced Product Quality Planning (AIAG, 2008) embed production readiness in their phase reviews, but they focus on process capability and part quality rather than on the timing of material supply.

In many firms, the material content of gate reviews is limited to a statement that "long-lead items have been identified" or that "the BOM is released." Such statements are binary and qualitative. They do not reveal how much slack remains for each part or whether the ERP system will in fact generate the right orders at the right time. Research on upstream capital projects identifies the same gap at a larger scale: field developments disappoint against their sanctioned budgets partly because long-lead equipment and logistics feasibility are treated as an after-the-fact scramble rather than part of the investment logic (Nwangwu et al., 2021).

1.2 Material flow and planning data

PFEP originated in lean material-handling practice as a single database containing every relevant fact about every part used in a facility (Harris et al., 2003). Typical fields include part number, description, supplier, supplier location, usage per assembly, daily usage, container type and quantity, container dimensions and weight, storage location, point of use, delivery frequency and safety stock. The PFEP underpins the design of supermarkets, delivery routes, kanban loops and line-side presentation, and it supports value stream thinking about material flow (Rother & Shook, 1999; Womack & Jones, 1996). It sits within the wider body of lean production practice (Liker, 2004; Shah & Ward, 2003, 2007) and supports level pull and material delivery routes (Smalley, 2004) as well as the choice of parts feeding policies at the assembly line (Kilic & Durmusoglu,

2015). More recent work links lean supply chain practices to waste reduction and competitiveness (Ike et al., 2022), proposes data-driven extensions of lean supply chain optimization in manufacturing (Efobi et al., 2022b), and applies Lean Six Sigma and lean process improvement to manufacturing processes and inventory management (Asiedu, 2025; Ezeugwa et al., 2023). Digital transformation of operations management through automation, analytics and process redesign has made it practical to maintain such part-level databases at scale (Agboada et al., 2018).

The PFEP literature is largely oriented to steady-state production. It is usually built or refreshed once volume production exists. In an NPI setting, however, many PFEP attributes are unknown or provisional for a long time, and the lead-time and supplier fields that matter most for launch risk are exactly those that are hardest to populate early. Using PFEP as an NPI risk instrument therefore requires a staged approach in which fields are completed progressively and checked at gates.

The BOM is the backbone of material planning. Material requirements planning explodes the master production schedule through the BOM, offsets requirements by planned lead times and generates planned orders (Jacobs et al., 2011; Ptak & Smith, 2011). The quality of the output depends entirely on the quality of the inputs: product structure, quantities per assembly, units of measure, item status, planning lead times, lot-sizing rules and sourcing assignments. Research on product modeling notes that the engineering BOM (EBOM), which reflects the design, and the manufacturing BOM (MBOM), which reflects how the product is built and planned, differ in structure and purpose and must be reconciled (Hegge & Wortmann, 1991). Generic BOM structures have been proposed for high-variety products (Jiao et al., 2000), and product lifecycle management systems maintain product structure across the life cycle (Stark, 2015; Terzi et al., 2010). ERP systems integrate planning and transaction data across functions (Davenport, 1998; Jacobs & Weston, 2007), but their benefits depend on implementation quality and on fit with plant conditions (Gattiker & Goodhue, 2005; Umble et al., 2003). MRP itself is known to be sensitive to lead-time and supply uncertainty (Dolgui & Prodhon, 2007; Whybark & Williams, 1976). Reviews of procurement strategy and ERP adoption link system implementation to logistics performance (Okonkwo et al., 2024d), and frameworks for integrating IT systems engineering with supply chain operations stress that system benefits depend on the integrity of the underlying data (Okonkwo, Ahiaeke Patrick, et al., 2023).

In NPI, these inputs are created under time pressure, often by several people, and frequently before the design is stable. Common defects include items created with default or placeholder lead times, mismatched units of measure, missing approved manufacturer data, phantom assemblies configured incorrectly and revisions that differ between the engineering change record and the purchase order. Each defect can cause MRP to under-plan, over-plan or plan the wrong revision. Data quality has several dimensions beyond accuracy, including completeness, timeliness and consistency (Wang & Strong, 1996), poor data quality is a recognized ERP implementation problem (Xu et al., 2002), and its costs are often hidden (Haug et al., 2011). Engineering changes, which are frequent during NPI, add further disruption to materials planning (Huang & Mak, 1999; Jarratt et al., 2011; Wänström & Jonsson, 2006). Structured user acceptance testing (Eyetsemitan et al., 2023) and digital transformation of manufacturing operations (Obukadata et al., 2021) are among the remedies proposed. Automation and digital twin approaches have been proposed to reduce such procurement errors and turnaround time (Akinlade et al., 2024), and inventory visibility across the asset life cycle depends on the same records (Okonkwo, Mayo, et al., 2023). GIS-enabled and automated ERP procurement processes (Ahiaeke Patrick et al., 2020; Akinleye & Adeyoyin, 2021), supply chain automation on service management platforms (Okonkwo et al., 2024f) and integrated digital procurement platforms (Okoruwa et al., 2024) all presuppose accurate

item and supplier records. Reviews of data integrity in regulated operations show that failures in such records are common and are best addressed through explicit controls (Aneke et al., 2023), and agile supply chain transformation frameworks recommend embedding IT risk and compliance controls in the data flow itself (Mbonu et al., 2020).

1.3 Supply risk, lead time and the policy context

Supply risk in NPI is strongly influenced by how early suppliers and procurement are involved. Supplier integration research shows that early involvement of suppliers in development improves cost, quality and time outcomes, provided it is managed deliberately (Handfield et al., 1999; Johnsen, 2009; Petersen et al., 2005; Ragatz et al., 1997; Van Echtelt et al., 2008; Wynstra et al., 2001). Supplier development likewise improves supplier performance over time (Krause et al., 2007), and supply chain integration more broadly is associated with operational performance (Flynn et al., 2010; Mentzer et al., 2001). Supply risk itself has been defined and studied extensively (Ho et al., 2015; Jüttner et al., 2003; Tang, 2006; Zsidisin, 2003). The severity of a disruption depends on supply chain design characteristics such as node criticality (Craighead et al., 2007), firms can choose between mitigation and contingency strategies (Chopra & Sodhi, 2004; Kleindorfer & Saad, 2005; Tomlin, 2006), and risk affects performance along several dimensions (Wagner & Bode, 2008). Resilience research stresses capabilities that allow firms to absorb and recover from disruption (Pettit et al., 2010; Ponomarov & Holcomb, 2009; Sheffi & Rice, 2005), and recent work examines visibility, digital technology and artificial intelligence as enablers (Barratt & Oke, 2007; Baryannis et al., 2019; Ivanov et al., 2019). Supplier relationship management is similarly associated with collaboration, innovation and resilience (Akinleye & Adeyoyin, 2022b; Ike et al., 2021). Portfolio approaches such as Kraljic's (1983) matrix classify purchased items by supply risk and profit impact, which helps focus attention on strategic and bottleneck items, although its measurement requires care in practice (Gelderman & van Weele, 2003; Monczka et al., 2016). Predictive models for vendor risk assessment (Tonoyan et al., 2024a), strategic sourcing and spend analytics for supply shock mitigation (Nwangwu et al., 2025), and big data approaches to manufacturing procurement (Akinleye et al., 2023) extend this classification with analytics. Data-driven vendor evaluation (Ahiaeke Patrick et al., 2021), procurement risk management in multinational enterprises (Bello et al., 2023), vendor management practice (Wedraogo et al., 2025), strategic procurement optimization (Okonkwo et al., 2018a), and contract negotiation and vendor governance (Akinleye & Adeyoyin, 2022a; Okonkwo et al., 2019) all bear on how quickly and reliably a long lead-time order can be placed. Vendor performance analytics and supply forecasting (Abdulrazaq et al., 2025), data visualization for procurement decisions (Babatope et al., 2023), supplier sustainability metrics (Akin-Oluyomi, Okoruwa, et al., 2023), digital procurement transformation (Okoruwa et al., 2025), sustainable and resilient procurement frameworks (Akinleye, 2024), and supply chain integration during energy asset acquisitions (Nwangwu et al., 2023) extend the same line of work. Work on supply chain design argues that innovative products with uncertain demand require responsive rather than purely efficient supply arrangements (Fisher, 1997), and work on resilience emphasizes visibility and early warning (Christopher & Peck, 2004). Risk management models for engineering, procurement and construction projects (Agbabiaka et al., 2019), resilient logistics frameworks (Anene & Clement, 2022) and reviews of post-disruption resilience in distribution networks (Anene, 2021) reinforce the value of identifying critical items early. Studies of pharmaceutical supply chains reach similar conclusions about mitigating disruption and ensuring availability

(Awulu et al., 2022b), and contractual mechanisms such as force majeure clauses shape how energy supply chains absorb shocks (Uchechi et al., 2020).

Variability in lead time also has well-understood operational consequences: longer and more variable lead times require more buffer, whether in time, capacity or inventory (Hopp & Spearman, 2008; Karmarkar, 1987; Silver et al., 2017), and lead-time reduction is itself a strategic lever (Suri, 1998). Demand-driven approaches propose positioning decoupling buffers to compress effective lead times (Ptak & Smith, 2016), but these approaches assume stable product structures and demand history that do not yet exist during NPI. Predictive procurement planning has likewise been proposed to sustain operational uptime (Okonkwo et al., 2024c), but it also relies on consumption history that a new product does not have. The same limitation applies to predictive analytics frameworks for supply chain management more broadly (Akin-Oluyomi & Akhigbe, 2023; Rukh et al., 2024). The federal supply chain reviews that followed Executive Order 14017 (2021) framed resilience in terms that map directly onto NPI material risk: dependence on single or foreign sources, limited visibility beyond first-tier suppliers, and long, volatile lead times for engineered components (The White House, 2021). The Department of Defense action plan emphasized the need to identify and mitigate single points of failure in defense-critical supply chains and to strengthen domestic sources (U.S. Department of Defense, 2022). The Department of Energy strategy for the clean energy transition highlighted grid equipment, including transformers and power electronics, as categories where supply is constrained and domestic capacity needs to expand (U.S. Department of Energy, 2022a).

These documents set direction at the level of industries and sectors. They do not prescribe the plant-level practices by which an individual manufacturer brings a new product to market without being stopped by its slowest part. Power systems manufacturers sit at the intersection of all three priorities: they supply equipment for domestic electrification and emissions reduction, they frequently serve defense and critical infrastructure customers, and they depend on exactly the engineered, long lead-time components identified as vulnerable. Resilience frameworks for critical infrastructure supply chains make a similar argument at the level of the facility (Ogunwole et al., 2021), and work on sustainable procurement in local manufacturing emphasizes the development of domestic supplier capability (Efobi et al., 2022a). Localized supply chain models for regional resilience (Anene & Clement, 2024), supply chain technology adoption in North America (Ekwunife et al., 2024) and workforce readiness for technical occupations in the United States (Joseph et al., 2025) are related strands.

1.4 Research objective and scope

Taken together, the literature offers mature tools for material flow (PFEP), for planning logic (BOM and MRP), for development governance (stage-gate) and for supply risk classification, and national policy has made resilience in these supply chains a priority. The closest antecedent is a conceptual model linking materials readiness to supply chain performance in maintenance-driven settings (Okonkwo, Agbabiaka, et al., 2021). It establishes materials readiness as a measurable construct but does not address the gated, design-driven context of NPI. What is missing is an integrated, gate-by-gate mechanism that combines these tools to answer a single operational question for every part in an NPI program: is there enough time, and is the data correct enough, for this part to be available at the build that needs it?

This paper proposes a stage-gated readiness framework that runs PFEP analysis and BOM/ERP readiness checks as two coordinated streams, joined at each NPI gate by a quantitative lead-time slack test and a Material Readiness Index (MRI). The framework holds PFEP attributes and ERP

master data in a single part-level record, so that one record shows both what a part needs physically and whether the system can plan it. It measures slack against an effective lead time that includes internal release lag, the time consumed by item creation, sourcing approval and purchase order release, which is often larger and less visible than the supplier lead time. It also sets auditable gate criteria from concept (G0) through post-launch stabilization (G5), with a decision rule of Go, Conditional Go with an expedite plan, or Hold. The approach is grounded in the management of bills of materials exceeding 200 parts across multiple power systems products. Its novelty lies in treating PFEP not as a steady-state material-flow tool but as a gate-bound NPI risk instrument, combined with ERP readiness checks through a common time-based and data-based test.

The readiness framework does not operate in isolation. Three adjacent supply chain capabilities exchange information with it at defined points: disruption early warning, which detects signals such as lead-time extensions and allocation notices before they reach the factory; inventory exposure control, which governs the value and risk held in stock once a product is in volume production; and compliance governance, which ensures that substance, emissions and sourcing obligations are met across the part base. Each relies on the part-level record that this framework builds during NPI, and Section 3.4 sets out the inputs and outputs exchanged with each.

The remainder of the paper is organized as follows. Section 1.5 relates the framework to operations research on supplier selection, lead-time and capacity buffering, receiving and storage constraints, and supply chain readiness during product development. Section 2 describes the research method and the design of the readiness framework. Section 3 presents and discusses the results of its application to an illustrative composite power systems product, together with its implications. Section 4 concludes.

1.5 Related operations research and design implications

The literature reviewed in Sections 1.1 to 1.3 explains why NPI material risk arises; a second body of operations research supplies the quantitative ideas from which the slack test, the buffer rule and the gate fields of this paper were built. Three strands are relevant: supplier selection under delay risk, lead time and capacity buffering, and receiving, storage and replenishment constraints. A fourth strand, on building supply chain readiness during product development (Tolonen et al., 2017), is the closest to the present problem. Most of these studies address steady-state planning, sectors other than power systems, or formal optimization. They are used here to justify specific design choices, not as evidence that the framework improves launch outcomes.

1.5.1 Supplier selection under delay risk

Supplier choice determines much of the effective lead time before any order is placed. Shidpour et al. (2025) propose a multi-phase analytics framework for supplier selection and order allocation that treats delay risk and Industry 4.0 readiness as explicit criteria. Their framing supports two choices in this paper. First, the source check $Q(i)$ in Equation (4) treats a supplier as ready only when it is approved and orderable, not merely identified. Second, the single-source flag and the quote date in Table 1 make delay exposure visible at G1, while an alternate source can still be qualified. Portfolio classification of bottleneck items (Gelderman & van Weele, 2003; Kraljic, 1983) explains why these fields are mandatory for long-lead parts first: for custom magnetics and power modules, a late supplier decision consumes release lag that no later expedite can recover.

1.5.2 Lead time, capacity and inventory buffers

Several studies treat capacity and inventory as substitutes when demand or supply is uncertain. Rajagopalan and Swaminathan (2001) coordinate production planning with capacity expansion and inventory, and Bradley and Arntzen (1999) plan production, capacity and inventory simultaneously under seasonal demand. Liu and Tu (2008) study production planning with limited inventory capacity where stockouts are allowed, which parallels the partial-kit and schedule-change recovery options for Red parts in Table 2. Wu (2001) models' inventory with variable lead time and random supplier capacity; this supports setting the buffer $k(i)$ as a proportion of effective lead time rather than as a fixed number of days only. In high-technology settings, Smirnov et al. (2021) examine whether long-term resource planning should hold capacity or inventory, and Uzsoy et al. (2018) survey demand planning, inventory and capacity models for semiconductor supply chains. Both bears directly on the IGBT power module in Table 5, for which the G4 choice is between reserving supplier capacity and holding safety stock.

Rodriguez et al. (2017) optimize production planning and inventory management jointly in a process plant, which indicates that the G4 safety stock decision for long-lead and single-source parts should be taken together with the production plan rather than separately from it. Turksen and Berg (1991) build an expert system prototype that applies approximate reasoning to inventory capacity planning. The MRI takes a deliberately simpler route, using coarse ordinal criticality weights in Equation (5) and accepting less nuance in exchange for a calculation that a gate committee can reproduce and audit.

1.5.3 Receiving, storage and replenishment constraints

The transit and receiving term $TR(i)$ in Equation (1) and the presentation fields required at G3 reflect constraints that conventional long-lead lists often omit. Campbell (1991) relates materials receiving capacity to inventory management, which matters at a pilot build when several long-lead parts arrive within the same window and compete for receiving inspection. Dai et al. (2021) plan inventory replenishment under storage capacity constraints, Bandaly and Hassan (2019) study postponement in an integrated production and inventory plan with limited storage and deteriorating stock, and Žic et al. (2023) optimize replenishment under an (R, s, S) policy. Together these studies support defining the replenishment method, storage location and container data before G3 rather than after launch. Work on deteriorating and perishable items (Chandramohan et al., 2023; Daroudi et al., 2021) is also relevant to power systems products, where shelf-life-limited materials such as electrolytic capacitors, adhesives and potting compounds can arrive on time yet be unusable at the build. Such items are candidates for an expiry attribute within the packaging and presentation field group of Table 1.

1.5.4 Supply chain readiness during product development

Tolonen et al. (2017) describe supply chain capability creation as the building of supply chain readiness for a new product during the product development process. Okonkwo, Agbabiaka, et al. (2021) model materials readiness as a driver of maintenance-driven supply chain performance, and supplier relationship management adds a complementary perspective on collaboration and resilience (Ike et al., 2021). The present framework operationalizes these ideas at the level of individual parts and gates. Two studies from outside manufacturing inform the treatment of evidence. Akers et al. (1990) account for core materials and fission product inventory at Three Mile Island Unit 2, and Poolsawad et al. (2016) assess whether a national life cycle inventory is ready for product environmental footprint use. Both treat an inventory statement as credible only

when each entry has a documented basis and is fit for a stated purpose. The same principle underlies the rule in Section 2.6 that missing readiness evidence counts as unready, and the requirement that compliance attributes be present in the item master before G2.

2. Research Method

The study follows a practitioner design science approach, in which an artifact (here, a management framework) is designed to solve an observed organizational problem and is then evaluated for utility in context (Hevner et al., 2004; Peffers et al., 2007; van Aken, 2004). Design science has been advocated in operations management as a way to bridge practice and theory (Holmström et al., 2009). The problem was identified, and the framework was developed and refined, through the first author's direct responsibility for PFEP analysis and for the management of bills of materials exceeding 200 parts across multiple power systems products during NPI.

The working material that informed the design included PFEP worksheets, ERP item master and BOM extracts, engineering change records, supplier quotations and acknowledgements, purchase order histories and build shortage logs. The design proceeded in three iterations. In the first, shortages and late changes at prototype and pilot builds were traced back to their origin, and recurrent root causes were grouped into failure modes (Section 3.2). In the second, a combined data model, a slack calculation and gate criteria were drafted to intercept each failure mode at the earliest gate where it could be detected. In the third, the criteria and thresholds were adjusted as they were applied to successive products, to balance rigor against the administrative effort required of engineering and supply chain staff. Because the evidence base is drawn from practice within a single organizational context and products cannot be named, the application in Section 3 is presented in anonymized and illustrative form. Values shown are representative and rounded. They demonstrate how the framework operates rather than claiming statistically generalizable effects, consistent with the use of case and field research for theory building in operations management (Eisenhardt, 1989; Meredith, 1998).

2.1 Readiness framework design

The framework runs two readiness streams in parallel across six gates (Figure 1). The **PFEP stream** establishes what each part physically requires: who supplies it, how long it takes, how much is needed, how it is packed and where it will be used. The **BOM/ERP stream** establishes whether the system can plan and procure it correctly: whether the part exists in the right product structure, with the right master data, revision and planning parameters. At each gate, the two streams meet in a quantitative review consisting of a lead-time slack test for every part and a Material Readiness Index for the product as a whole. The stream structure follows stage-gate governance, in which criteria are visible and tighten from gate to gate (Cooper, 2008; Cooper et al., 2002), while the PFEP stream retains the part-by-part discipline of lean material planning (Harris et al., 2003). As Figure 1 shows, neither stream alone determines the gate decision; the joint review converts both into Go, Conditional Go or Hold.

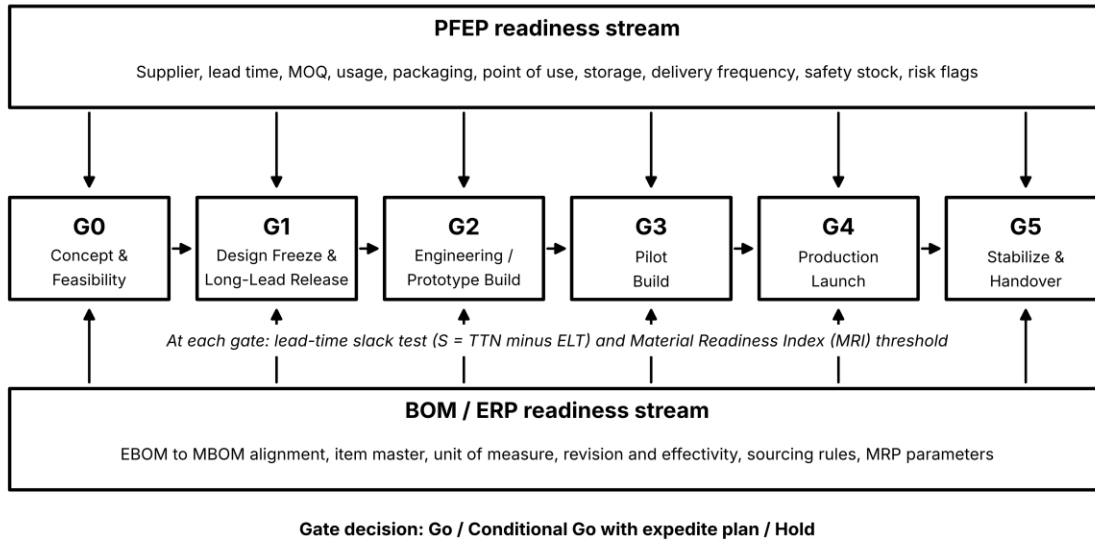


Figure 1. Stage-gated readiness framework combining the PFEP stream and the BOM/ERP stream.

2.2 Part-level data model

The foundation of the framework is a single record per part that joins PFEP attributes with BOM and ERP attributes. Keeping these in one structure, whether a controlled workbook or a database view drawn from PLM and ERP, removes the reconciliation that otherwise happens informally between functions. Table 1 lists the core fields and the gate by which each must be populated. The record follows the distinction between engineering and manufacturing product structures (Hegge & Wortmann, 1991) and treats completeness and timeliness, not only accuracy, as dimensions of data quality (Wang & Strong, 1996). The required-by column staggers population across gates, because attributes such as pack quantity and point of use cannot be known at concept, whereas the risk flags are refreshed at every gate.

Table 1. Core fields of the combined PFEP and BOM/ERP record

Field group	Fields	Stream	Required by
Identity	Part number, description, revision, commodity, make or buy	Both	G0
Supply source	Supplier, manufacturer and manufacturer part number, supplier location, single or sole source flag	PFEP	G1
Lead time	Quoted supplier lead time, quote date, internal release lag, transit and receiving time	PFEP	G1

Field group	Fields	Stream	Required by
Order economics	Minimum order quantity, order multiple, unit cost, tooling or NRE	PFEP	G1 (long lead), G2 (all)
Usage	Quantity per assembly, units per build, forecast daily usage	Both	G2
Product structure	EBOM position, MBOM position, phantom or kit status, effectivity	BOM/ERP	G2
Item master	Item status, unit of measure, approved manufacturer list, compliance attributes (for example RoHS, REACH, safety agency recognition)	BOM/ERP	G2
Planning parameters	Planning lead time, lot sizing rule, safety stock, sourcing rule, buyer and planner codes	BOM/ERP	G3
Packaging and presentation	Container type, pack quantity, container dimensions and weight, storage location, point of use, replenishment method, delivery frequency	PFEP	G3
Risk flags	Long-lead class, allocation status, single source, open engineering change, last-time-buy or obsolescence notice	Both	Every gate
Origin and sourcing restrictions	Country of origin, domestic content eligibility, defense or customer sourcing restrictions, export control classification where applicable	Both	G1 (long lead), G2 (all)

Note: Long-lead parts must meet G1 requirements for supply source, lead time and order economics even though other parts may defer them to G2.

2.3 Effective lead time and the slack test

Conventional long-lead lists compare supplier lead time against the program schedule. Practice shows that this understates risk because a substantial and often unmeasured interval passes before the supplier's clock even starts. The framework therefore defines an **effective lead time** for part i :

$$ELT(i) = RL(i) + LT(i) + TR(i) \quad (1)$$

where $RL(i)$ is the internal release lag (from the date the part's design is sufficiently defined to order, through item creation, sourcing approval and requisition, to purchase order transmission), $LT(i)$ is the supplier lead time from order acknowledgement to shipment, and $TR(i)$ is transit, receiving and inspection time. For imported parts, port clearance and customs delays can make

this last term significant (Okonkwo et al., 2020). **Time to need** for build b is measured from the gate review date $t(g)$ to the date the part must be at the point of use, $D(i,b)$:

$$TTN(i, b) = D(i, b) - t(g) \quad (2)$$

The **slack** for each part at each gate is then:

$$S(i, b) = TTN(i, b) - ELT(i) \quad (3)$$

Parts are classified using a buffer threshold $k(i)$, set as the greater of a fixed number of working days and a percentage of effective lead time, to reflect the larger uncertainty of longer lead times (Hopp & Spearman, 2008). Table 2 shows the classification and the required response.

Table 2. Slack classification and required response

Class	Condition	Required response at the gate
Red	$S(i,b) < 0$	Part cannot arrive on time by normal means. Requires an approved recovery plan: expedite, alternate source, design substitution, build with a partial kit, or schedule change.
Amber	$0 \leq S(i,b) < k(i)$	Part can arrive on time only if nothing slips. Requires a named owner, a release date commitment and weekly tracking until the order is acknowledged.
Green	$S(i,b) \geq k(i)$	Sufficient slack. Normal monitoring through the PFEP and MRP exception reports.

Note: In the case application, $k(i)$ was set as the greater of 10 working days or 20 percent of $ELT(i)$. Organizations should calibrate this to their own lead-time variability.

2.4 Material Readiness Index

Slack answers the timing question. Readiness of the record answers the data question. For each part, five binary checks are evaluated at the gate: PFEP fields required by that gate are complete (P); the part is correctly placed in the BOM with the correct quantity and effectivity (B); the ERP item master is complete and consistent (E); a source is approved and orderable (Q); and the part is not classified Red (T). A part is ready at the gate if all applicable checks pass:

$$R(i) = P(i) \times B(i) \times E(i) \times Q(i) \times T(i), \quad \text{where each term is 0 or 1} \quad (4)$$

The product-level **Material Readiness Index** weights each part by its criticality, so that a missing custom transformer counts for more than a missing washer:

$$MRI = \frac{\sum_i w(i) R(i)}{\sum_i w(i)} \quad (5)$$

The MRI is a summary indicator in the tradition of real-time KPI tracking and operational performance metrics (Awulu et al., 2022a; Tonoyan et al., 2024b). Weights are assigned on a simple ordinal scale (for example 1, 3 or 9) based on long-lead class, single-source status and cost or schedule impact, in the spirit of supply risk portfolio classification (Kraljic, 1983). The index plays a role similar to the readiness maturity models used to assess regulatory preparedness before market entry (Eze et al., 2022b). The weighting is intentionally coarse: its purpose is to prevent a high count of simple, ready parts from masking a small number of critical, unready ones.

2.5 BOM and ERP readiness checks

The BOM/ERP stream applies a defined set of checks rather than relying on the general assertion that the BOM is released. Each check targets one of the MRP inputs on which planned orders depend, namely product structure, quantity, unit of measure, item status, planning lead time, lot sizing and sourcing (Jacobs et al., 2011; Ptak & Smith, 2011). Table 3 lists the checks and the failure each is designed to prevent. The structural checks (EBOM to MBOM alignment, revision and effectivity, phantom and kit structure) determine the term B(i) in Equation (4), the item master and planning checks determine E(i), and the approved manufacturer and sourcing checks also inform Q(i). Revision and effectivity receive particular attention because engineering changes during NPI are a recognized source of materials planning disruption (Wänström & Jonsson, 2006).

Table 3. BOM and ERP readiness checks

Check	Test	Failure prevented
EBOM to MBOM alignment	Every EBOM component appears in the MBOM with the same quantity, or the difference is documented	Parts omitted from planning; double counting
Item status	Item is active and purchasable, not in a prototype or hold status	MRP ignores or blocks requirement
Unit of measure	Purchasing, stocking and BOM units agree, with conversion factors defined (for example, cable in feet versus each)	Order quantities wrong by a factor
Revision and effectivity	BOM revision, open engineering changes and purchase order revision agree	Wrong revision ordered or received
Phantom and kit structure	Phantom subassemblies are flagged correctly; kits explode to their components	Requirements not passed to components
Approved manufacturer list	At least one approved manufacturer and part number per item; second source noted where available	Unapproved substitution; single-source exposure not visible
Planning lead time	ERP lead time equals the latest quoted lead time, not a default	MRP releases orders too late
Lot sizing and MOQ	Lot sizing rule and supplier MOQ are reflected in the item master	Excess or insufficient quantities
Sourcing rule and buyer code	Item is assigned to a supplier and an accountable buyer	Requisitions unowned or unconverted
Cost roll-up	Standard or estimated cost is present	Purchase order approval delays; inaccurate product cost

2.6 Gate criteria and decision rule

Table 4 specifies what must be true at each gate. Criteria tighten as the program advances, which reflects the progressive nature of NPI information while ensuring that the parts that matter most for timing are addressed first.

Table 4. Gate criteria for the integrated readiness framework

Gate	PFEP stream	BOM/ERP stream and joint review
G0 Concept and feasibility	Preliminary part list with commodity and make or buy. Candidate long-lead list from commodity history (magnetics, power modules, breakers, fabrications).	Preliminary EBOM structure. Long-lead candidates reviewed with procurement. Indicative lead times obtained.
G1 Design freeze and long-lead release	All long-lead parts have supplier, quoted lead time, MOQ and release lag recorded. Single-source flags set.	Long-lead item masters created and active. Slack test run for all long-lead parts. No Red part without an approved recovery plan. Long-lead purchase orders released or committed.
G2 Engineering or prototype build	PFEP fields for supply source, lead time, order economics and usage complete for all parts.	Full EBOM released; MBOM drafted and reconciled. Item masters complete. Slack test for all parts against pilot build need date. MRI at or above 0.80.
G3 Pilot build	Packaging, storage location, point of use and replenishment method defined for all parts.	MBOM validated against pilot build. Planning parameters set from current quotes. No Red parts. MRI at or above 0.95.
G4 Production launch	Supermarket and line-side quantities sized from PFEP usage and pack data. Safety stock set for long-lead and single-source parts.	All BOM/ERP checks pass. Supplier first article or equivalent approvals complete. MRI equal to 1.00 or documented exceptions accepted.
G5 Stabilization and handover	PFEP updated with actual lead times and pack data observed in the first production period.	ERP lead times corrected to actuals. Open engineering changes closed. Record transferred to sustaining owners.

Note: MRI thresholds shown are those applied in the case application and should be calibrated by each organization.

Each gate concludes with one of three decisions. **Go** is given when all criteria are met. **Conditional Go** is given when criteria are met except for named parts that have an approved recovery plan with an owner and date, and when the weighted shortfall does not threaten the next build. **Hold** is given when a Red part has no credible recovery path or when the MRI is below the threshold for reasons that cannot be resolved before the next build. The value of the rule lies less in the label than in forcing an explicit, recorded decision about each critical part. Recovery plans attached to a

Conditional Go work like corrective and preventive actions in quality management systems and benefit from the same discipline of root-cause analysis and effectiveness checks (Aneke et al., 2022). Three protocol rules make the decision reproducible. First, the eligible bill-of-materials revision and the criticality weights are frozen at each gate, so that the MRI is calculated on a defined population of parts. Second, missing readiness evidence counts as unready, whereas a missing lead time triggers investigation rather than a zero-duration assumption that would produce spurious slack. Third, time to need and effective lead time are calculated on the same working-day calendar. An MRI below the gate threshold ordinarily produces Hold; a Conditional Go below the threshold requires a documented, approved exception that names the parts, recovery owners, due dates and an assessment of the next build. Mandatory safety, quality and legal requirements are not waived through an internal expedite plan.

3. Results and Discussion

3.1 Application to a power systems product

The framework was applied across multiple power systems products whose bills of materials each exceeded 200 parts. To illustrate its operation without disclosing proprietary information, this section uses a composite product, referred to as Product A: a floor-standing power conversion cabinet with a 214-line BOM. Product A combines custom magnetics, power semiconductor modules, a DC link capacitor bank, protective devices, fabricated copper busbar, a sheet metal enclosure, wire harnesses, printed circuit board assemblies and fasteners, the component mix typical of converter assemblies (Mohan et al., 2003). All figures are representative and rounded, and the results that follow illustrate the decision logic rather than measured effects (Meredith, 1998).

Table 5 shows the slack test for a selection of Product A parts at gate G1, with the pilot build as the target. The pilot build was scheduled 140 working days after the G1 review.

Table 5. Illustrative slack test at G1 for selected Product A parts (working days)

Part (commodity)	RL	LT	TR	ELT	TTN	S	Class
Main power transformer (custom magnetics)	25	110	10	145	140	-5	Red
IGBT power module	15	105	5	125	140	15	Amber
DC link film capacitor	20	80	5	105	140	35	Green
Molded case circuit breaker	10	70	5	85	140	55	Green
Fabricated copper busbar set	30	45	5	80	135	55	Green
Enclosure (sheet metal, painted)	35	60	5	100	115	15	Amber
Control PCBA	20	75	5	100	140	40	Green
Main harness assembly	25	40	5	70	130	60	Green

Note: RL = internal release lag; LT = supplier lead time; TR = transit, receiving and inspection; ELT = RL + LT + TR; TTN = time to need; S = TTN minus ELT. Buffer $k(i)$ = greater of 10 days or 20 percent of ELT.

Three observations follow from Table 5. First, the transformer appears on any conventional long-lead list, yet its Red status arises only when internal release lag is included: on supplier lead time alone, it would have appeared to have 30 days of slack. Second, the enclosure is Amber not because of its supplier lead time but because of the longest release lag in the set, driven by late dimensional changes and a drawing approval loop. Third, the busbar, harness and enclosure have shorter times to need than the other parts because they are needed earlier in the build sequence (the busbar, for example, for a fit check before final assembly), which illustrates why $D(i,b)$ must be set from the build sequence rather than from a single build date.

At the G1 review, the transformer was given a Conditional Go: the purchase order was released against a frozen electrical specification ahead of final mechanical drawings, with the supplier agreeing to hold mounting details open for two weeks. This shortened the internal release lag enough to recover the negative slack. The IGBT module and enclosure were assigned owners and weekly tracking until acknowledgements were received.

Table 6 shows how the MRI for Product A progressed across gates. The unweighted percentage of ready parts is shown for comparison.

Table 6. Illustrative Material Readiness Index progression for Product A

Gate	Parts ready (unweighted)	MRI (weighted)	Red parts	Decision
G1	61%	0.48	1	Conditional Go
G2	84%	0.77	0	Conditional Go
G3	96%	0.95	0	Go
G4	100%	1.00	0	Go

Note: At G1 only long-lead parts are assessed against full criteria; the unweighted figure is therefore not directly comparable across gates.

At G2, 84 percent of parts were ready, but the weighted MRI of 0.77 was below the 0.80 threshold because several unready parts were single-source or long-lead. The illustration labels the decision Conditional Go only as a documented exception requiring approval, recovery owners and dates, and evidence of protection for the pilot build. Without this exception record, the stated threshold requires Hold. The example demonstrates the importance of weighting rather than an automatic permission to proceed below threshold.

3.2 Failure modes detected

Across the products on which the framework was used, a consistent set of failure modes was encountered. Table 7 relates each to the earliest gate and check at which the framework is designed to detect it. The failure modes are consistent with prior findings: default or placeholder lead times and inconsistent units are among the data quality problems reported in ERP implementations (Xu et al., 2002), and revision mismatches reflect the planning disruption caused by engineering changes (Huang & Mak, 1999; Jarratt et al., 2011). The common feature of all eight is that they

were detectable from data available before the build, which is why each is assigned to a specific check and gate rather than left to build shortage reports.

Table 7. Recurrent failure modes and the point of interception

Failure mode	Typical consequence	Detected by	Earliest gate
Long-lead part identified late because the early BOM lacked supplier data	Negative slack discovered at prototype or pilot	PFEP supply source fields; slack test	G1
Item created with a default ERP lead time	MRP releases requisition too late	Planning lead time check	G1 (long lead), G2
Release lag not visible to the program	Supplier clock starts weeks later than assumed	RL field in ELT	G1
Unit of measure mismatch, for example cable or busbar stock	Orders wrong by a large factor	Unit of measure check	G2
Revision mismatch between engineering change and purchase order	Wrong revision received; rework or scrap	Revision and effectivity check	G2
Phantom subassembly flagged incorrectly	Components not planned or double planned	Phantom and kit check	G2
Packaging and point-of-use data missing	Material arrives but cannot be presented at the line	PFEP presentation fields	G3
Quoted lead time changed after release	Previously Green part becomes Red	Re-run of slack test with quote date	Every gate

3.3 Interpretation of the results

The framework extends PFEP from a steady-state material-flow tool to an NPI risk instrument by making its population progressive and gate-bound. It extends BOM accuracy from a general aspiration to a set of specific checks with defined timing. Its main conceptual contribution is the combination of the two through a time-based measure (slack) and a data-based measure (MRI), so that a gate decision considers both whether there is enough time and whether the system is correct enough to use that time. In this respect it extends the lean material-flow database of Harris et al.

(2003) and the MRP input logic of Ptak and Smith (2011) in the direction that stage-gate research recommends, toward visible and progressively tightening criteria (Cooper, 2008). The explicit inclusion of internal release lag is, in practice, the most consequential element. Supplier lead times are visible, quoted and often debated. Internal lag, accumulated through drawing approvals, item creation queues, sourcing decisions and purchase order approvals, is rarely measured, yet it can be comparable in size to the supplier lead time for fabricated parts. Making it a field in the record changes the conversation from "the supplier is slow" to "we have not yet started the supplier's clock." This is consistent with evidence that overlapping development activities pay off only when upstream information is released early and reliably (Terwiesch & Loch, 1999).

3.4 Interfaces with adjacent supply chain capabilities

NPI material readiness interfaces with three adjacent supply chain capabilities, each of which addresses a different phase of exposure and exchanges data with the readiness framework. **Disruption early warning** detects signals of supply trouble, such as lead-time extensions, allocation notices, supplier financial distress or regional events, before they reach the factory, in the manner of shortage early warning models developed for other critical supply chains (Eze et al., 2022a) and supply chain resilience indices (Efobi et al., 2023), supported by predictive risk analytics (Okwesa et al., 2024) and real-time risk dashboards (Filani et al., 2022). **NPI material readiness, the subject of this paper**, ensures that new products enter production with material that is available, correctly specified and correctly planned. **Inventory exposure control** governs the value and risk held in stock once products are in production, including safety stock, excess and obsolescence, building on models that link inventory availability to plant uptime (Okonkwo et al., 2018b) and predictive analytics for inventory management (Aifuwa et al., 2020), and on digital supply chain models for cost control and operational continuity (Okonkwo et al., 2024e). **Regulatory compliance governance** ensures that substance, emissions and sourcing obligations are met across the part base, consistent with frameworks for regulatory-compliant procurement in energy environments (Okonkwo, Ogunwole, et al., 2021) and end-to-end supply chain traceability (Nnabueze et al., 2021), as well as with supplier risk assessment for regulatory compliance (Akin-Oluyomi, Atima, et al., 2023), shared responsibility in multi-jurisdictional supply chain governance (Ominyi et al., 2021) and real-time compliance pipelines (Uchechi et al., 2022), supply chain governance models for compliance (Akin-Oluyomi & Akhigbe, 2022) and the standardization of compliance controls (Uchechi et al., 2023). Table 8 sets out the interfaces between this paper's framework and the three adjacent capabilities.

Table 8. Interfaces between NPI material readiness and adjacent supply chain capabilities

Adjacent capability	Input to NPI material readiness	Output from NPI material readiness
Disruption early warning	Lead-time extensions, allocation notices and supplier risk alerts trigger a re-run of the slack test and can move a part from Green to Amber or Red between gates.	The long-lead and single-source list for each new product, so that monitoring covers new parts and suppliers from G1 rather than after launch.

Adjacent capability	Input to NPI material readiness	Output from NPI material readiness
Inventory exposure control	Commodity lead-time history and exposure limits inform safety stock and buffer decisions at G4.	At G5, a validated record of actual lead times, MOQs, pack quantities and usage, which becomes the baseline for safety stock and excess and obsolescence control.
Regulatory compliance governance	Substance, emissions and sourcing requirements define the compliance attributes that must be present in the item master before G2.	A complete, part-level record of compliance attributes, country of origin and sourcing restrictions for every new part, captured at the point of creation rather than reconstructed later.

The common element is the part-level record. When the combined PFEP and BOM/ERP record of Table 1 is built correctly during NPI, it becomes the shared data foundation on which the three adjacent capabilities operate. When it is built poorly, each adjacent capability inherits its errors: early warning cannot monitor suppliers it does not know about, inventory control sets buffers from default lead times, and compliance governance must chase missing declarations after parts are already in use. Because the record is shared across functions and, in part, with suppliers, it needs controlled access (H. Shittu & Nabil, 2023) and transparent multi-enterprise data pipelines (Ogundairo, 2025), particularly where planning data meets operational technology networks (Adegbite et al., 2022).

3.5 Implications for national priorities

Domestic manufacturing. Reshoring and nearshoring bring new suppliers into existing products and new products into U.S. plants. New suppliers have no lead-time history, uncertain capacity and often longer qualification paths. The framework's explicit treatment of internal release lag, quote dating and slack makes these uncertainties visible early, which reduces the risk that a domestic sourcing decision is reversed because a launch slip.

Defense supply. Defense and critical infrastructure customers frequently impose sourcing restrictions and place a premium on assured supply. The framework's single-source flags, origin and sourcing restriction fields, and criticality weighting in the MRI give program managers an auditable, part-level view of exposure at each gate, consistent with the emphasis on identifying single points of failure in defense-critical supply chains (U.S. Department of Defense, 2022).

Emissions compliance and electrification. Power systems products are enabling equipment for grid modernization, electrified transport and industrial decarbonization. Delays in their introduction delay the emissions reductions they make possible. At the same time, these products carry their own compliance obligations for restricted substances and reporting. By requiring compliance attributes before G2 and by shortening the path from design to production for long lead-time power components, the framework supports both the timely deployment of this equipment and the compliance governance interface described in Section 3.4. Greenhouse gas

disclosure obligations for energy and infrastructure enterprises (Ominyi & Anichukwueze, 2022), the accuracy of GHG inventory reporting (Azeez & Badmus, 2024), and ESG-integrated and digital twin-driven approaches to sustainable procurement (Ike et al., 2025; Okojie et al., 2020) all depend on part and supplier data of the kind the framework captures during NPI.

3.6 Implementation and governance

The framework requires clear ownership, and the same staff often support several programs at once, which makes capacity planning across programs important (Edivri & Oteri, 2022). Table 9 summarizes the roles that proved effective. Clear role definition is equally central to governance of multinational infrastructure programs (Amayo et al., 2023).

Table 9. Roles in the integrated readiness framework

Role	Responsibilities
NPI materials lead	Owns the combined record and the gate readiness package; runs the slack test and MRI; chairs material readiness reviews.
Design engineering	Releases EBOM and specifications in a sequence that prioritizes long-lead parts; approves substitutions.
Procurement and sourcing	Obtains and refreshes quotes; records lead time, MOQ and quote dates; negotiates early release and supplier holds.
Production planning and ERP data owners	Create and validate item masters, MBOM and planning parameters; resolve BOM/ERP check failures.
Manufacturing and lean engineering	Define packaging, point of use, storage and replenishment; size supermarkets and line-side quantities.
Program manager and gate committee	Accept or reject recovery plans; make the Go, Conditional Go or Hold decision.

Several practices proved important in implementation. Early effort should concentrate on long-lead parts: a full PFEP for a 200-part product at concept is neither possible nor useful, and in the case application the 10 to 20 percent of parts that drove timing accounted for most of the benefit. The PFEP and BOM/ERP fields should be held in one record, whether a controlled spreadsheet or a PLM and ERP report, because separate lists invite divergence. Every quote should carry a date, since a lead time without one cannot be trusted during periods of allocation, and the slack test should flag quotes older than a defined age. Slack and MRI should be recalculated from data at each gate rather than carried forward as status statements.

Documenting the readiness review as a standard operating procedure, with a fixed report format and an MRI dashboard, sustains the practice beyond the first program (Agboada et al., 2019; Alieme et al., 2022; Ezeako et al., 2024). Fabricated parts such as welded supports, busbar and enclosures should be treated as quality-critical and should pass the inspection and non-destructive testing practices used in power infrastructure before G4 (Atta et al., 2021; Atta et al., 2022), because quality assurance is itself a determinant of supply reliability (Asiedu & Asiedu, 2024) and early failures in such parts become field reliability problems (Gideon et al., 2019). Variance analytics on expedite and premium freight costs (Aliliele et al., 2024) and workflow redesign to

remove logistics bottlenecks (Nwangwu et al., 2024) show whether the framework is reducing late recovery effort. Finally, feeding actual lead times and pack data back into ERP and the commodity history at G5 improves the long-lead candidate list for the next program. Where analytics or AI tools are added to automate parts of the record or the slack test, adoption tends to depend as much on how the tools are introduced to users as on their technical quality (Ogundairo & Ayivi-Donkor, 2024; Rukh et al., 2024). The study has limitations. The framework was developed within one organizational context and one industry segment, and its evaluation is illustrative rather than statistical. The thresholds for buffer and MRI are practitioner calibrations and are not derived from an optimization model. The weighting scheme is deliberately simple and could be refined. Maintaining the combined record requires effort that smaller programs may find difficult to justify, and the approach depends on reasonably disciplined ERP practices. Finally, the framework addresses material timing and data readiness; it does not replace process capability, quality planning or supplier qualification activities. Several directions for further research follow. Multi-site empirical studies could test the relationship between gate MRI values and launch outcomes such as shortage hours, expedite cost and schedule adherence. Integration with PLM and ERP systems could automate much of the record and enable continuous rather than gate-based monitoring. Statistical or machine learning models of lead-time variability could replace fixed buffer thresholds with probability-based ones. The readiness framework could also be evaluated jointly with disruption early warning, inventory exposure control and compliance governance, to measure whether a shared part-level record reduces disruption impact across the full product life cycle. Finally, the transition from NPI to steady state could be studied as the point at which demand-driven buffer positioning takes over from the slack-based approach described here. Material readiness gates complement advanced product quality planning and do not replace process capability or supplier qualification (Automotive Industry Action Group, 2008). Buffer values, criticality weights and MRI thresholds require calibration and sensitivity testing before they support release decisions.

4. Conclusion

The framework connects part-level supply timing and data readiness to explicit new-product gate decisions. Its composite illustration demonstrates how lead-time slack and a weighted readiness index can expose risks hidden by a complete bill of materials. The framework does not prove that the proposed thresholds improve launch outcomes. Documented exceptions, calibrated buffers and independent supplier qualification remain necessary. Multi-program studies should test whether this shared record reduces shortages, expedite costs and schedule variance.

Practical deployment requires one controlled part record joining supply attributes with bill-of-materials and planning-system status. Each gate should use a frozen eligible revision, documented criticality weights and a consistent calendar. Missing readiness evidence counts as unready, while an unknown lead time requires investigation. Part creation, sourcing approval and purchase-order release contribute to effective replenishment time. Recording these internal delays helps distinguish an apparently complete bill of materials from a launch plan supported by executable sourcing and planning data at the required date. The illustration demonstrates why a high unweighted completion percentage does not necessarily protect a build involving critical long-lead parts. A weighted readiness score below the stated threshold ordinarily requires Hold. Conditional Go requires a documented exception identifying affected parts, recovery owners, dates and evidence of protection for the next build. An expedite plan does not waive mandatory safety,

quality or legal conditions. Gate thresholds and buffers therefore need calibration to actual build risk rather than acceptance as universal readiness standards across products.

Future research should compare programs with consistent launch definitions and track shortages, expedite costs, supplier acknowledgements and schedule changes through stabilization. Evaluation should include programs proceeding under approved exceptions as well as programs held for recovery. Researchers should examine whether the combined record reduces data-related delays or transfers administrative effort to another function. Supplier qualification and design changes need separate treatment from planning completeness. The framework provides an auditable method for coordinating timing and data readiness, while its effect on launch reliability requires measured outcomes across multiple programs.

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