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Adapting sales and operations planning to engineer-to-order complexity: a multifaceted information processing approach to managing uncertainty and equivocality

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ABSTRACT

Engineer-to-order (ETO) manufacturing firms face challenges in their sales and operations planning (S&OP) processes due to inherent environmental uncertainty and equivocality stemming from extensive customization and project complexity. These factors result in frequent resource allocation inefficiencies and delays in project execution. This study investigates how the S&OP process design is adapted to manage these complexities. We build a multifaceted theoretical framework to enrich organizational information processing theory (OIPT) with insights from contingency theory, the dynamic capabilities view (DCV), and socio-technical systems (STS) theory. Through a multiple-case study of four large ETO manufacturers, we explore how firms design their S&OP processes to achieve a fit between their information processing requirements (IPRs) and capacity (IPC).

Key findings indicate that effective S&OP design depends on the firm's ETO archetype (design-to-order vs. redesign-to-order), which dictates the dominant information problem (equivocality vs. uncertainty). Furthermore, the success of the technical S&OP system depends on the health of its social system.

The study serves two primary contributions. It develops a contingent and socio-technical framework for ETO S&OP. It also extends the OIPT by introducing socio-behavioral ambiguities as a distinct class of IPRs and by identifying non-technical information-processing mechanisms (e.g., trust-building) as the corresponding behavioral solutions. The proposed model explains how ETO firms enhance S&OP quality through a contingent, dynamic, and socio-technical planning process. The findings are synthesized into a practical framework for managers to diagnose S&OP challenges and guide process improvement.

1. Introduction

Engineer-to-order (ETO) firms operate in increasingly dynamic markets, where customers request extensive customization requirements that trigger engineering work after placing an order (Gosling et al., 2017). These dynamic conditions in ETO settings call for thoughtful strategies to maintain equilibrium between demand and supply (Bhalla et al., 2023a). Even small mismatches can be damaging to ETO businesses and lead to lost customer orders or wasted resources (Alfnes et al., 2021). To stay competitive, ETO manufacturers must find ways to anticipate and handle their inherent complexities and uncertainties (Shurrab et al., 2022a), where sales and operations planning (S&OP) stands out as a relevant process (Shurrab et al., 2022b). Yet its application in ETO operations is far from straightforward due to the one-of-a-kind nature of their projects. Their inherent novelty creates a constant risk of costly rework and poses an information-processing challenge that standard planning models are ill-equipped to handle.

Early S&OP literature offered general blueprints (e.g., Wallace and Stahl, 2008), which is why more recent studies call for context-specific S&OP approaches (Kristensen and Jonsson, 2018). The ETO context remains largely underexplored (Bhalla et al., 2023a, 2023b) and is not a monolithic category. ETO environments range from pure design-to-order (DTO), where novel solutions create ambiguity in translating requirements, to redesign-to-order (RTO), where work based on existing platforms creates high execution uncertainty (Alfnes et al., 2021). Existing S&OP process frameworks are designed for predictable

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high-volume environments but not to handle these distinct information challenges (Shurrab et al., 2022b). The S&OP challenge in ETO settings shifts from balancing aggregate forecasts to managing the feasibility, profitability, and resource alignment for unique high-stakes projects (Bhalla et al., 2023b).

A comprehensive theoretical framework is needed to explain how S&OP processes are (and should be) adapted to the multifaceted challenges of ETO environments, which is what this study aims to develop and empirically ground. To this end, we begin with organizational information processing theory (OIPT) as a foundational lens and join a few S&OP studies in that (e.g., Laari et al., 2023; Schlegel et al., 2021). OIPT posits that a firm works best when achieving a fit between its information processing requirements (IPRs), shaped by inherent uncertainty and ambiguity (equivocality) (Daft and Macintosh, 1981), and its information processing capacity (IPC) (Galbraith, 1977). To fully capture the dynamic, contextual, and human-centered complexities of ETO S&OP, this classic view alone is insufficient. We enrich this foundation by integrating insights from three complementary theoretical lenses, including the dynamic capabilities view (DCV) (Teece, 2007), contingency theory (Sousa and Voss, 2008), and socio-technical systems (STS) theory (Appelbaum, 1997). This multifaceted view serves as the basis for our exploratory study, which investigates how S&OP practices can be adapted to manage ETO uncertainty and equivocality. The following research questions (RQs) guide this purpose:

RQ 1. How do ETO manufacturers use their S&OP practices to manage the uncertainty and ambiguity (producing information processing requirements) typical of their business?

RQ 2. How do the identified information processing mechanisms impact S&OP quality outcomes?

To address these questions, we investigate four ETO manufacturers using a multiple-case study method. On the theory side, this work builds on and extends traditional OIPT (e.g., Galbraith, 1977) by operationalizing its constructs in demanding ETO settings and demonstrating how it can be integrated with complementary theories to provide a more holistic explanation. Furthermore, we develop empirically grounded propositions on how firms can contingently design their planning processes to manage the information challenges inherent in ETO projects. Our analysis explores how these contingent responses can build S&OP's dynamic capabilities. This deepens our understanding of what makes S&OP implementation effective in complex environments (Kristensen and Jonsson, 2018). For practitioners, we offer a diagnostic road map for an iterative ETO S&OP process improvement.

The remainder of this paper unfolds as follows: Section 2 reviews the literature on S&OP, ETO challenges, and the multifaceted theoretical framework guiding our study. Section 3 describes the research method. Section 4 presents the case study findings. Section 5 discusses the findings and their implications. Section 6 highlights the main findings, contributions, limitations, and future research.

2. Literature review

2.1. S&OP and challenges in the ETO context

S&OP is a cross-functional tactical planning process that aligns an organization's plans to balance demand and supply, typically over a rolling 12-18 month horizon (Wallace and Stahl, 2008). Through a structured monthly cycle of activities (data gathering, demand and supply planning, and executive reviews), the process is intended to optimize resources, improve service, and maximize profitability (Tuomikangas and Kaipia, 2014). It has proven valuable for improving performance, but its adaptation to complex and dynamic environments has led to the emergence of more advanced approaches such as integrated business planning (IBP) (Smith et al., 2010), which promote greater strategic alignment, flexibility, and the integration of functions like finance and product development.

Despite these developments, S&OP continues to face socio-technical challenges. It requires substantial changes to organizational structures to overcome functional silos (Danese et al., 2017; Goh and Eldridge, 2024). This is a social challenge that often determines the success of technical hurdles, such as the adoption of advanced planning systems (Kjellsdotter Ivert and Jonsson, 2014), analytics tools (Schlegel et al., 2021), and emerging digital technologies like artificial intelligence (AI) (Singh and Lee, 2013) and digital twins (Overbeck et al., 2024).

In the ETO context, S&OP tackles additional (unique) challenges where the high uncertainty and equivocality caused by dynamic customer requirements and intensive post-order product and process customization requirements are as much behavioral as they are technical (Bhalla et al., 2023b; Shurrab et al., 2022a).

To analyze S&OP in ETO contexts with the necessary precision, we begin with the foundational archetypal distinction between DTO and RTO (Alfnes et al., 2021). We operationalize this distinction for engineering activities using the granular framework of Gosling et al. (2017), which classifies ETO projects along a spectrum based on their degree of engineering novelty. At the high-novelty end of this spectrum, pure DTO categories involve activities such as research into entirely new solutions. At the low-novelty end, RTO categories involve work on existing designs based on established platforms. We hypothesize that these archetypes present distinct dominant information-processing challenges. DTO environments, being inherently novel and vague, are likely to be characterized by high equivocality, in which the primary S&OP task is interpreting one-of-a-kind project needs. On the other hand, RTO environments remain complex but in a different way. They face more pronounced execution uncertainty, in which the S&OP task primarily involves managing variability in production and supply chains.

These differing information problems manifest in several challenges. The infeasibility of sales forecasts, for instance, is a major challenge (Bhalla et al., 2023b), particularly in DTO environments where projects lack any historical precedent. Similarly, the need for an adaptive capability to manage evolving customer requirements (Alfnes et al., 2021) is universal, but the nature of this challenge differs. In DTO settings, the evolution of requirements can be so fundamental that it alters the core project scope, whereas in RTO, changes are typically bounded by the constraints of the existing platform (Gosling et al., 2017). Therefore, success in both archetypes depends less on the initial plan's quality and more on the S&OP process's inherent flexibility (Shurrab et al., 2022b).

Furthermore, the complexity of ETO products and the need for customization often result in longer lead times and increased variability in related production processes (Bhalla et al., 2023a), which often lead to dynamic bottlenecks, unexpected delays, and disruption (Shurrab et al., 2022b).

2.2. OIPT and ETO S&OP

OIPT offers a lens for exploring S&OP in the ETO context. The theory posits that a firm's IPC must be sufficient to handle its IPRs (Galbraith, 1977). These IPRs are primarily driven by *uncertainty*, the gap between the information needed to perform a task and the information available (ibid), and *equivocality*, the ambiguity and multiple interpretations of available information (Daft and Macintosh, 1981). In ETO settings, the one-of-a-kind nature of projects (the very essence of the DTO archetype) is the engine that intensifies both uncertainty and equivocality. Failing to manage them results in costly rework, which, from an OIPT perspective, motivates ETO firms to invest in building their IPC.

In the context of one-of-a-kind DTO projects, the challenge of equivocality becomes so profound that it aligns with what recent megaproject and supply chain planning literature terms epistemic uncertainty, i.e., a lack of knowledge rooted in the unprecedented nature of a task that cannot be reduced by simply collecting more data on existing variables (Benjaminsen and Sørnes, 2025; Sengupta et al., 2025). Managing this deep knowledge-based ambiguity is arguably the central information processing challenge for DTO firms.

The literature highlights several ETO-specific drivers that intensify the uncertainty and equivocality S&OP processes must handle. Table 1 categorizes nine such drivers by their dominant information challenge type.

The first four drivers create uncertainty by introducing variability into planning (e.g., production process deviations, technology integration failures). The next four generate equivocality because they require interpretation and negotiation to resolve (e.g., ambiguous customer specifications, communication gaps across functions). The final driver, managing multiple unique projects, generates both types simultaneously.

To manage IPRs driven by such uncertainties and equivocalities, OIPT suggests that firms must develop and embed a portfolio of information processing mechanisms (IPMs) within their processes (Galbraith, 1977). The classic mechanisms are structural and technical in nature. However, we argue that the socio-technical complexities of ETO S&OP demand a broader conceptualization of IPMs. After all, these mechanisms are intended to align a firm's IPRs that emerge in their planning environments with the IPC generated through their processes and resources (Laari et al., 2023).

IPMs can be classified into IPR-reducing and IPC-building mechanisms (Srinivasan and Swink, 2018). IPR-reducing mechanisms include creating slack resources and self-contained tasks. Slack resources, such as excess capacity or inventory buffers, help organizations cope with uncertainty by providing cushions against unexpected events (Galbraith, 1977). Self-contained tasks focus on reducing the volume and complexity of information to be processed by coordinating and exchanging information across different parts of the organization (ibid). Examples of such mechanisms include standardizing processes or creating self-contained teams to reduce coordination complexity (Rosado Feger, 2014).

IPC-building mechanisms, on the other hand, focus on increasing the organization's ability to process information (Galbraith, 1977), such as by investing in advanced planning systems (Schlegel et al., 2021) and establishing lateral relations (e.g., cross-functional teams and integrative roles) (Rosado Feger, 2014).

Table 1
Drivers of uncertainty and equivocality in ETO environments.

Driver	Type	Description	Source
1. Limited visibility into future demand	Uncertainty	Difficulty anticipating specific, highly customized demand	Shurrab et al. (2022b)
2. Limited forecast feasibility	Uncertainty	Unique nature of customized demand challenges traditional forecasting methods	Alfnes et al. (2021)
3. Variability in production processes	Uncertainty	Diverse materials and skills, and long lead times required for custom orders	Gosling et al. (2017)
4. Integration of new/complex technologies	Uncertainty	Unpredictability in designing/manufacturing with novel technologies	Mello et al. (2015)
5. Complexity of customized products	Equivocality	Difficulty interpreting the implications of complex product designs	Cannas et al. (2019)
6. Ambiguity in customer specifications	Equivocality	Vague, incomplete, and evolving requirements need interpretation	Bhalla et al. (2023a)
7. Communication gaps	Equivocality	Technical complexity, functional diversity, and dispersion hinder clarity	Shurrab et al. (2022a)
8. Complex supply chain	Equivocality	Diverse suppliers/ subcontractors increase the information load and conflicts	Wikner and Rudberg (2005)
9. Managing multiple unique projects	Both	Simultaneous coordination of distinct project needs and resources	Bhalla et al. (2023b)

In the context of digital transformation, an organization's IPC is increasingly defined by its digital maturity. As comprehensive reviews have established, successful digital transformation unlocks improved firm performance through enhanced IPC (Vial, 2019). Traditional systems like ERP remain foundational, but the emergence of next-generation digital technologies may fundamentally reshape a firm's IPC. For instance, AI and machine learning (ML) offer unprecedented capabilities for demand sensing (Walter et al., 2025). Building on such predictive insights, prescriptive analytics (often leveraging ML outputs) can then optimize complex resource trade-offs to recommend a best course of action (Bertsimas and Kallus, 2020). Further, IBP (Swink et al., 2025) and digital twins (Overbeck et al., 2024) provide platforms for effective responses and for simulating entire production systems. Within the OIPT framework, these technologies represent a new class of powerful IPC-building mechanisms (Srinivasan and Swink, 2018). However, their implementation also introduces new IPRs, such as the need to manage data trustworthiness and mitigate the cybersecurity risks inherent in digitally transformed supply chains (Kumar and Mallipeddi, 2022). A key distinction of these systems is that they serve as bridging mechanisms that enhance adaptive capability, rather than as simple buffers. For example, in a large-scale study on the impact of the COVID-19 pandemic, Swink et al. (2025) found that firms using advanced supply chain planning systems (bridging) demonstrated significantly greater resilience than firms relying on traditional inventory buffers (buffering).

2.3. Complementary theoretical insights to OIPT

The classic IPMs described by OIPT focus on structural and technical solutions and do not fully capture the socio-technical complexities embedded in ETO environments. Therefore, to build a richer understanding, we integrate insights from three complementary perspectives.

We integrate from the DCV (see Teece, 2007) the possibility to perceive a process like S&OP as an evolving organizational capability that adapts to changing environments. We postulate that such a capability cannot be generic, drawing on contingency theory (Sousa and Voss, 2008) and the need for ETO-specific S&OP (Bhalla et al., 2023b). Finally, we resort to the STS theory to make the internal human element particularly pronounced, since any technical S&OP system is embedded within a social system of culture, trust, and politics (Tuomikangas and Kaipia, 2014).

In such a social system, we argue that human interaction poses difficult information problems beyond the data itself, since, after all, organizations are coalitions of actors with inherently conflicting goals (Cyert and March, 1963). Therefore, we extend OIPT by distinguishing classic equivocality from what we term socio-behavioral ambiguities. Classic equivocality concerns ambiguity in information (Daft and Macintosh, 1981), which can be perceived in ETO operations as the challenge of collective sense-making inherent in deciphering the needs of a one-of-a-kind project. We propose that socio-behavioral ambiguities, rooted in the human system, entail challenges of negotiation and goal alignment. This includes information problems, such as resolving conflicts in priorities across functions (stakeholder misalignment).

To manage these human-centered IPRs, firms must develop non-technical IPMs, including routines that build their capacity for human interaction. Since conflicting goals represent a well-documented S&OP challenge (Oliva and Watson, 2011), these routines include establishing trust to facilitate reliable information exchange (cf. Villena et al., 2011), processes to manage the inevitable conflict between functions (De Dreu and Weingart, 2003), and leveraging leadership to foster a shared vision that aligns interpretations across silos (Wang et al., 2011).

2.4. Conceptual framework: planning quality for assessing IPR-IPC gaps

Several S&OP studies have revealed that advancing process maturity (e.g., Danese et al., 2017; Grimson and Pyke, 2007) can generally enhance performance (Hulthén et al., 2016). However, there is limited empirical guidance on how specific process maturity configurations lead to specific performance improvements. Therefore, we adopt the following cross-functional integration constructs suggested by Oliva and Watson (2011) as indicators of IPR-IPC gaps, which we label planning quality dimensions (operationalized in Appendix C):

1. Informational quality (IQ): The degree of information support for decision-making in terms of accuracy, comprehensiveness, accessibility, availability, and timeliness.
2. Procedural quality (PQ): The degree to which informational inputs are validated using sound logic and criteria.
3. Alignment quality (AQ): The degree of contribution to fulfilling organizational and functional goals and synchronizing the resulting activities.
4. Constructive engagement (CE): The degree to which relevant individuals are enabled to actively participate in planning through constructive dialogue and the integration of perspectives.

These planning quality dimensions reflect key aspects of information processing and cross-functional integration that are central to managing uncertainty and equivocality within S&OP (Tuomikangas and Kaipia, 2014). For example, IQ and PQ align with OIPT's technical focus, whereas AQ and CE address the contingent and socio-technical challenges ETO firms face.

Accordingly, using causal logic, planning quality acts as the performance measure that connects the key synthesized constructs of our conceptual framework, as shown in Fig. 1.

The framework's left side depicts the ETO planning environment, where the nine drivers of uncertainty and equivocality (light blue boxes) synthesized in Table 1 feed into the three conceptualized IPR categories (blue boxes). The (+) symbol on the shared arrow between the categories indicates their intensifying effect. On the framework's right side, the S&OP process maturity level (grey box at the top) is depicted as an antecedent condition that enables the synthesized portfolio of IPR-reducing and IPC-building IPMs (light green boxes) in an S&OP process design (grey box at the center). These mechanisms serve our RQ1.

The (−) symbol on the left descending arrow toward IPRs (green box at left) indicates decreases in their levels, while the (+) symbol on the right descending arrow toward IPC (green box at right) indicates increases. The resulting increases and decreases in IPRs and IPC lead to a degree of IPR-IPC fit (yellow diamond), which is measured by observable gaps in S&OP quality (grey box at bottom) across four dimensions (light yellow boxes). The higher the quality, the narrower the gap. The manifestation of this quality serves our RQ2.

3. Method

3.1. Study design

Our study design followed a structured multi-step approach common

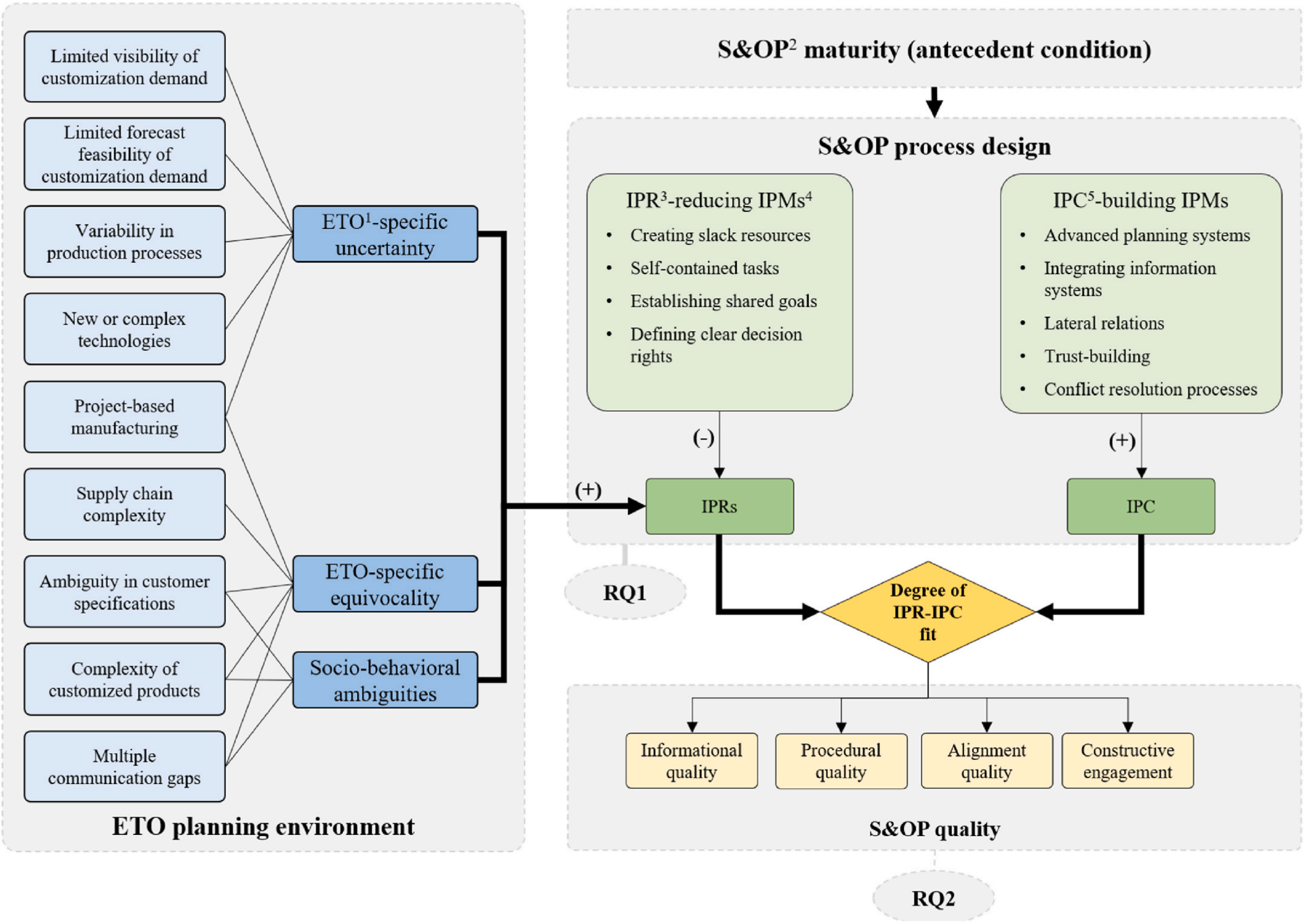


Fig. 1. Conceptual framework
Note: ¹ Engineer-to-Order, ² Sales and Operations Planning, ³ Information Processing Requirements, ⁴ Information Processing Mechanisms, ⁵ Information Processing Capacity.

in theory-building case study research (Eisenhardt, 1989). We used the conceptual framework presented earlier (Fig. 1) to guide case selection, data collection, and analysis, as described in the next sections.

Case selection was based on purposive sampling that yielded four information-rich high-performing ETO firms. These firms exhibited diversity in ETO archetypes, size, and industry, as shown in Table 2. This diversity enabled an in-depth comparative analysis of how different S&OP process designs address various ETO-specific uncertainties and equivocalities.

In the next step, data were collected according to a detailed protocol (see Appendix A) and involved a triangulated approach comprising semi-structured interviews, direct observations, and document analysis. The rightmost column of Table 2 lists the informants involved across semi-structured interviews, along with their job titles and interview durations.

Finally, the collected data underwent an iterative process of within-case and cross-case analyses. The analysis step resulted in identifying patterns, refining the conceptual framework, and developing empirically grounded propositions.

3.2. Data collection

The fieldwork for this multi-case study was conducted by the two authors over a three-year engagement period (March 2019 – February 2022), followed by follow-up interviews in 2025. We employed a standardized case study protocol (Appendix A) across all four firms to ensure consistency. Moreover, we resorted to a triangulated data collection strategy that incorporated semi-structured interviews, direct observations, and extensive document analysis (Voss et al., 2002). Our protocol involved 2 to 4 on-site visits per company, where we attended demonstrations of planning tools and toured several ETO manufacturing plants and engineering offices.

The primary data sources were 48 semi-structured interviews with 31 informants, which were supplemented by a wide range of company documents. To ensure a deep and context-rich discussion, we first analyzed internal S&OP documents to create a swimlane diagram of each firm's information-processing flows. These diagrams, refined through pilot interviews with S&OP coordinators, informed the development of a detailed company-specific interview protocol. A core part of

Table 2
Case study overview.

Case: Industry	Product family	Turnover [million €;]/Employee, 2019	Engineer-to-order (ETO) decoupling setting		S&OP domain	Informant: job title (No. x length of interviews in minutes)
			Engineering	Production		
AeroEngine: Aerospace	Jet engine structures	670/2000	Design-to-order	Make-to-order	Independent local S&OP per plant Plan other standard product families	A1: S&OP coordinator (1 x 180) A2: S&OP coordinator (1 x 60) A3: Marketing director (2 x 60) A4: Logistics manager (2 x 60) A5: Logistics specialist (2 x 60) A6: Engineering manager (3 x 60) A7: Production manager (1 x 60) A8: S&OP coordinator (1 x 60)
AutoBus: Automotive	Electric vehicles	960/1000	Redesign-to-order (minor[a])	Finalize-to-order [b]	S&OP per 6 plants linked to a global group-level S&OP Plan other standard product families	B1: S&OP coordinator (3 x 60) B2: S&OP coordinator (1 x 60) B3: Marketing director (1 x 30, 1 x 120) B4: Sales specialists (1 x 60) B5: Demand planner (3 x 30) B6: Engineering manager (2 x 120) B7: Production manager (1 x 90) B8: Procurement manager (1 x 60) B9: S&OP coordinator (1 x 60)
MediSterilizer: Medical systems	Sterilizers	3000/15600	Redesign-to-order (major [c])	Finalize-to-order	Independent local S&OPs per 1-3 plants Dedicated to ETO product families	C1: S&OP coordinator (4 x 30, 1 x 60) C2: Marketing director (1 x 30) C3: Demand planner (1 x 90) C4: Sales specialist (1 x 90) C5: Plant manager (1 x 90) C6: Production manager (1 x 90) C7: Engineering manager (1 x90) C8: Design estimators (1 x 60)
InduCrane: Industrial equipment	Industrial cranes	3330/16000	Redesign-to-order (major)	Finalize-to-order	Independent local S&OPs per 1-3 plants Dedicated to ETO product families	D1: S&OP coordinator (1 x 60) D2: ETO planning manager (3 x 90) D3: Engineering manager (1 x 30) D4: Production manager (1 x 60) D5: Sales specialist (1 x 60) D6: S&OP coordinator (1 x 60)

[a] Using existing detailed designs as starting points to fulfill the specifications of each incoming order: integrations within the brief's parameters.

[b] When an order is placed, the following steps are initiated: assembly of standard items (available in stock) and purchasing and making the rest of the bill of material (BOM) items.

[c] Integrating existing standard designs as starting points to fulfill incoming orders' specifications: forms, layouts, integrations of designs available as stored files/drawings in expert systems.

this protocol was to anchor each interview in a purposively selected sample of 5 to 10 recent and representative ETO projects to elicit concrete examples of the challenges and mechanisms under study.

Finally, all findings were presented to company representatives during a concluding 4-hour workshop for final reflections. These were followed by individual company meetings to validate the results and final frameworks.

3.3. *Data analysis*

Our data analysis process iteratively combined within-case and cross-case analyses for data-driven theory building (Eisenhardt, 1989). The process began with data familiarization through multiple readings of transcripts and documents to establish a deep contextual understanding. We then engaged in iterative coding and theme development, using deductive codes informed by the conceptual framework and inductive codes that emerged from the data (Strauss and Corbin, 1998). We adopted Gioia et al.'s (2013) systematic data-structure approach to organize these codes into a reliable framework for comparing key constructs (IPRs, IPMs, and IPR-IPC gaps). Accordingly, we synthesized first-order concepts into second-order themes, which were distilled into six aggregate dimensions. These dimensions represent the core information-processing domains utilized throughout our analysis to identify patterns and understand unique IPR-IPC dynamics. The iterative comparisons between the data and the evolving framework constructs continued until theoretical saturation was reached (Voss et al., 2002).

We employed several measures to enhance the reliability and credibility of the analysis findings. To ensure a systematic assessment of S&OP quality, we developed a detailed planning quality assessment rubric to operationalize the four quality dimensions (see Appendix C). To enable quantitative triangulation, we developed a protocol for systematically coding findings on ordinal scales, including a 5-point scale for S&OP maturity and a 3-point scale for IPR intensity, as well as other qualitative assessments. Additionally, throughout the coding process, we conducted researcher triangulation, in which the two authors independently coded the data and then compared and reconciled their findings (Patton, 2014). Finally, we performed member checking by sharing the initial findings with key informants for feedback and by conducting a validation workshop and final company meetings (Lincoln and Guba, 1985).

The validity of findings was further assessed using pattern matching and explanation-building techniques (Barratt et al., 2011). The refined insights and patterns were used to develop a set of empirically grounded propositions, which were supported by analytical generalization, i.e., linking case-based findings back to the broader OIPT and S&OP literature. Throughout this entire process, we maintained a detailed audit trail of all analysis procedures, coding schemes, and analytic memos to ensure the dependability of the study (Yin, 2017).

4. Findings

To provide a high-level comparison of the cross-case analysis, this section presents key findings. It outlines each firm's S&OP maturity (Appendix B), a key antecedent condition for our analysis. It then presents an overview of the identified IPRs and the underlying landscape of uncertainty and equivocality (Table 4), the portfolio of deployed IPMs (Table 5), and the IPR-IPC gaps.

4.1. *Cross-case comparison of S&OP process maturity*

The cross-case analysis revealed a causal pattern in which higher antecedent maturity enabled firms to implement sophisticated operational practices (IPMs). AeroEngine demonstrated the highest S&OP maturity (Stage 4) and employed a portfolio of advanced IPMs. This contrasts with InduCrane at the other end of the spectrum, whose low S&OP maturity (Stage 1-2) resulted in a fragmented set of basic IPMs. These differences in maturity led to vastly different IPM portfolios, which, in turn, resulted in corresponding differences in planning quality. To triangulate this finding, we quantified our assessments using maturity and quality gap scores across the four cases, as summarized in Table 3.

The left-hand columns report S&OP maturity scores on a 1-5 scale (visualized in green) across four maturity dimensions, as defined by Danese et al. (2017). The right four columns report S&OP quality gaps, where each score represents the aggregate severity of IPR-IPC mismatches for the corresponding planning quality dimension (visualized in red).

The data show an inverse relationship, as indicated by the contrasting scores. AeroEngine's high maturity scores (all 4s) correspond to the lowest gap scores, whereas InduCrane's low maturity scores (1s and 2s) correspond to the highest gap scores. This pattern provides quantitative evidence supporting our argument that mature S&OP processes yield a better IPR-IPC fit. But behind this numeric overview lie contextual nuances that elaborate on how they manifest across the maturity dimensions.

For organization and people (the first dimension), a notable difference emerged in how companies structured their collaborations. AeroEngine (Stage 4) fostered cross-functional integration through frequent multilevel meetings involving over 50 participants, which enabled and enhanced extensive communication across multiple channels. InduCrane (Stage 2) struggled with internal silos that limited engineering involvement (only 10 participants) and hampered the communication needed to resolve requirement ambiguities.

As for processes and methodologies (the second dimension), we found that highly mature S&OP processes employ structured adaptive approaches tailored to specific needs. For instance, AutoBus (Stage 4) implemented structured financial integration within the S&OP and employed risk-focused scenario planning. These practices are aligned with managing the company's specific financial and market challenges. AeroEngine (Stage 4) features similarly sophisticated processes,

Table 3

Summary of scores and comparative visualization for S&OP maturity and quality.

Case company	S&OP maturity*				S&OP quality gap**			
	People	Processes	IT	Performance	IQ gaps	PQ gaps	AQ gaps	CE gaps
AeroEngine	4	4	4	4	5	8	9	9
AutoBus	4	4	3	3	7	8	12	12
MediSterilizer	4	3	3	1	9	11	14	14
InduCrane	2	2	2	1	12	15	16	16

*Maturity scores (green bars) are based on the 1-5 point scale from Appendix B. Higher scores indicate higher maturity.

**S&OP quality gap scores (red bars) represent the aggregate severity of the IPR-IPC mismatch for each planning quality dimension. Each score is the sum of the 1-3 point severity ratings from Appendix E for all gap areas related to that dimension (e.g., IQ). A lower score indicates a smaller gap and thus higher planning quality.

Table 4

Drivers of uncertainty and equivocality and IPRs across case companies.

		AeroEngine				AutoBus				MediSterilizer				InduCrane			
Drivers of uncertainty	Limited visibility (future customization needs)	2				1				2				1			
	Complexity of customized products	3				2				3				2			
	Variability in production processes	3				2				1				2			
	Flexibility (customer-driven dates and volumes)	2				1				2				1			
	Variability in revenue from diverse order sizes	1				2				1				2			
	Engineering capacity constraints	2				1				2				1			
	Supplier dependability	2				1				1				2			
	Market demand fluctuations	2				1				1				1			
	Financial planning complexity	1				2				1				2			
Drivers of equivocality	Ambiguity in customer specifications	3				2				2				3			
	Communication gaps	2				2				3				2			
	Organizational silos	1				1				2				1			
	Lack of trust between engineering and other functions	1				2				1				2			
	Technological adaptation rates	2				1				1				1			
Information-processing domain	**Information processing requirement (IPR)***	**IQ**	**PQ**	**AQ**	**CE**	**IQ**	**PQ**	**AQ**	**CE**	**IQ**	**PQ**	**AQ**	**CE**	**IQ**	**PQ**	**AQ**	**CE**
Demand and customer interface management	Need for accurate/reliable customer requirement information	3	1	3	3	3	1	3	2	3	1	3	2	3	1	3	3
	Need for frequent/rich customer communication	1	3	2	3	1	2	1	2	1	2	1	2	1	3	1	3
	Need to achieve a shared understanding of customer requirements	1	1	3	3	1	1	2	2	1	1	3	3	1	1	3	3
	Need for processing broad/diverse demand information sources	3	2	1	1	3	2	1	1	2	1	1	1	2	1	1	1
	Need for proactive/continuous demand information gathering	2	3	1	1	2	3	1	1	2	2	1	1	2	2	1	1
	Need for detailed project information processing (demand)	3	2	2	1	3	2	2	1	3	2	2	1	3	2	2	1
Product and engineering integration	Need for detailed product information processing	3	2	2	1	3	2	2	1	3	2	2	1	2	1	1	1
	Need to interpret product information iteratively/adaptively	1	3	2	3	1	3	2	2	1	3	2	2	1	3	2	3
	Need for proactive/anticipatory technology information processing	1	3	1	1	1	3	1	1	1	2	1	1	1	2	1	1
	Need for rapid technology information acquisition/assimilation	1	3	1	1	1	3	1	1	1	2	1	1	1	2	1	1
	Need for continuous technology information dissemination/learning	1	1	3	3	1	1	3	2	1	1	2	2	1	1	2	2
	Need to integrate product and process information	2	2	3	1	2	2	3	1	2	2	2	1	2	2	3	1
Operations and capacity alignment	Need for precise/accurate process information processing	3	3	1	1	2	2	1	1	2	2	1	1	3	3	1	1
	Need for continuous process information monitoring/control	2	3	1	1	2	2	1	1	2	2	1	1	2	3	1	1
	Need for adaptive/real-time project information processing (operations)	2	3	3	1	2	3	2	1	2	2	2	1	2	3	3	1
Supply chain coordination and risk management	Need for timely/accurate supply chain information sharing	3	3	2	1	2	2	2	1	2	2	2	1	3	3	2	1
	Need for proactive/predictive supply chain information processing	1	3	2	1	1	2	2	1	1	2	2	1	1	2	2	1
	Need for collaborative supply chain risk information management	1	2	3	3	1	2	2	2	1	1	2	2	1	1	2	2
Cross-functional collaboration and governance	Need to integrate demand information across planning levels	1	2	3	1	1	2	3	1	1	1	2	1	1	1	2	1
	Need for integrated/coordinated cross-functional project information	2	2	3	2	2	2	2	2	2	2	2	2	2	2	3	2
	Need to integrate cross-functional process information	2	2	3	2	2	2	2	2	2	2	2	2	2	2	3	2
	Need for rich/frequent cross-boundary communication	1	3	2	3	1	2	2	2	1	2	2	2	1	3	2	3
Information systems and analytics support	Need for integrated/compatible information systems	3	2	3	1	2	1	2	1	2	1	2	1	3	1	3	1
	Need for standardized information formats/protocols	2	3	2	1	2	3	2	1	2	3	2	1	3	3	3	1

* IPRs are represented by the corresponding planning quality dimensions: Informational Quality (IQ), Procedural Quality (PQ), Alignment Quality (AQ), and Constructive Engagement (CE).

Note: The red shading corresponds to a 3-point scale representing the intensity of the IPR: Lighter Shade = 1 (Low requirement); Medium Shade = 2 (Moderate requirement); Darker Shade = 3 (High requirement).

including systematic S&OP improvement loops designed to manage high uncertainty stemming from customization and production complexities. On the contrary, InduCrane (Stage 2) used a simpler S&OP structure with fewer review steps (three, compared to AeroEngine's eight or AutoBus's five), lacked financial integration, and reported process inconsistencies. These aspects reflect less developed methods for managing a company's ETO complexities.

In information technology (the third dimension), AeroEngine (Stage 4) leverages a suite of advanced IT tools (e.g., 3D modeling and discrete-event simulation software) to manage variability in its complex production processes. It also utilizes a financial planning platform within its S&OP cycle to run scenario analyses based on evolving market assumptions. MediSterilizer (Stage 3) used systems such as ERP and spreadsheets but demonstrated a less intensive use of specialized IT than AeroEngine when addressing similar ETO-specific production uncertainties. At the lowest level, InduCrane's (Stage 1-2) reliance on its ERP system (operated via disconnected manual spreadsheets) hindered the development of an integrated data strategy.

Finally, regarding measuring S&OP performance (the fourth dimension), AeroEngine (Stage 4) embedded an assessment routine into its monthly S&OP cycle and used comprehensive metrics to guide resource allocation and supplier coordination. However, MediSterilizer and InduCrane (Stage 1) lacked formal S&OP performance metrics. They reported consequent difficulties in these coordination-critical areas.

4.2. *Cross-case comparison of IPRs for S&OP*

The cross-case analysis yielded insights into how the ETO context imposes IPRs that are universal to ETO businesses and those that stem from their specific archetype (DTO/RTO). Table 4 maps the identified IPRs (and underlying drivers of uncertainty/equivocality) across the four case companies.

The table connects the identified environmental drivers of uncertainty and equivocality (upper section) to the specific IPRs they trigger (lower section) across the cases. We synthesized these requirements into six information-processing domains, which served as the structural themes for the subsequent analysis of IPMs and IPR-IPC gaps. The table's red-shaded heat map indicates intensity on a 3-point scale (light = low, medium = moderate, dark = high). Intensity in the upper section reflects the severity of the drivers, while intensity in the lower section reflects the required planning quality to meet the corresponding IPRs.

The DTO environment at AeroEngine, characterized by a portfolio of novel research-heavy projects, generated intense IPRs in sense-making domains (e.g., customer interface), driven by high equivocality. Because no design precedent exists, the primary S&OP challenge is interpreting vague (often conflicting) customer requirements to define the task itself. On the other hand, the RTO environments of firms like InduCrane, which base portfolios on adapting existing platforms, faced the most intense IPRs in execution-related domains (e.g., operations), driven by higher execution uncertainty. Here, the core product is known, but numerous adaptations introduce significant variability that complicates predictable delivery. The following exemplifies these patterns across the six domains:

(1) Demand and customer interface management: The one-of-a-kind nature of ETO projects created a universal need for accurate customer requirement information. This challenge was most pronounced as equivocality in the DTO environment at

Table 5
S&OP IPMs across case companies.

Information-processing domain	Secondary information processing mechanism (IPM)*	Primary IPM	Impact	AeroEngine				AutoBus				MediSterilizer				InduCrane			
				IQ	PQ	AQ	CE	IQ	PQ	AQ	CE	IQ	PQ	AQ	CE	IQ	PQ	AQ	CE
Demand and customer interface management	Judgmental forecasting with external partners (e.g., transport providers)	Lateral relations	IPC[1]+					▒			▒								
	Demand review meetings with cross-functional participation	Lateral relations	Both	▓	▓	▓	▓	▓	▓	▓	▓	▒	▒	▒	▒	░	░	░	░
	Use of configurators for quoting/scoping customer needs	Information systems support	Both	▒	▒			▒	▒										
	Collaborative product development/Co-creation with customers	Lateral relations	Both		▓	▓	▓												
Product and engineering integration	Engineering representatives' involvement in S&OP	Lateral relations	Both		▒	▓	▓		░	░	░		░	░	░		░	░	░
	Use of specific tools by engineering reps. (capacity/risk tracking)	Information systems support	IPC+	▒	▒	▓													
	Roadmap for competence development	Environmental management	IPR[2]-		▒	▒													
	Review of product life cycle/new product introduction in S&OP	Self-contained tasks	IPR-		▒	▒			▒	▒									
	Dedicated S&OP process steps for engineering requirements	Self-contained tasks	IPR-		▓	▓													
	Use of 3D modeling for layouts/products	Information systems support	Both	▓	▓														
Operations and capacity alignment	Static capacity setting with marginal flexibility (buffer)	Creating slack resources	IPR-						▒	▒									
	Capacity review meetings with cross-functional participation	Lateral relations	Both	▓	▓	▓	▓	▓	▓	▓	▓	▒	▒	▒	▒	░	░	░	░
	Use of workforce planning tools	Information systems support	IPC+	▒	▓	▓													
	Use of capacity matrix/rough-cut capacity planning tools	Information systems support	IPC+	▓	▓			░	░			░	░			░	░		
	Use of simulation tools (flow, layout, system performance)	Information systems support	Both	▓	▓														
	Integration with Master Production Scheduling	Vertical information systems	IPC+	▒	▒	▓		▒	▒	▓		▒	▒	▒		▒	▒	▒	
	Reviewing/updating medium-term production development plans	Lateral relations	Both	▒	▒	▒		▒	▒	▒									
	Updating value stream development plans	Self-contained tasks	IPR-	▒	▒	▒		▒	▒	▒									
	Involvement of production engineering/shop floor specialists	Lateral relations	Both	▓	▓	▓	▓	▒	▒	▒	▒	▒	▒	▒	▒	░	░	░	░
	Flexible order intake/production location decisions	Creating slack resources/lateral relations	IPR-	▒	▒			▒	▒			░	░			░	░		
Supply chain coordination and risk management	Integration of ERP/MRP for high-level material planning	Vertical information systems/info. systems support	IPC+	▓	▒	▓		▓	▒	▓		▒	░	▒		▒	░	▒	
	Involvement of the procurement/supply chain function in S&OP	Lateral relations	Both	▓	▒	▓	▓	▓	▒	▓	▓	▓	▒	▓	▓	▒	░	▒	▒
	Review and update of risk & assumption trackers	Self-contained tasks	IPR-	▓	▓			▒	▒			▒	▒			▒	▒		
	Collaboration with key suppliers/partners within S&OP interfaces	Lateral relations	Both	▓	▒	▓	▓	▒	░	▒	▒	▒	░	▒	▒	░	░	░	░
Cross-functional collaboration and governance	Dedicated S&OP improvement meeting/cycle	Self-contained tasks	Both	▒	▓	▓	▒												
	Advanced bottom-up escalation tools	Creating slack resources	IPR-	▒	▓	▒													
	Formal S&OP Team establishment & facilitation	Lateral relations	Both	▓	▓	▓	▓	▓	▓	▓	▓	▒	▒	▒	▒	░	░	░	░
	Increased number of functions involved in S&OP meetings	Lateral relations	IPC+	▓	▒	▓	▓	▓	▒	▓	▓	▒	░	▒	▒	▒	░	▒	▒
	Involvement of the human resources function for inputs	Lateral relations	IPC+	▒		▒		▒		▒									
	Integrating planning information across hierarchical levels	Vertical information systems	IPC+	▓	▒	▓	▒	▓	▒	▓	▒	▒	░	▒	░	░	░	░	░
	Dedicated S&OP process for ETO families (vs. mixed)	Self-contained tasks	IPR-									▒	▒	▒		▒	▒	▒	
	Iterative S&OP meetings for scenario planning/issue resolution	Lateral relations	Both	▓	▓	▓	▓	▓	▓	▓	▓	▒	▒	▒	▒	░	░	░	░
	Linkage between plant-level and group-level S&OP	Vertical information systems	IPC+					▒		▓		▒		▒					
Information systems and analytics support	Use of specific planning tools (optimization, engineering capacity)	Information systems support	IPC+	▓	▓			▒	▒										
	Use of collaborative platforms (internal/external)	Information systems support	IPC+	▒		▒	▒	░		░	░	░		░	░				
	Use of specific core systems (SAP, sales trackers, tooling DB, MRP)	Information systems support	IPC+	▓	▒	▓		▓	▒	▓		▒	░	▒		▒	░	▒	
	Use of calculators/spreadsheets for specific analyses	Information systems support	IPC+	░	░			░	░			▒	▒			▒	▒		
	Use of analytics on historical data	Information systems support	IPC+	▒	▒			▒	▒			▒	▒			░	░		
	Scenario planning capabilities (as enabled by tools/process)	Information systems support/lateral relations	Both	▓	▓	▓		▓	▓	▓		▒	▒	▒		░	░	░	

[1] Information processing capacity, [2] Information processing requirements.
* IPMs are represented by the corresponding planning quality dimensions: Informational Quality (IQ), Procedural Quality (PQ), Alignment Quality (AQ), and Constructive Engagement (CE).
Note: The green shading corresponds to a 3-point scale representing the IPM's impact on planning quality: Lighter Shade = 1 (Low impact); Medium Shade = 2 (Moderate impact); Darker Shade = 3 (High impact).

AeroEngine. Still, the prevalent ambiguity in customer specifications was a widespread issue. One manager at InduCrane (D5) noted, 'customers are usually more than 90% uncertain about their truly desired specifications,' which was echoed at MediSterilizer (C1): 'customers do not know what they want.' This ambiguity amplified the need for a shared understanding and rich customer communication across all firms. For instance, AeroEngine managed the dynamism of customer-driven flexibility by processing inputs from ' … business development teams, dedicated to monitoring and gathering data from certain clients' (A3).

(2) Product and engineering integration: The need for detailed product information processing was intense across all cases, but the nature of the challenge depended on the ETO archetype. For AeroEngine (DTO), whose products involved less than 50% shared components, the core IPR was resolving the equivocality in novel designs. As their engineering manager (A6) explained, 'we are constantly integrating new technologies into our production processes. This creates a need for continuous learning and adaptation of our S&OP process.' For RTO firms like AutoBus, the challenge was managing the execution uncertainty of integrating new technologies into established platforms.

(3) Operations and capacity alignment: Production variability fueled a universal IPR for precise process information, but this manifested most intensely as high execution uncertainty in the RTO environments. The production manager at InduCrane (D3) described extreme variability, where 'deviations between planned and actual job durations can reach up to 500%.' A logistics manager at AeroEngine (A4) acknowledged similar, though less extreme, challenges. The need to manage multiple projects simultaneously amplified the IPR for adaptive real-time operational adjustments for all firms.

(4) Supply chain coordination and risk management: Supply chain complexity created IPRs for all firms, but these were again most pronounced as execution uncertainty in the RTO environments. The InduCrane case showed a gap, as admitted by a sales specialist (D5): 'We have limited visibility into subcontractor lead times and capacity.' This was echoed by a sales specialist at AutoBus (B4) in their RTO segments: 'sometimes we are not able to get the full transparency we want from suppliers.' Where S&OP processes were more strategically oriented, like at AeroEngine and AutoBus, a more pronounced need for proactive supply chain information processing and collaborative supply chain risk information management was evident. This need was driven by uncertainties about subcontracting costs and supplier reliability.

(5) Cross-functional collaboration and governance: Communication gaps were the primary source of the pervasive need for rich/frequent cross-boundary communication. This requirement was intense and often unmet, where organizational silos were strong. For example, D1 stated that 'sales are very much in the center, and the other functions are satellites around, not talking too much with each other.' This situation contrasts with AeroEngine's S&OP, which involves more than 50 participants per cycle. The need to integrate demand information across planning levels and to provide integrated/coordinated cross-functional project information was also consistently identified. It reflected the struggle to achieve holistic planning and execution alignment across diverse ETO projects.

(6) Information systems and analytics support: A foundational need for integrated/compatible information systems emerged across all cases, particularly where fragmentation was an issue, such as InduCrane's reliance on spreadsheets and manual information consolidation. This has created a need for standardized information formats and protocols to ensure data consistency and flow. The lack of such standards was palpable in MediSterilizer's S&OP, where C2 lamented that 'important information is not sufficiently reaching the right people on time … a lot is missed on the way since the type of information we deal with is subjective assumptions and theories from word of mouth.' This challenge

was addressed at AeroEngine, where the use of a planning tool bridged the gap between operational, financial, and business planning. This system provided a ‘single source of truth’ that replaced the fragmented subjective data flows that were problematic in the other cases.

4.3. Cross-case comparison of IPMs generated by S&OP

To manage the IPRs dictated by their ETO archetypes, the case companies employed portfolios of IPMs representing contingent responses to their dominant information challenges. We classified these mechanisms using the categories synthesized in the conceptual framework (Fig. 1), and patterns matching six of them were identified: (1) slack resources that buffer against variability, (2) self-contained tasks that reduce coordination complexity, (3) environmental management that shapes external conditions, (4) vertical information systems that enable hierarchical data flow, (5) lateral relations that facilitate cross-functional coordination, and (6) information technology support that enhances analytical capacity. Appendix D details how each mechanism operates, its specific impact on IPR reduction or IPC building, and the case companies that applied them.

Table 5 maps the deployment of the identified IPMs across the four cases.

The table lists the specific observed practices (secondary IPMs) alongside their primary classification and functional role: building capacity (IPC+), reducing requirements (IPR-), or both. The table's green-shaded heatmap illustrates the magnitude of each mechanism's impact on planning quality across the four firms. Shading intensity follows a 3-point scale (light = low, medium = moderate, dark = high), where darker cells represent a stronger contribution to the specific quality dimensions (IQ, PQ, AQ, CE), and blank cells indicate the absence of an observed impact.

The shading patterns reveal a gradient in the intensity and breadth of deployed IPM portfolios. AeroEngine deployed IPMs across all six primary categories, which are particularly intensive in lateral relations (cross-functional meetings with 50+ participants) and information technology support (simulation, 3D modeling, workforce planning tools). AutoBus exhibited comparable breadth but lower intensity in environmental management and self-contained tasks. At the opposite end, MediSterilizer and InduCrane concentrated their efforts on vertical information systems and basic lateral relations but left gaps in slack resources and environmental management. The following domain-by-domain analysis details these patterns:

(1) Demand and customer interface management: The case companies employed various IPMs focused on external linking and internal interpretation. Lateral relations were central to these efforts. For instance, AutoBus built IPC by gathering forward-looking information through judgmental forecasting with transportation providers to anticipate large municipal orders. All companies utilized cross-functional demand review meetings (lateral relations) to build IPC (by sharing information) and reduce IPRs (by resolving forecast ambiguities), although effectiveness varied; AeroEngine and AutoBus held more comprehensive reviews than their lower-maturity counterparts. IT tools also played a key role. As a contingent response to RTO uncertainty, AutoBus's use of configurators for quoting/scoping (information systems support) aimed to reduce uncertainty by standardizing the translation of requirements. Contrastingly, AeroEngine's engagement in collaborative product development with customers (lateral relations) was an intensive equivocality-reducing mechanism designed to clarify the ambiguous requirements inherent in its DTO environment.

(2) Product and engineering integration: Managing the complexity of customized products and new technology demanded specific IPMs linking engineering knowledge to S&OP. AeroEngine exemplified strong lateral relations through the dedicated involvement of engineering representatives in S&OP, who used specific tools for capacity and risk tracking (information systems support). This both built IPC and reduced IPRs related to engineering feasibility. AeroEngine also employed environmental management via a competence development roadmap to proactively reduce IPRs related to future skill availability. The formal review of the product life cycle, seen in both AeroEngine and AutoBus, served as a self-contained task to reduce uncertainty during product evolution. However, AeroEngine layered this with IPMs tailored specifically for its DTO context. Its dedicated S&OP process steps for engineering (self-contained tasks) and advanced 3D modeling were designed as equivocality-reducing IPMs to clarify and resolve ambiguity in its novel designs.

(3) Operations and capacity alignment: As a classic uncertainty-reducing strategy for its RTO environment, AutoBus implemented slack resources via its static capacity setting with marginal flexibility to absorb demand volatility. This maturity was evident in the use of advanced information technology to build IPC for capacity planning. AeroEngine exemplified this. At the strategic level, its S&OP process was underpinned by a financial planning tool that assessed the business impact and viability of various production scenarios against top-level financial assumptions. This strategic direction guided the tactical use of more granular operational tools (e.g., workforce planning, capacity matrix/rough-cut capacity, and simulation) to align and execute capacity plans. The firms also used vertical information systems (e.g., integration with master production scheduling) to link tactical S&OP with operational execution. At higher-maturity firms, lateral relations were also used to interface with production development, and the involvement of production engineering and shop-floor specialists (most notably in AeroEngine) enriched the information flow.

(4) Supply chain coordination and risk management: Specific IPMs were required to manage the complexity of the ETO supply chain. Core vertical information systems (e.g., ERP) were used by all firms to build basic IPC, but lateral relations were key. This included the involvement of procurement/supply chain functions in S&OP teams and mechanisms for addressing uncertainty, such as the review and update of risk and assumption trackers (self-contained tasks). The formality of this varied. AeroEngine dedicates eight meetings to risk compared to more limited reviews elsewhere. Direct collaboration with key suppliers/partners (lateral relations) was another IPM used by AeroEngine, AutoBus, and MediSterilizer to build IPC and reduce supply risk, although MediSterilizer's involvement was often reactive, while InduCrane suffered from limited visibility.

(5) Cross-functional collaboration and governance: S&OP effectiveness relied on mechanisms that fostered internal alignment. Firms used self-contained tasks, such as AeroEngine's dedicated S&OP improvement meeting, to systematically build IPC over time, and slack resources, like AeroEngine's bottom-up escalation tools, to reduce the IPR burden on standard meetings. The formal S&OP team establishment and facilitation (lateral relations) was observed in all cases, but its effectiveness varied with maturity level. AeroEngine and AutoBus further expanded IPC by adding more functions (e.g., human resources and business development). To ensure information flow across levels, firms relied on vertical information systems and lateral relations (e.g., iterative S&OP meetings). MediSterilizer and InduCrane used dedicated S&OP processes for ETO families (self-contained tasks) to reduce coordination complexity compared with the mixed-model approach used by other firms.

(6) Information systems and analytics support: Beyond core ERP/MRP systems, the pattern of IT investment was contingent on each firm's ETO archetype. AeroEngine, facing high design

equivocality in its DTO work, invested in simulation, 3D modeling, workforce planning, a tooling database, and collaborative platforms (information systems support). AutoBus, facing high process and demand uncertainty in its RTO environment, focused on configurators and sales trackers. MediSterilizer relied more on its core SAP system supplemented by analytics, while InduCrane's IT support was limited mainly to its foundational MRP and spreadsheets, which hindered its ability to leverage modern data analytics.

4.4. Cross-case comparison of S&OP quality gaps

The cross-case analysis revealed variations in IPR-IPC alignment. Appendix E provides a detailed gap assessment across all six information processing domains. The aggregate gap counts presented earlier in Table 3 are detailed in the following domain-by-domain analysis:

(1) Demand and customer interface management: A primary gap in lower-maturity firms was insufficient forecasting capability (IPC), which failed to meet IPRs for reliable proactive demand information. This manifested as a gap for MediSterilizer and InduCrane that impacted IQ and PQ due to long-term visibility issues. A manager at MediSterilizer (C2) noted, ‘We have no clue what the customers want to order in 9 months … our forecasting process is never accurate in a helpful way.’ While less severe, AeroEngine and AutoBus also showed room for improvement. Relatedly, limited real-time sensing (IPC) hindered the processing of diverse demand information, which appeared as a moderate gap for most firms but a major one for InduCrane. Furthermore, weak customer engagement mechanisms (IPC) failed to enable the communication needed for a shared understanding of requirements (failing CE and AQ IPRs). This was a major gap for MediSterilizer and InduCrane, but only a minor one for AeroEngine and AutoBus, which had stronger customer collaboration.

(2) Product and engineering integration: Gaps in integrating engineering with S&OP were prominent in lower-maturity firms. Poor sales-engineering alignment (IPC) was an issue for InduCrane and AutoBus (impacting AQ, CE, and PQ). A manager from InduCrane (D1) stated that ‘sales and engineering often have different views on what the customer really wants.’ A noticeable, though less severe, gap was also identified at MediSterilizer. Consequently, weak engineering integration in S&OP (IPC) failed to provide the required cross-functional communication and was identified as a major gap for InduCrane due to explicit silos and mistrust, while a moderate gap was identified at MediSterilizer. Finally, the lack of a structured technology integration process (IPC) was most severe for InduCrane, which failed IPRs for proactive tech information processing and impacted its S&OP PQ and AQ.

(3) Operations and capacity alignment: Large gaps existed in matching operational capacity with volatile ETO demands. First, inadequate capacity planning methods (IPC) failed to provide the necessary IPRs for adaptive real-time project processing. This represented a major gap for MediSterilizer and InduCrane (impacting PQ and AQ). An InduCrane manager (D3) noted that ‘Deviations between planned and actual job durations can reach up to 500%.’ AeroEngine and AutoBus faced a similar, though less severe, challenge. Second, poor resource visibility (IPC), particularly for engineering skills, has led to unfulfilled IPRs for precise project information, which represents a major gap for InduCrane and a moderate one for AeroEngine. Finally, limited shopfloor feedback loops (IPC) hindered IPRs for continuous process monitoring, which was a moderate gap for AeroEngine and a major gap for InduCrane (affecting S&OP PQ, IQ, and CE).

(4) Supply chain coordination and risk management: External coordination was a challenge. Poor supplier visibility (IPC) failed to meet the IPR for timely and accurate information sharing (impacting IQ, PQ, and AQ). This was a major gap at both AutoBus, where a manager (B4) stated, ‘Sometimes we are not able to get the full transparency …,’ and at InduCrane due to its limited visibility into subcontractor lead times. The gap was also explicitly noted at MediSterilizer. Concurrently, weak supplier collaboration mechanisms (IPC) failed IPRs for proactive and collaborative risk management. This was a major gap (impacting AQ and CE) for the reactive MediSterilizer and the limited-engagement InduCrane, and a moderate gap for AutoBus. Finally, underdeveloped risk/scenario processes (IPC) failed IPRs for risk management and adaptive planning. This constituted another major gap for MediSterilizer and InduCrane and a moderate long-term gap for AeroEngine and AutoBus.

(5) Cross-functional collaboration and governance: This domain revealed widespread gaps, particularly in lower-maturity firms. First, silos and weak integration (IPC) failed to meet IPRs for cross-functional information sharing and rich communication. This was a major gap (impacting AQ, CE, and PQ) for InduCrane and MediSterilizer. One manager (D1) described it as, ‘Sales … center, others satellites … ‘. A related gap was the lack of standard formats/protocols (IPC), which hindered communication and was a major issue for InduCrane and an explicit one for MediSterilizer. Second, a weak strategic-operational linkage (IPC) failed to meet the IPR for integrating information across planning levels. This was a major gap for MediSterilizer and InduCrane, and a moderate one for the higher-maturity firms. Third, a lack of formal S&OP performance measurement (IPC) was a major gap (impacting PQ and AQ) for MediSterilizer and InduCrane. Finally, weak continuous improvement and change management mechanisms (IPC) represented a major gap (affecting AQ and CE) across most cases, which hindered their adaptation.

(6) Information systems and analytics support: Foundational IT gaps plagued the lower-maturity firms. Poor system integration (IPC) failed the IPR for coherent information flow and presented as a major gap for InduCrane and MediSterilizer, moderate for AutoBus, and minor for AeroEngine. A reliance on fragmented manual systems (IPC) failed IPRs for efficient processing, which was a major gap for InduCrane and an explicit one for MediSterilizer. Consequently, the lack of advanced analytics (IPC) has led to unfulfilled IPRs for interpreting complex signals and anticipating future needs. This was a major gap for the lower-maturity firms and a moderate one for AeroEngine and AutoBus. Finally, an inflexible IT architecture (IPC) failed the IPR for adaptable systems, which was rated as a major gap for InduCrane and an explicit one for MediSterilizer.

5. Discussion

Our findings provide an empirical basis for exploring how S&OP processes are adapted for the complexities of ETO manufacturing. This section discusses the theoretical implications of these findings, using the multifaceted framework (Fig. 1), and interprets why the firms' S&OP configurations differ by analyzing their contingent nature, examines the dynamic capabilities that enable process adaptation, and explores the socio-political realities that influence their effectiveness, leading to five empirically grounded propositions.

5.1. S&OP capabilities and contingent design

The fundamental premise of OIPT found support in our context. The cross-case comparison revealed a causal relationship whereby higher S&OP process maturity, treated as a structural antecedent, led to a better IPR-IPC fit. This finding, supported by both our qualitative analysis and the quantitative triangulation (Table 3), aligns with the S&OP works claiming that mature processes yield better outcomes (e.g., Danese et al., 2017; Grimson and Pyke, 2007). However, our findings also reveal that overall maturity alone does not guarantee an effective S&OP design. Its effectiveness is contingent on the firm's ETO archetype and its dominant information problem. The specific S&OP capabilities firms built, such as cross-functional integration or scenario planning, were contingent responses whose importance varied across DTO and RTO environments. These capabilities are not separate from the IPM portfolio but are rather embodied by a mature portfolio of practices.

First, an IPM portfolio that enables cross-functional integration proved essential for managing the high equivocality inherent in the DTO archetype, where reconciling information from additional functions (e.g., engineering) is the central challenge (Mello et al., 2015). AeroEngine's portfolio, incorporating its highly participative meeting structures and dedicated engineering involvement (strong lateral relations IPMs), was a necessary strategic choice to build the capability for shared understanding needed to resolve ambiguity in its novel projects. This contrasts with InduCrane's siloed portfolio, which halted its ability to resolve ambiguity and resulted in a major IPR-IPC gap. This finding reiterates that higher S&OP quality, particularly when facing high equivocality, cannot be achieved without deep cross-functional integration (e.g., Goh and Eldridge, 2024; Tuomikangas and Kaipia, 2014).

Second, a portfolio that builds scenario-planning capabilities was instrumental in managing ETO uncertainty. The ability to explore multiple futures across demand scenarios and supply responses enables firms to prepare for variability (Singh and Lee, 2013). Both AeroEngine and AutoBus embedded scenario analysis IPMs (IT-supported lateral relations) in their S&OP processes. The portfolio at AutoBus, for example, which included a static capacity buffer and IT-supported scenario tools, was a contingent response to high-demand volatility in its RTO setting that enabled robust resource-allocation decisions (high PQ). MediSterilizer and InduCrane lacked formal scenario processes and thus exhibited larger gaps in managing operational variability and risk. Swink et al. (2025) provide corroborating evidence from a different context. Their analysis of firm performance during the COVID-19 pandemic found that advanced supply chain planning systems conferred resilience advantages over simpler inventory-based approaches. The parallel suggests that IT-enabled planning capabilities, whether for pandemic response or ETO demand management, outperform passive buffers in high-uncertainty environments.

Third, an IPM portfolio that facilitates integrated risk management appeared highly relevant for managing the high execution uncertainty of complex ETO projects. Given that ETO environments present numerous project-specific risks (Alfnes et al., 2021), IPMs such as dedicated risk review points and assumption trackers (self-contained tasks), as seen in AeroEngine, or risk discussions in executive reviews, as seen in AutoBus, were necessary. This proactive approach contrasts with MediSterilizer and InduCrane, where S&OP-linked risk management was underdeveloped. An IPM portfolio for integrating risk management into S&OP allows firms to anticipate disruptions and incorporate mitigation strategies (Dittfeld et al., 2021; Kalla et al., 2024), which in turn enhances the robustness of their other planning IPMs.

These observations frame our first proposition, which is contingent on the ETO context:

Proposition 1. *If an ETO firm embeds an IPM portfolio that cultivates specific S&OP capabilities for cross-functional integration, scenario planning, and integrated risk management, then it will achieve a higher degree of IPC-IPR fit. This is because these capabilities are necessary to process the high levels of equivocality and uncertainty inherent in the ETO context. The relationship is moderated by the firm's overall S&OP maturity*.

A low-maturity state (a descriptive fact about a firm's flawed structural condition) prevents the effective deployment of the necessary sophisticated practices. The case of InduCrane illustrates this. Its inconsistent processes (a state of low maturity) rendered even basic IPMs ineffective, which led to poor planning outcomes.

5.2. S&OP as a dynamic capability

Given the fluid nature of ETO environments (Cannas et al., 2019), where customer requirements constantly shift (Mello et al., 2015), a firm's IPRs are in a constant state of flux. To sustain an effective S&OP process, firms must cultivate a dynamic capability (Teece, 2007). This manifests as both flexibility within the existing process to handle immediate disruptions and the ability to reconfigure the process itself over the long term. A mature ETO S&OP process appears to function as such, embedding higher-order routines for sensing misalignments, seizing opportunities by adapting plans, and transforming the process through reconfiguration.

The first of these routines, sensing, is the firm's diagnostic capability to identify IPR-IPC gaps. This challenge is substantial in ETO, where the plan is an emergent outcome. The sensing task moves beyond monitoring variance against a stable plan to surfacing deep equivocality in novel project requirements. Unsurprisingly, our findings confirm that this sensing capability depends on the firm's performance measurement systems. The lack of formal S&OP metrics at MediSterilizer and InduCrane, for instance, crippled their ability to identify process deficiencies objectively (Appendix B). Higher-maturity firms, such as AutoBus, use metrics and dashboards to simplify communication in executive meetings, yet even with advanced tools, they still struggle to identify systemic bottlenecks precisely. This leads to our second proposition:

Proposition 2. *If an ETO firm embeds a proactive IPR-IPC gap sensing capability, then it will achieve a higher degree of IPC-IPR fit. This is because it enables the firm to diagnose misalignments in an environment without stable performance benchmarks systematically. This relationship is moderated by ETO-specific performance metrics that distinguish between inherent project novelty and process-driven failure.*

The need for this IPR-IPC gap-sensing capability is found particularly acute in three domains. The struggles of MediSterilizer and InduCrane to produce reliable demand forecasts (Domain 1) indicate a lack of awareness of the gap between their forecasting IPC and the IPRs, which undermines accurate demand information. Similarly, pervasive IT gaps, from InduCrane's fragmented manual systems to the insufficient use of advanced analytics at most firms (Domain 6), highlight the need to sense mismatches between existing IT capabilities and emerging IPRs proactively (Schlegel et al., 2021). Finally, persistent gaps in cross-functional collaboration (Domain 5) stemming from silos and a lack of standard protocols require ongoing assessment of relational and governance mechanisms. Overcoming these sensing challenges may require moving beyond traditional IPMs toward next-generation tools like IBP platforms (Swink et al., 2025).

We also found that a firm's sensing capabilities can be informed by environmental management mechanisms that scan the external landscape. This process refers to the systematic acquisition of information about external events and trends (Daft et al., 1988). The value of this data depends on a firm's absorptive capacity to translate it into improved decisions (Zahra and George, 2002). We observed different levels of this capability in practice. AeroEngine maintained structured interfaces with customers for joint product development and with universities for technology scouting. Both represent environmental management mechanisms that channel external knowledge into the S&OP process. The company's internal R&D culture, evidenced by a steady pipeline of internships and doctoral research projects embedded in operations, provided the absorptive capacity to act on these inputs. AutoBus employed judgmental forecasting with transportation providers to gather demand intelligence, though its absorptive capacity was concentrated in commercial functions rather than distributed across operations. MediSterilizer and InduCrane showed limited external engagement and correspondingly weak absorptive capacity, which left them reactive to market shifts they could have anticipated.

Accordingly, environmental management mechanisms within S&OP fulfill two connected functions. First, they enhance a firm's ability to proactively sense current and future IPRs originating from the external environment (P2). For example, robust market intelligence can reveal an impending IPR for greater production flexibility long before internal systems signal capacity constraints. Second, the insights derived from these external-facing IPMs are essential inputs for reconfiguring the internal IPM portfolio. Knowledge of disruptive technology, acquired through environmental scanning, may prompt changes to product development liaisons (lateral relations) or investment in new simulation tools (information technology support). The finding that higher-maturity firms like AeroEngine and AutoBus employed more structured environmental management mechanisms than MediSterilizer and InduCrane supports this connection, leading to our third proposition:

Proposition 3. *If an S&OP process design incorporates environmental management mechanisms (e.g., market intelligence, customer co-creation), then it will enhance the firm's overall dynamic capability for S&OP. This is because, in a DTO-dominant environment, external co-creation unlocks intelligence to reduce equivocality, whereas in an RTO environment, deep supplier integration provides intelligence to reduce execution uncertainty.*

The final components of a firm's dynamic capability, seizing and reconfiguration, represent its adaptive response (Teece, 2007). Seizing is the capacity to act on sensed opportunities by adapting plans within the current S&OP process, for instance, through the use of ad hoc task forces to manage unexpected disruptions. We observed this at AutoBus, where challenges such as unexpected regulatory changes and monitoring high-risk projects were managed by flexible teams that leveraged the existing S&OP structure without fundamentally altering it.

Reconfiguration, in turn, is the higher-order capability to transform the underlying IPM portfolio itself when the old ways of working are no longer sufficient. This transformation can be perceived as a form of organizational learning (Argyris and Schön, 1997), which again requires a firm to possess sufficient absorptive capacity to recognize the value of new information and adjust its planning configurations accordingly (Zahra and George, 2002). This can involve adapting cross-functional collaboration mechanisms (lateral relations) (Goh and Eldridge, 2024), adopting more flexible decision-making processes (Jonsson et al., 2021), and integrating big data analytics (Schlegel et al., 2021) and simulation tools (Kjellsdotter Ivert and Jonsson, 2014) to enhance scenario planning. Embedding further flexibility in ETO S&OP seems a prerequisite for process effectiveness (Bhalla et al., 2023a, 2023b; Shurrab et al., 2022a, 2022b), which calls for integrating even more advanced systems that can take scenario planning a step ahead, such as digital twins (Overbeck et al., 2024) and companywide IBP platforms (Swink et al., 2025).

We found examples of these varying reconfiguration capabilities. For instance, AeroEngine institutionalized this capability through its dedicated S&OP improvement meeting, which served as a self-contained task performed at each cycle to reconfigure its planning process continuously. AutoBus also demonstrated this capability through planned IT upgrades and periodic reviews of its risk trackers. Contrariwise, the IPR-IPC gaps at MediSterilizer and InduCrane, particularly their lack of focus on continuous improvement, indicated weaker adaptive capabilities and the absence of a structured reconfiguration routine.

These observations and theoretical connections frame our fourth proposition:

Proposition 4. *If an ETO firm embeds a dynamic adaptation capability, then it will achieve a sustained or improved IPC-IPR fit over time, because this capability enables the firm to continuously reconfigure its IPM portfolio in response to sensed IPR-IPC gaps. This relationship is moderated by the firm's ETO archetype, as effective reconfiguration in DTO environments requires enhancing equivocality-reducing IPMs (e.g., deeper customer integration), whereas in RTO environments it requires enhancing uncertainty-reducing IPMs (e.g., supply chain flexibility and buffering).*

5.3. S&OP's socio-political reality in ETO contexts

Our findings reveal that S&OP, beyond a rational planning exercise, can be understood through the lens of STS theory. The theory's core principle is that a technical system (tools, data) is inseparable from the social system (culture, trust, politics) in which it is used (Appelbaum, 1997). We corroborate this, unlike most S&OP literature that treats people, process, and technology separately (e.g., Tuomikangas and Kaipia, 2014). We argue that S&OP is an archetypal example of such a system, where technical components, such as ERP and IBP platforms, forecasting tools, and the formal process, cannot be understood in isolation from the human dynamics of the cross-functional teams. The one-of-a-kind nature of every ETO project means the technical plan is perpetually novel, which places a burden on the social system to engage in constant negotiation. The disparity between the social systems at AeroEngine and InduCrane demonstrates how this joint optimization is the enabler (or disabler) of the entire S&OP process.

InduCrane's struggles exemplify a case of socio-technical misalignment. Its departments operated as distinct thought worlds with conflicting goals, a common social S&OP challenge (Ambrose and Rutherford, 2016), amplified by a broken social system. As evidenced by a documented lack of trust and the political reality that sales was the 'center' and other functions were 'satellites,' this social failure created the socio-behavioral ambiguity of stakeholder misalignment. This, in turn, halted the technical process, where engineering was uninvolved, and trust was absent. Consequently, technical IPMs, such as the firm's planning systems, were rendered less effective by unreliable and politically biased information.

AeroEngine's success resulted from this joint optimization. Its advanced technical subsystem (e.g., simulation tools, risk trackers) was only effective because it was embedded in a high-functioning social subsystem. The firm cultivated a culture of deep cross-functional collaboration through highly participatory meetings that involved over 50 people serving as non-technical IPMs. This intensive engagement fostered a state of polyvocality, i.e., the inclusion of multiple perspectives (Benjaminsen and Sørnes, 2025), which built the interpersonal trust necessary to resolve the extreme equivocality inherent in its novel DTO projects.

These social dynamics manifest in uniquely ETO ways. There is tension between centralized planning (demanded for resource allocation) and decentralized adaptation (required by the novelty of each project) (Bertrand and Muntslag, 1993). InduCrane's sales-dominated decision-making was a dysfunctional response to this trade-off, which disconnected its central plans from operational reality. Furthermore, the problem of failing to share knowledge and avoid 'reinventing the wheel' is uniquely damaging in ETO due to the high engineering investment in each project (Schindler and Eppler, 2003). The siloed culture at InduCrane created systemic barriers to this organizational learning and fueled a failure to capture value from its most critical asset, meaning the knowledge gained from past projects.

Behavioral factors are important in all S&OP processes, but they are more decisive in the ETO context. The evidence from our cases suggests that trust is a foundational prerequisite for effective IPC. Without it, information is withheld or distorted, which renders even sophisticated IT systems less effective (cf. Mayer et al., 1995). Because the technical system in ETO is perpetually unstable, the social system must bear a much heavier load for coordination and sense-making. Therefore, the socio-behavioral ambiguities we identified are often the dominant IPRs a firm faces. This confirms that non-technical IPMs, such as the trust-building routines at AeroEngine, are as valuable as, if not more valuable than, technical IPMs for any ETO firm seeking a high-quality S&OP process. This leads to our fifth proposition:

Proposition 5. *If an ETO firm deploys non-technical behavioral IPMs (e.g., trust-building routines, conflict management processes), then the effectiveness of its technical IPM portfolio in achieving an IPC-IPR fit increases.*

Technical tools require accurate information, and behavioral mechanisms prevent the stakeholder conflicts that would otherwise distort it.

5.4. Proposed model for ETO S&OP

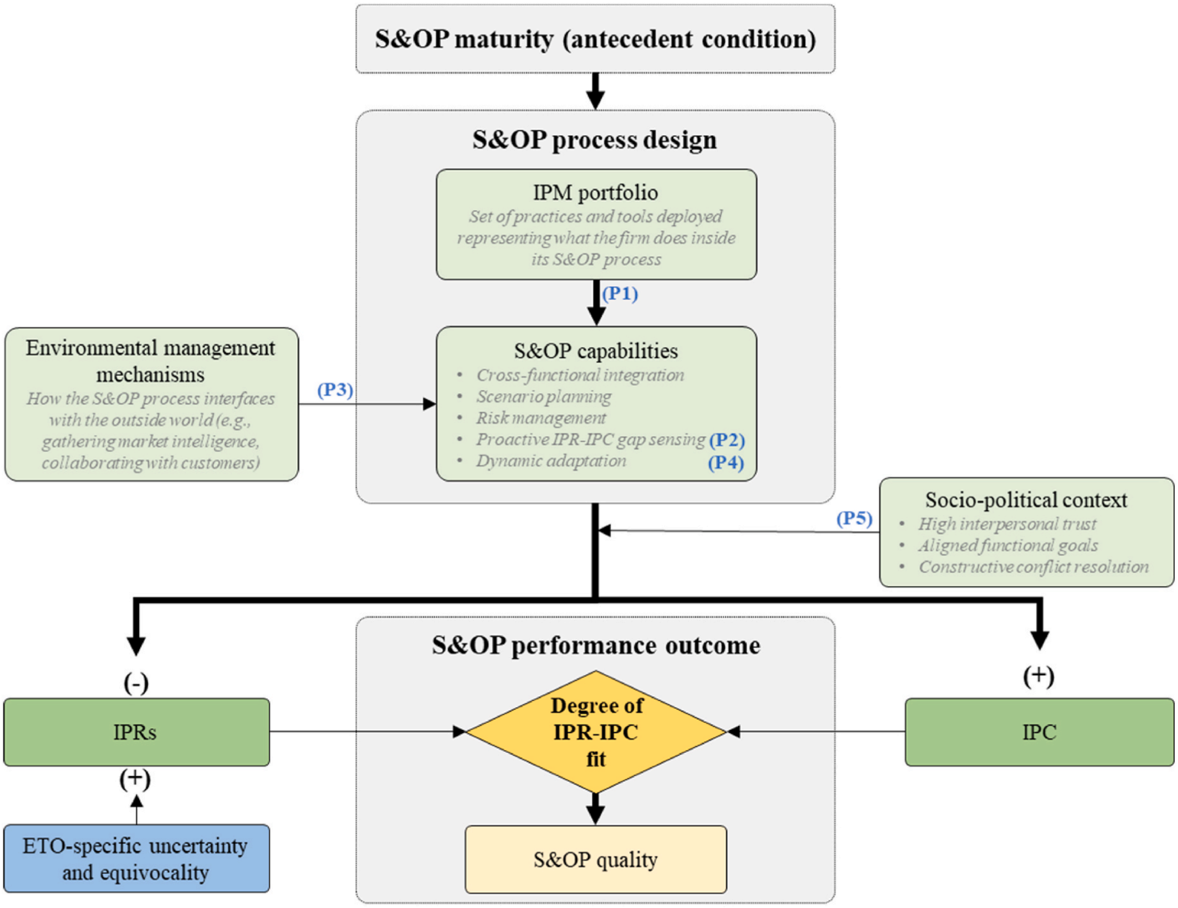
To provide a holistic view of the relationships discussed earlier, we propose an integrated model shown in Fig. 2. The model synthesizes our theoretical framework to visually depict the contingent, dynamic, and socio-technical nature of S&OP in ETO environments. The causal path flows from top to bottom. The S&OP maturity (grey box) serves as an antecedent condition that enables the deployment of an IPM portfolio (light green top box), which cultivates specific S&OP capabilities (light green center box). Environmental management mechanisms (light green left box) feed external intelligence into this capability-building process. The socio-political context (light green right box) moderates the translation of capabilities into performance outcomes in the bottom section by reducing IPRs and building IPC towards a degree of achieved IPR-IPC fit (orange diamond) across S&OP quality dimensions. The five propositions (P1-P5), summarized in the box below the diagram, formalize several embedded relationships.

6. Implications

6.1. Theoretical implications

This study makes four primary contributions to theory. First, we develop and empirically ground a multifaceted theoretical framework for analyzing S&OP that demonstrates how the foundational insights of OIPT can be integrated with contingency theory, the DCV, and STS theory to create a more holistic explanatory model of S&OP as a technical, contingent, dynamic, and socio-political system.

Second, our work provides a contingent theory of S&OP design for



P1: If an ETO firm embeds an IPM portfolio that cultivates specific S&OP capabilities (cross-functional integration, scenario planning, risk management), then it will achieve a higher degree of IPC-IPR fit, because these are necessary to manage ETO equivocality and uncertainty. This is moderated by S&OP maturity.

P2: If an S&OP process design embeds a proactive IPR-IPC gap sensing capability, then it will achieve a higher degree of IPC-IPR fit, because it enables systematic diagnosis of misalignments. This is moderated by the presence of formal performance metrics.

P3: If an S&OP process design incorporates environmental management mechanisms, then it will enhance the firm's overall dynamic capability, because external intelligence fuels internal adaptation and reconfiguration.

P4: If an ETO firm embeds a dynamic adaptation capability, then it will achieve a sustained or improved IPC-IPR fit over time, because this enables the continuous reconfiguration of the IPM portfolio. This is moderated by the firm's ETO archetype.

P5: If an ETO firm deploys non-technical behavioral IPMs (e.g., trust-building), then the effectiveness of its technical IPM portfolio will be enhanced, because these mechanisms reduce the socio-political conflict that distorts information.

Fig. 2. Proposed model for the constructs driving ETO S&OP process design.

ETO environments. Responding to calls for context-specific research (e.g., Kristensen and Jonsson, 2018), we show that a firm's ETO archetype (DTO vs. RTO) shapes its dominant information problem and thus dictates the required IPM portfolio. This moves the discussion from generic best practices to a contingent understanding of what works where and why.

Third, we propose extending OIPT's core constructs. We argue that classic OIPT is insufficient for human-intensive systems, such as S&OP, and introduce two new constructs, including socio-behavioral ambiguities (IPRs rooted in social dynamics) and non-technical IPMs (behavioral mechanisms such as trust-building). Theorizing these human-centered elements equips OIPT with the necessary tools to analyze the socio-political realities of cross-functional integration.

Fourth, our study reconceptualizes ETO S&OP as an observable dynamic capability. We detail its microfoundations, show how the abstract concepts of sensing, seizing, and reconfiguring (Teece, 2007) manifest as S&OP capabilities, and provide an empirically grounded model of how firms can build an adaptive S&OP process.

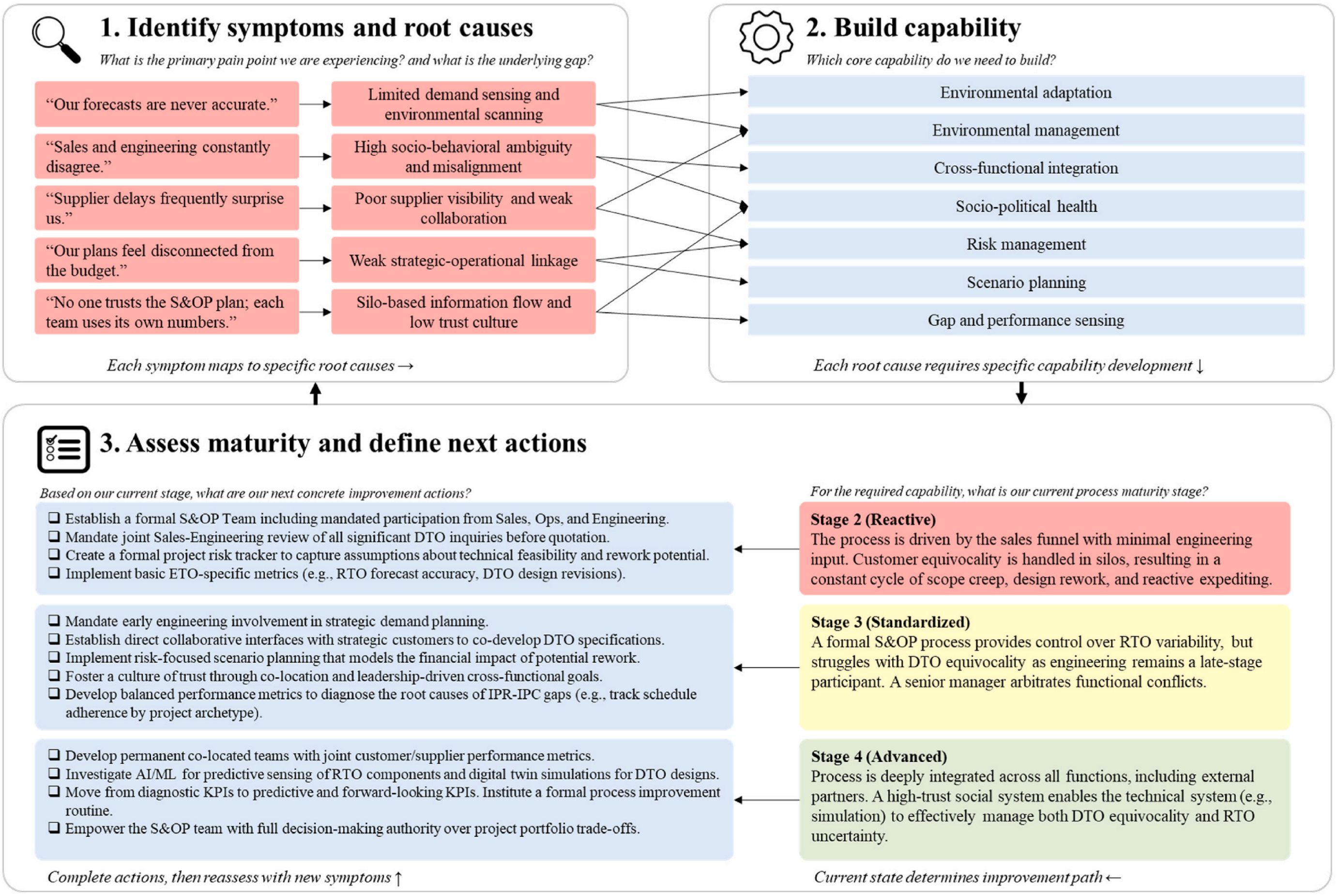
6.2. Practical implications

Our findings indicate that, to be effective in an ETO context, an S&OP process must be augmented by several distinct components. This involves (1) extending the traditional five-step S&OP cycle to include *a pre-demand engineering review* to assess technical feasibility and rework potential before any quotation is made, particularly for DTO projects. Structurally, (2) the process must move beyond core functions to formally mandate the *participation of engineering, procurement, and human resources*, where a senior manager is empowered as the arbiter for resolving the inevitable functional conflicts. From a technology standpoint, this means (3) moving beyond ERP systems to leverage *more advanced tools*, such as configurators for standardizing RTO quotations and simulation software to model the financial impact of potential rework in novel DTO designs. Finally, (4) a practical *project-based risk tracker* that captures assumptions about both technical and supply chain uncertainty must be established as a central non-negotiable input to the entire process.

We synthesize these implications into a diagnostic roadmap, illustrated in Fig. 3, that guides managers by providing examples of how to improve ETO S&OP through three-step iterations continuously.

The roadmap operates as follows. Step 1 (top left, red boxes) prompts managers to identify symptoms (common operational complaints such as 'our forecasts are never accurate' or 'sales and engineering constantly disagree') and maps each to its underlying root cause. Step 2 (top-right, blue boxes) identifies which core capability must be built to address the root cause. The arrows connecting Steps 1 and 2 show these diagnostic mappings. Step 3 (bottom) presents maturity-staged action checklists, where managers assess their current maturity stage (colored boxes on the right (Stage 2 Reactive, Stage 3 Standardized, or Stage 4 Advanced), then select the corresponding action items (checkbox lists on the left). The color coding distinguishes symptom identification (red), capability building (blue), and maturity assessment (red/yellow/green). After completing the prescribed actions, managers return to Step 1 to reassess whether additional symptoms warrant further iterations.

Building on emerging research (e.g., Swink et al., 2025), our case findings also imply economic and socio-political justification for these investments. Investments in technical IPMs (such as AeroEngine's scenario planning tools) are necessary to align with market assumptions



☐ Establish a formal S&OP Team including mandated participation from Sales, Ops, and Engineering.
☐ Mandate joint Sales-Engineering review of all significant DTO inquiries before quotation.
☐ Create a formal project risk tracker to capture assumptions about technical feasibility and rework potential.
☐ Implement basic ETO-specific metrics (e.g., RTO forecast accuracy, DTO design revisions).

Stage 2 (Reactive)
The process is driven by the sales funnel with minimal engineering input. Customer equivocality is handled in silos, resulting in a constant cycle of scope creep, design rework, and reactive expediting.

☐ Mandate early engineering involvement in strategic demand planning.
☐ Establish direct collaborative interfaces with strategic customers to co-develop DTO specifications.
☐ Implement risk-focused scenario planning that models the financial impact of potential rework.
☐ Foster a culture of trust through co-location and leadership-driven cross-functional goals.
☐ Develop balanced performance metrics to diagnose the root causes of IPR-IPC gaps (e.g., track schedule adherence by project archetype).

Stage 3 (Standardized)
A formal S&OP process provides control over RTO variability, but struggles with DTO equivocality as engineering remains a late-stage participant. A senior manager arbitrates functional conflicts.

☐ Develop permanent co-located teams with joint customer/supplier performance metrics.
☐ Investigate AI/ML for predictive sensing of RTO components and digital twin simulations for DTO designs.
☐ Move from diagnostic KPIs to predictive and forward-looking KPIs. Institute a formal process improvement routine.
☐ Empower the S&OP team with full decision-making authority over project portfolio trade-offs.

Stage 4 (Advanced)
Process is deeply integrated across all functions, including external partners. A high-trust social system enables the technical system (e.g., simulation) to effectively manage both DTO equivocality and RTO uncertainty.

Fig. 3. Diagnostic roadmap with examples for ETO S&OP continuous improvement.

and strategic plans and to mitigate the substantial financial risk of rework and delays in DTO projects. The case of InduCrane demonstrates that investments in such tools are likely to fail if the underlying social system is dysfunctional. For managers, this translates into actively building trust and utilizing leadership to align goals across the cross-functional team, as our final proposition argues.

7. Conclusion

We explore how S&OP is adapted to the complex ETO context using OIPT as a foundation, complemented by the DCV, contingency theory, and STS theory. We analyzed how four ETO firms use technical and non-technical IPMs to manage a full spectrum of information challenges, from classic uncertainty to socio-behavioral ambiguities.

Our cross-case analysis revealed three overall findings. First, S&OP maturity enables a more effective IPM portfolio, and the portfolio's design depends on the firm's ETO archetype. DTO S&OP, facing high equivocality, needs to deploy collaborative sense-making IPMs, whereas RTO S&OP, facing high execution uncertainty, needs buffering IPMs. Second, a mature ETO S&OP functions as a dynamic capability that embeds routines for sensing misalignments and reconfiguring the process. Third, the effectiveness of the technical S&OP system is determined by the health of its social system; where trust and alignment are absent, the process fails.

Theoretically, this study contributes a contingent, dynamic, and socio-technical framework for ETO S&OP and extends OIPT with socio-behavioral constructs. For practitioners, we synthesize our findings into a diagnostic roadmap (Fig. 3) to provide a process-improvement guide. These contributions are relevant for any firm facing substantial uncertainty and equivocality in project-based environments.

Despite these contributions, the study's theory-building approach has limitations that frame a rich agenda for future research. Our focus on a small sample of high-performing European firms introduces a potential selection bias, and future work should include lower-performing or failed cases to test the boundary conditions of our model. Furthermore, the cross-sectional design, despite providing a valuable snapshot, cannot fully capture the temporal evolution of S&OP capabilities. A longitudinal study is the next necessary step. Finally, our extension of OIPT invites new research to quantitatively test the proposed socio-behavioral constructs, e.g., by formally modeling the impact of interpersonal trust on a firm's IPC and its effect on S&OP performance.

CRediT authorship contribution statement

Hafez Shurrab: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Patrik Jonsson:** Writing – review & editing, Writing – original draft, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis, Conceptualization.

Declarations of interest

None.

Appendix F. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijpe.2026.110023.

Appendix

Appendix A
Case study protocol

Source 1. Face-to-face interviews	
General overview	Introduction about the informants' experience and role in the company and within the S&OP process. Description of the company's ETO product families. Discussions were grounded by referencing 5 to 10 pre-selected representative ETO projects to elicit concrete examples of planning challenges and successes.
S&OP process	Description of each S&OP step and underlying activity: Demand planning: Product portfolio planning, data gathering, forecasting, and demand review (assumption tracking and risk management) Supply planning: Capacity (including engineering) planning, production planning, and supply chain planning Pre-S&OP executive: Financial planning and meeting S&OP executive meeting Describe the activities' sequence, the interacting entities (participants and information systems), inputs and how they are received and utilized, and outcomes and how they are communicated and utilized within and outside S&OP. For each meeting with S&OP, describe the agenda, duration, participants, review routines, inputs, and outcomes.
S&OP setup and maturity	Describe the S&OP setup (frequency, focus) and the changes in the S&OP implementation maturity since the last assessment.
S&OP integration with other processes	Describe other processes that S&OP interacts with: Medium of interaction: Face-to-face or distanced interfaces, information system platforms: How do reciprocations of inputs and outcomes occur between processes? Integrated points (S&OP steps and activities): Where in the S&OP process do the other processes' outcomes enter as inputs? From where do the S&OP process outcomes enter as inputs to the other processes? Interacting entities: Participants and information systems between the processes Inputs from S&OP and how inputs are received and utilized Outcomes to S&OP and how outcomes are communicated and utilized in S&OP
Decoupling position	Referring to ETO product families: What are the engineering and production activities performed before and after the entry of customer orders?
Demand-supply balancing	Describe how S&OP affected the performance over the last three years in terms of engineering utilization and delays, sales loss due to engineering capacity constraints, and perfect order fulfillment.
S&OP's information processing performance	Describe how S&OP affected: Informational quality: e.g., forecast accuracy, timeliness and visualization of problems, identification of bottlenecks outside the most extended supply lead-time, information about new product introductions, and inventory-related information. Procedural quality: e.g., ability to perform what-if modeling and scenario-based decisions to optimize demand and supply planning using

(*continued on next page*)

Appendix A (*continued*)

Source 1. Face-to-face interviews	
	valid inference rules to estimate future demand and supply capacity needs. Alignment quality: e.g., horizontal alignment (goals and decisions of demand and supply functions), vertical alignment (operational goals contribute to the company's growth and product innovation plans and other long-term objectives and decisions), proactivity instead of reactivity. Constructive engagement: e.g., feedback from functional areas, coordination (e.g., executive support and cross-functional teaming), collaborative culture.
Source 2. Direct observations	
Joint meetings	Additional notes about discussions between informants during joint interviews
Demo sessions	Presentations of internal systems – e.g., ERP and planning software – supporting data collection, processing, and transmitting within forecasting, S&OP, capacity planning, engineering activities, tendering, and project management.
Source 3. Publicly available documents	
Company's website	General introduction about the company: e.g., industry, product portfolio, strategy, mission, history, and descriptions of products and the solutions (e.g., product range, technical characteristics, machine performance, product comparison).
Annual report 2019	Turnover, employees, recent technology launches, new markets, yearly evaluations
Source 4. Internal documents	
Digital or paper materials	Detailed process descriptions and maps of S&OP, forecasting, capacity planning, tendering, product portfolio management, product life cycle management, project management, and other supporting documents that relate to the study constructs variables, e.g., most recent S&OP maturity assessments, previous meeting agendas and minutes, reports about delays and deviations concerning planned vs. reported engineering hours from earlier projects over the last three years, information about rejected orders due to lack of capacity.

Appendix B

S&OP process maturity across case companies

S&OP process maturity	AeroEngine	AutoBus	MediSterilizer	InduCrane
Overall maturity level	*Highest overall maturity*:	*Relatively high maturity*:	*Mixed maturity*:	*Lowest overall maturity*:
Primary areas of high and low maturity	Advanced capabilities across all dimensions, formal and financially integrated processes, and performance measurement	Executive participation, structured approach to financial integration and risk management, collaboration (external partners)	Developing planning cycles are hindered by limited technology integration and inadequate risk management	Developing data-driven decision-making and feedback, limited cross-functional integration
People and organization	Stage 4	Stage 4	Stage 4	Stage 2
Processes and methodologies	Stage 4	Stage 4	Stage 3	Stage 2
Information technology	Stage 4	Stage 3	Stage 3	Stage 2
Performance measurement	Stage 4	Stage 3	Stage 1	Stage 1

Note: The maturity stages correspond to a 5-point ordinal scale, where Stage 1 = 1 point through to Stage 5 = 5 points. The assessment of maturity stages was based on the framework of Danese et al. (2017).

Appendix C. Planning quality assessment rubric

This rubric was used to systematically assess S&OP quality across the four case companies. The following observable indicators were derived from the literature and our case evidence and used as a coding framework to evaluate informational quality (IQ), procedural quality (PQ), alignment quality (AQ), and constructive engagement (CE). The rubric provides contrasting criteria for high, moderate, and low levels of quality, corresponding to the shadings used in the cross-case analysis tables.

C1

Informational quality: Degree of information support for decision-making

Observable indicator	High quality (darkest shade)	Moderate quality (medium shade)	Low quality (lightest shade)
System integration	Utilizes advanced integrated planning systems (e.g., simulation, advanced analytics) that are centrally linked to core ERP and external partner data sources.	Utilizes a core centralized system (e.g., SAP) for demand consolidation but relies on spreadsheets and manual processes for detailed analysis and capacity planning.	Relies on fragmented manual spreadsheets for most planning activities using inconsistent data formats and no central integrated information system.
Data sourcing	Systematically gathers and formally integrates quantitative and qualitative data from external sources (e.g., customers, suppliers, market intelligence) into the planning process.	Some external data is gathered informally or on an ad-hoc basis (e.g., through sales teams), but it is not systematically integrated into the formal S&OP data set.	Relies almost exclusively on internal historical data (e.g., past sales orders) that offer limited or no visibility into external market or supply chain dynamics.
Forecasting logic	Employs sophisticated data-driven forecasting logic that includes advanced scenario modeling and simulation to test multiple future outcomes and their financial implications.	Employs a consensus-based forecasting process that aggregates functional inputs but lacks the tools for advanced simulation or systematic what-if analysis.	Forecasting is based on simple subjective estimates from a single function (e.g., sales) without any formal process for creating consensus or analyzing scenarios.

C2

Procedural quality: Degree to which informational inputs are validated and processed

Observable indicator	High quality (darkest shade)	Moderate quality (medium shade)	Low quality (lightest shade)
Process formalization	Process is well-defined and consistently executed with a comprehensive set of formal review meetings covering all key aspects (e.g., demand, engineering, supply, finance).	Process is formalized and structured with a regular meeting cadence, but some key review steps are missing or are handled inconsistently (e.g., no dedicated engineering review).	Process is inconsistent, emerging, or partially implemented. The meeting cycle is irregular, and the steps are not clearly defined or followed by all participants.
Adaptability and learning	Includes formal institutionalized mechanisms for process refinement and continuous organizational learning (e.g., a dedicated S&OP improvement meeting in every cycle).	Process improvement is discussed on an ad-hoc basis when problems arise, but there are no formal recurring routines for systematic review or organizational learning.	Process is static and reactive. There is no evidence of formal mechanisms for reviewing the effectiveness of the process itself or for driving continuous improvement.
Scenario and risk management	Employs robust and proactive scenario planning and integrated risk management routines to systematically evaluate alternatives and develop contingency plans.	Scenario planning is used to some extent (e.g., to close gaps between demand and supply), but there is no formal integrated risk management process in place.	Lacks a formalized risk management process and the capacity for systematic scenario planning. Decisions are made without formally evaluating alternatives.

C3

Alignment quality: Degree of contribution to organizational and functional goals

Observable indicator	High quality (darkest shade)	Moderate quality (medium shade)	Low quality (lightest shade)
Cross-functional integration	Exhibits deep seamless integration with all relevant functions, including engineering, actively involved and collaborating in formal S&OP routines. Evidence of mutual trust.	Formal cross-functional team exists and key functions are present, but engineering involvement is limited or siloed. Information sharing is structured but may not be fully collaborative.	Functions operate in distinct silos and perform limited inconsistent information sharing. S&OP is driven by a single function. Evidence of a documented lack of trust.
Strategic-operational link	S&OP outcomes are explicitly and consistently linked to strategic objectives and formally integrated into the financial planning and budgeting processes.	S&OP has a clear operational focus, but its connection to high-level business strategy and financial impact is informal, inconsistent, or not formally measured.	The S&OP process is purely operational and lacks a formal connection to strategic business objectives or financial planning.
Performance measurement	Utilizes a comprehensive and balanced set of formal S&OP performance metrics that are reviewed and used to drive continuous improvement.	Some operational metrics are tracked, but the system is not comprehensive, not formally linked to S&OP, or lacks strategic or financial dimensions.	No formal S&OP performance metrics are in place. The effectiveness of the planning process is not systematically measured.

C4

Constructive engagement: Degree to which individuals actively participate & contribute

Observable indicator	High quality (darkest shade)	Moderate quality (medium shade)	Low quality (lightest shade)
Breadth of participation	Involves a broad and diverse range of participants from multiple functions and hierarchical levels to ensure a rich information base.	Participation is established across key central functions (e.g., sales, ops, finance), but the breadth is limited to fewer than multiple participants in a typical cycle.	Participation is limited to a small core group of managers with narrow functional representation (e.g., less than 10 participants) and limited hierarchical depth.
Depth of engagement	Empowers cross-functional teams with clearly defined roles and promotes a culture of participatory consensus-driven decision-making to resolve trade-offs.	Decision-making authority is not clearly defined or is concentrated within a single function. Collaboration exists, but consensus-building on difficult trade-offs is weak.	Decision-making is centralized or dominated by a single function (e.g., sales). Evidence of organizational politics hindering open and collaborative dialogue.
External stakeholder engagement	Systematically and proactively involves key external stakeholders (customers and suppliers) in the planning process through formal interfaces and routines.	Engagement with external stakeholders is primarily informal, ad hoc, or reactive (e.g., involving suppliers only during a crisis).	No structured or systematic engagement with external stakeholders exists within the S&OP process. Visibility into the external environment is low.

Appendix D

Primary and secondary IPMs and their information processing impact

Primary IPM	Secondary IPM	Explanation	Impact (IPR reduced/IPC built)	Case(s)
Slack resources	Utilization of advanced bottom-up escalation tools	Provides a mechanism to absorb issues at lower levels, which reduces information load/need for immediate replanning higher up (buffer).	Reduces IPR by handling exceptions efficiently, which frees up core S&OP capacity (+PQ).	AeroEngine
	Setting static capacity for 12 months (buffer)	Creates planned reserve capacity to absorb demand fluctuations without constant replanning.	Reduces IPR related to frequent capacity adjustments; enhances predictability (+PQ, AQ).	AutoBus
	Flexible order intake/production location decisions	Allows adjustment of workload acceptance/ placement based on available capacity, which acts as a flexibility buffer.	Reduces IPR by aligning demand intake with known capacity and avoiding overload processing (+PQ, AQ).	All

(continued on next page)

Appendix D (*continued*)

Primary IPM	Secondary IPM	Explanation	Impact (IPR reduced/IPC built)	Case(s)
Self-contained tasks	Dedication of S&OP improvement meeting/cycle	Creates a focused, separate process unit dedicated to process refinement, which reduces load on regular S&OP meetings.	Reduces IPR for main cycle by handling improvement separately; Builds IPC via focused learning/adaptation (+PQ).	AeroEngine
	Review of product life cycle/new product introduction in S&OP	Dedicates specific agenda points/reviews to handle new product introduction information, which reduces complexity within the general S&OP flow.	Reduces IPR associated with new production introduction uncertainty/equivocality by structured handling (+AQ).	AeroEngine, AutoBus
	Dedicated S&OP process steps for engineering requirements	Creates focused sub-processes for specific complex information (engineering), which reduces load on general S&OP steps.	Reduces IPR by targeted processing of complex engineering info (+AQ, PQ).	AeroEngine
	Review and update of risk and assumption trackers	Establishes a distinct task/routine for managing specific risk/assumption info outside the general discussion flow.	Reduces IPR by making risks/assumptions explicit and managing them systematically (+PQ).	All
	Dedicated S&OP process for ETO families (vs. mixed)	Segments planning focus onto specific product types, which reduces inter-unit coordination needs compared to mixed S&OP.	Reduces IPR by limiting scope and interdependencies within the planning unit (+AQ, PQ).	MediSterilizer, InduCrane
	Updating value stream development plans	Links S&OP outputs to a separate, focused improvement activity/plan.	Reduces IPR by ensuring structured follow-up on improvement actions identified in S&OP (+PQ, AQ).	AeroEngine, AutoBus
Environmental management	Roadmap for competence development	Proactively manages the internal resource (skills) environment to reduce future uncertainty about capability.	Reduces IPR related to future skill availability and planning complexity (+AQ, PQ).	AeroEngine
	Co-creation with customers and university partners	Manages external environment by collaborating deeply to shape requirements/solutions and reduce future uncertainty.	Reduces IPR by clarifying ambiguity/uncertainty early via collaboration; Builds IPC through external knowledge input (+PQ, CE).	AeroEngine
Vertical information systems	Integration with master production scheduling	Connects tactical S&OP outputs to operational scheduling systems, which enables hierarchical information flow.	Builds IPC by facilitating smooth translation of plans down the hierarchy (+AQ, PQ).	AeroEngine, AutoBus, InduCrane
	Integration of ERP/MRP for high-level material planning	Utilizes core business systems for structured vertical/sequential data processing for material requirements.	Builds IPC by providing structured data management and calculation capacity (+IQ, AQ).	All
	Integrating planning information across hierarchical levels	Establishes processes/systems for information flow between strategic, tactical (S&OP), and operational levels.	Builds IPC by ensuring vertical alignment and data consistency (+AQ).	All
	Linkage between plant-level and group-level S&OP	Creates formal hierarchical links for information sharing and coordination between local and central planning.	Builds IPC by enabling aggregation/disaggregation and coordinated decision-making across levels (+AQ).	AutoBus
Lateral relations	Demand review meetings with cross-functional participation	Uses scheduled meetings for horizontal information sharing, interpretation, and consensus on demand plans.	Builds IPC via info pooling/discussion; Reduces IPR by resolving demand forecast equivocality/uncertainty (+IQ, AQ, CE).	All
	Capacity review meetings with cross-functional participation	Uses scheduled meetings for horizontal sharing and alignment of capacity information and constraints.	Builds IPC via info pooling/discussion; Reduces IPR by resolving capacity allocation conflicts/uncertainties (+PQ, AQ, CE).	All
	Formal S&OP team establishment and facilitation	Creates a dedicated standing team for managing cross-functional coordination and S&OP process execution.	Builds IPC via established coordination structure; Reduces IPR by providing a clear channel for issue resolution (+AQ, CE).	All
	Engineering representatives' involvement in S&OP	Designates specific roles (liaisons/team members) for engineering input/coordination within S&OP.	Builds IPC by bringing engineering knowledge; Reduces IPR by clarifying technical feasibility/specs early (+AQ, CE).	AeroEngine
	Involvement of procurement/supply chain function	Integrates SC/Procurement expertise into the S&OP team/process for horizontal coordination.	Builds IPC via supply chain knowledge sharing; Reduces IPR by aligning plans with supply realities (+AQ).	All
	Increased number of functions involved (e.g., human resources, business development, new product development)	Broadens participation in S&OP teams/meetings for wider horizontal information sharing and perspective integration.	Builds IPC by incorporating diverse inputs and enhancing organizational alignment (+AQ, CE).	AeroEngine, AutoBus
	Involvement of production engineering/shop floor specialists	Includes operational expertise in planning via meetings or specific input channels for horizontal coordination.	Builds IPC via practical insights; Reduces IPR by grounding plans in shop-floor reality (+PQ, AQ, CE).	AeroEngine, AutoBus, MediSterilizer
	Collaboration with key suppliers/partners in S&OP interfaces	Establishes horizontal links with external entities for joint planning, risk assessment, and information sharing.	Builds IPC via access to external info; Reduces IPR through collaborative risk/uncertainty management (+AQ, CE).	AeroEngine, AutoBus, MediSterilizer
	Judgmental forecasting with external partners	Utilizes horizontal communication with external parties (non-suppliers) to gather specific forecast inputs.	Builds IPC by accessing unique external information sources (+IQ, CE).	AutoBus
	Scenario planning techniques (as a collaborative process)	Employs structured cross-functional discussion/methods to explore alternatives and manage uncertainty.	Builds IPC via shared analysis/understanding; Reduces IPR by clarifying potential futures/responses (+PQ, AQ, CE).	All
	Iterative S&OP meetings for issue resolution	Uses meeting frequency/structure for ongoing horizontal dialogue and adaptation to resolve emerging issues.	Builds IPC via continuous info sharing; Reduces IPR by tackling uncertainty/equivocality iteratively (+PQ, AQ, CE).	All

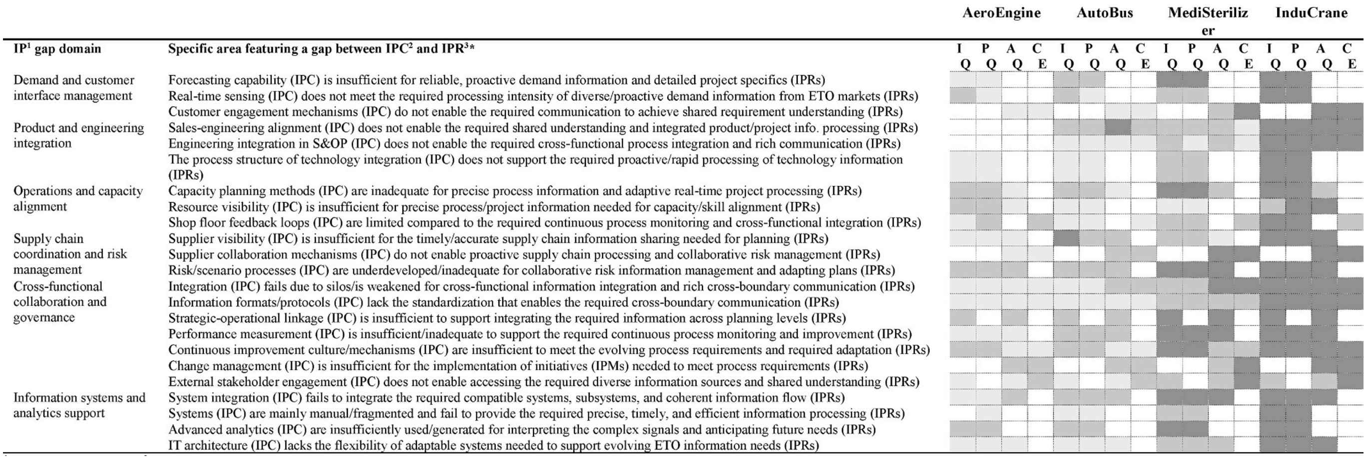
(*continued on next page*)

Appendix D (*continued*)

Primary IPM	Secondary IPM	Explanation	Impact (IPR reduced/IPC built)	Case(s)
	Collaborative planning culture	Fosters norms and values supporting open horizontal communication and joint problem-solving across functions.	Builds IPC via enhanced willingness to share; Reduces IPR by facilitating informal ambiguity resolution (+AQ, CE).	MediSterilizer
Information technology support	Use of configurators for quoting/scoping/costing	Employs IT tools to structure/standardize complex product configuration information, which automates processing.	Builds IPC via efficient processing; Reduces IPR by simplifying/standardizing requirement input (+IQ, PQ).	AutoBus, AeroEngine
	Use of specific planning tools (optimization, engineering capacity)	Deploys specialized software beyond core ERP/MRP to enhance analytical/planning capacity for specific tasks.	Builds IPC by providing advanced calculation/modeling capabilities (+PQ, IQ).	AeroEngine, AutoBus
	Use of simulation tools (flow, layout, system performance)	Utilizes IT for modeling complex systems to analyze performance and test scenarios, which builds analytical capacity.	Builds IPC via advanced analysis; Reduces IPR by decreasing uncertainty about system behavior (+PQ, IQ).	AeroEngine
	Use of workforce planning tools	Leverages IT to manage complex workforce data and optimize allocation, which enhances planning capacity.	Builds IPC by enabling efficient processing of workforce data for planning (+PQ, AQ).	AeroEngine
	Use of capacity matrix/rough-cut capacity tools	Employs specific tools/templates (often IT-based) for analyzing capacity, which increases analytical capacity.	Builds IPC by providing structured capacity analysis capabilities (+IQ, PQ).	AeroEngine
	Use of 3D modeling for layouts/products	Uses visualization software to represent complex spatial/product information, which enhances analytical capacity.	Builds IPC via better visualization/analysis; Reduces IPR by clarifying spatial/design ambiguities (+IQ, PQ).	AeroEngine
	Use of collaborative platforms (internal/external)	Implements shared digital workspaces/tools to facilitate information sharing and interaction across boundaries.	Builds IPC by increasing speed/reach of communication and enabling richer lateral relations (+AQ, CE).	AeroEngine
	Use of specific core systems (e.g., SAP, Sales Trackers)	Leverages core enterprise/functional systems as central repositories/processors for S&OP-relevant data.	Builds IPC by providing foundational data management and processing power (+IQ, AQ).	All
	Use of calculators/spreadsheets for specific analyses	Employs basic IT/manual tools for focused calculations or data handling where integrated systems are lacking.	Builds IPC (basic level) by providing essential calculation/data organization support (+IQ, PQ).	MediSterilizer, InduCrane
	Use of analytics on historical data	Applies analytical techniques/tools to past data to generate insights for planning, which enhances analytical capacity.	Builds IPC by extracting patterns/knowledge from existing data (+IQ, PQ).	MediSterilizer, AeroEngine, AutoBus

Appendix E

IPR-IPC gaps across case companies



		AeroEngine				AutoBus				MediSterilizer				InduCrane			
IP[1] gap domain	**Specific area featuring a gap between IPC[2] and IPR[3]***	**IQ**	**PQ**	**AQ**	**CE**	**IQ**	**PQ**	**AQ**	**CE**	**IQ**	**PQ**	**AQ**	**CE**	**IQ**	**PQ**	**AQ**	**CE**
Demand and customer interface management	Forecasting capability (IPC) is insufficient for reliable, proactive demand information and detailed project specifics (IPRs)	░	░			▒	▒			▓	▓			▓	▓		
	Real-time sensing (IPC) does not meet the required processing intensity of diverse/proactive demand information from ETO markets (IPRs)	▒	░			▒	░			▒	▒			▓	▓		
	Customer engagement mechanisms (IPC) do not enable the required communication to achieve shared requirement understanding (IPRs)			░	░			░	░			▒	▓			▓	▓
Product and engineering integration	Sales-engineering alignment (IPC) does not enable the required shared understanding and integrated product/project info. processing (IPRs)					▒	▒	▓	▒	▒	▒	▒	░	▓	▓	▓	▓
	Engineering integration in S&OP (IPC) does not enable the required cross-functional process integration and rich communication (IPRs)					░	░	░	░	▒	░	▒	░	▓	▓	▓	▓
	The process structure of technology integration (IPC) does not support the required proactive/rapid processing of technology information (IPRs)	░	░			░	░			▒	▒			▓	▓		
Operations and capacity alignment	Capacity planning methods (IPC) are inadequate for precise process information and adaptive real-time project processing (IPRs)	▒	▒	░		▒	▒	░		▓	▓	▒		▓	▓	▒	
	Resource visibility (IPC) is insufficient for precise process/project information needed for capacity/skill alignment (IPRs)	▒	▒	░		░	░			░	░			▒	▓	▓	
	Shop floor feedback loops (IPC) are limited compared to the required continuous process monitoring and cross-functional integration (IPRs)	░	▒		▒	░	░		░	▒	▒		▒	▓	▓		▒
Supply chain coordination and risk management	Supplier visibility (IPC) is insufficient for the timely/accurate supply chain information sharing needed for planning (IPRs)	░	░	░		▓	▒	▒		▒	▒	░		▓	▓	▓	
	Supplier collaboration mechanisms (IPC) do not enable proactive supply chain processing and collaborative risk management (IPRs)			░	░			▒	▒			▓	▓			▓	▓
	Risk/scenario processes (IPC) are underdeveloped/inadequate for collaborative risk information management and adapting plans (IPRs)	▒	▒	▒		▒	▒	▒		▓	▓	▓		▓	▓	▓	
Cross-functional collaboration and governance	Integration (IPC) fails due to silos/is weakened for cross-functional information integration and rich cross-boundary communication (IPRs)	░	░	░	░	░	░	▒	▒	▒	▒	▓	▓	▓	▓	▓	▓
	Information formats/protocols (IPC) lack the standardization that enables the required cross-boundary communication (IPRs)	░	░	░	░	░	░	░	░	▒	▒	▒	▒	▓	▓	▓	▓
	Strategic-operational linkage (IPC) is insufficient to support integrating the required information across planning levels (IPRs)	▒		▒		▒		▒		▓		▓		▓		▓	
	Performance measurement (IPC) is insufficient/inadequate to support the required continuous process monitoring and improvement (IPRs)	░	░	░		▒	▒	▒		▓	▓	▓		▓	▓	▓	
	Continuous improvement culture/mechanisms (IPC) are insufficient to meet the evolving process requirements and required adaptation (IPRs)	▒	▒	░	░	▒	▒	░	░	▓	▓	▒	▒	▓	▓	▓	▓
	Change management (IPC) is insufficient for the implementation of initiatives (IPMs) needed to meet process requirements (IPRs)			▒	▒			▒	▒			▒	▓			▓	▓
	External stakeholder engagement (IPC) does not enable accessing the required diverse information sources and shared understanding (IPRs)	░		░	▒	░		░	▒	▒		▒	▓	▒		▒	▓
Information systems and analytics support	System integration (IPC) fails to integrate the required compatible systems, subsystems, and coherent information flow (IPRs)	░	░	▒		▒	▒	▒		▓	▓	▓		▓	▓	▓	
	Systems (IPC) are mainly manual/fragmented and fail to provide the required precise, timely, and efficient information processing (IPRs)		░			░	░			▒	▒			▓	▓		
	Advanced analytics (IPC) are insufficiently used/generated for interpreting the complex signals and anticipating future needs (IPRs)	▒	▒			▒	▒			▓	▓			▓	▓		
	IT architecture (IPC) lacks the flexibility of adaptable systems needed to support evolving ETO information needs (IPRs)	░	░	░		░	░	░		▒	▒	▒		▓	▓	▓	

[1] Information processing, [2] Information processing capacity, 3 Information processing requirements.

* Gap areas are represented by the corresponding planning quality dimensions: Informational Quality (IQ), Procedural Quality (PQ), Alignment Quality (AQ), and Constructive Engagement (CE).

Note: The grey shading corresponds to a 3-point scale representing the severity of the IPR-IPC gap: Lighter Shade = 1 (Minor gap); Medium Shade = 2 (Moderate gap); Darker Shade = 3 (Severe gap).

Data availability

Data will be made available on request.

References

Alfnes, E., Gosling, J., Naim, M., Dreyer, H.C., 2021. Exploring systemic factors creating uncertainty in complex engineer-to-order supply chains: case studies from Norwegian shipbuilding first-tier suppliers. Int. J. Prod. Econ. 240 (October 2021), 108–211. https://doi.org/10.1016/j.ijpe.2021.108211.

Ambrose, S.C., Rutherford, B.N., 2016. Sales and operations planning (S&OP): a group effectiveness approach. Acad. Market. Stud. J. 20 (2), 17–41.

Appelbaum, S.H., 1997. Socio-technical systems theory: an intervention strategy for organizational development. Manag. Decis. 35 (6), 452–463. https://doi.org/10.1108/00251749710173823.

Argyris, C., Schön, D.A., 1997. Organizational learning: a theory of action perspective. Reis 77/78, 345–348. https://doi.org/10.2307/40183951.

Barratt, M., Choi, T.Y., Li, M., 2011. Qualitative case studies in operations management: trends, research outcomes, and future research implications. J. Oper. Manag. 29 (4), 329–342. https://doi.org/10.1016/j.jom.2010.06.002.

Benjaminsen, H., Sørnes, J.-O., 2025. Epistemic uncertainty in megaprojects. Prod. Plann. Control 1–23. https://doi.org/10.1080/09537287.2025.2548560.

Bertrand, J., Muntslag, D., 1993. Production control in engineer-to-order firms. Int. J. Prod. Econ. 30, 3–22. https://doi.org/10.1016/0925-5273(93)90077-X.

Bertsimas, D., Kallus, N., 2020. From predictive to prescriptive analytics. Manag. Sci. 66 (3), 1025–1044. https://doi.org/10.1287/mnsc.2018.3253.

Bhalla, S., Alfnes, E., Hvolby, H.-H., 2023a. Tools and practices for tactical delivery date setting in engineer-to-order environments: a systematic literature review. Int. J. Prod. Res. 61 (7), 2339–2371. https://doi.org/10.1080/00207543.2022.2057256.

Bhalla, S., Alfnes, E., Hvolby, H.-H., Oluyisola, O., 2023b. Sales and operations planning for delivery date setting in engineer-to-order manufacturing: a research synthesis and framework. Int. J. Prod. Res. 1–31. https://doi.org/10.1080/00207543.2022.2148010.

Cannas, V.G., Gosling, J., Pero, M., Rossi, T., 2019. Engineering and production decoupling configurations: an empirical study in the machinery industry. Int. J. Prod. Econ. 216, 173–189. https://doi.org/10.1016/j.ijpe.2019.04.025.

Cyert, R.M., March, J.G., 1963. A Behavioral Theory of the Firm. Prentice-Hall, Englewood Cliffs, NJ.

Daft, R.L., Macintosh, N.B., 1981. A tentative exploration into the amount and equivocality of information processing in organizational work units. Adm. Sci. Q. 207–224. https://doi.org/10.2307/2392469.

Daft, R.L., Sormunen, J., Parks, D., 1988. Chief executive scanning, environmental characteristics, and company performance: an empirical study. Strateg. Manag. J. 9 (2), 123–139. https://doi.org/10.1002/smj.4250090204.

Danese, P., Molinaro, M., Romano, P., 2017. Managing evolutionary paths in sales and operations planning: key dimensions and sequences of implementation. Int. J. Prod. Res. 56 (5), 2036–2053. https://doi.org/10.1080/00207543.2017.1355119.

De Dreu, C.K.W., Weingart, L.R., 2003. Task versus relationship conflict, team performance, and team member satisfaction: a meta-analysis. J. Appl. Psychol. 88 (4), 741–749. https://doi.org/10.1037/0021-9010.88.4.741.

Dittfeld, H., Scholten, K., Van Donk, D.P., 2021. Proactively and reactively managing risks through sales & operations planning. Int. J. Phys. Distrib. Logist. Manag. 51 (6), 566–584. https://doi.org/10.1108/IJPDLM-07-2019-0215.

Eisenhardt, K.M., 1989. Building theories from case study research. Acad. Manag. Rev. 14 (4), 532–550. https://doi.org/10.2307/258557.

Galbraith, J.R., 1977. Organization Design. Addison-Wesley, London.

Gioia, D.A., Corley, K.G., Hamilton, A.L., 2013. Seeking qualitative rigor in inductive research: notes on the Gioia methodology. Organ. Res. Methods 16 (1), 15–31. https://doi.org/10.1177/1094428112452151.

Goh, S.H., Eldridge, S., 2024. Sales and operations planning culture and supply chain performance: the mediating effects of five coordination mechanisms. Prod. Plann. Control 35 (3), 225–237. https://doi.org/10.1080/09537287.2022.2069058.

Gosling, J., Hewlett, B., Naim, M.M., 2017. Extending customer order penetration concepts to engineering designs. Int. J. Oper. Prod. Manag. 37 (4), 402–422. https://doi.org/10.1108/IJOPM-07-2015-0453.

Grimson, J.A., Pyke, D.F., 2007. Sales and operations planning: an exploratory study and framework. Int. J. Logist. Manag. 18 (3), 322–346. https://doi.org/10.1108/09574090710835093.

Hulthén, H., Näslund, D., Norrman, A., 2016. Framework for measuring performance of the sales and operations planning process. Int. J. Phys. Distrib. Logist. Manag. 46 (9), 809–835. https://doi.org/10.1108/IJPDLM-05-2016-0139.

Jonsson, P., Kaipia, R., Barratt, M., 2021. Guest editorial. Int. J. Phys. Distrib. Logist. Manag. 51 (6), 553–565. https://doi.org/10.1108/IJPDLM-07-2021-452.

Kalla, C., Scavarda, L.F., Hellingrath, B., 2024. Integrating supply chain risk management activities into sales and operations planning. Rev. Manag. Sci. https://doi.org/10.1007/s11846-024-00756-y.

Kjellsdotter Ivert, L., Jonsson, P., 2014. When should advanced planning and scheduling systems be used in sales and operations planning? Int. J. Oper. Prod. Manag. 34 (10), 659–681. https://doi.org/10.1108/IJOPM-03-2011-0088.

Kristensen, J., Jonsson, P., 2018. Context-based sales and operations planning (S&OP) research: a literature review and future agenda. Int. J. Phys. Distrib. Logist. Manag. 48 (1), 19–46. https://doi.org/10.1108/IJPDLM-11-2017-0352.

Kumar, S., Mallipeddi, R.R., 2022. Impact of cybersecurity on operations and supply chain management: emerging trends and future research directions. Prod. Oper. Manag. 31 (12), 4488–4500. https://doi.org/10.1111/poms.13859.

Laari, S., Lorentz, H., Jonsson, P., Lindau, R., 2023. Procurement's role in resolving demand–supply imbalances: an information processing theory perspective. Int. J. Oper. Prod. Manag. 43 (13), 68–100. https://doi.org/10.1108/IJOPM-06-2022-0382.

Lincoln, Y.S., Guba, E.G., 1985. Naturalistic Inquiry. SAGE Publications, Beverly Hills, CA.

Mayer, R.C., Davis, J.H., Schoorman, F.D., 1995. An integrative model of organizational trust. Acad. Manag. Rev. 20 (3), 709–734. https://doi.org/10.5465/amr.1995.9508080335.

Mello, M.H., Strandhagen, J.O., Alfnes, E., 2015. Analyzing the factors affecting coordination in engineer-to-order supply chain. Int. J. Oper. Prod. Manag. 35 (7), 1005–1031. https://doi.org/10.1108/IJOPM-12-2013-0545.

Oliva, R., Watson, N., 2011. Cross-functional alignment in supply chain planning: a case study of sales and operations planning. J. Oper. Manag. 29 (5), 434–448. https://doi.org/10.1016/j.jom.2010.11.012.

Overbeck, L., Graves, S.C., Lanza, G., 2024. Development and analysis of digital twins of production systems. Int. J. Prod. Res. 62 (10), 3544–3558. https://doi.org/10.1080/00207543.2023.2242525.

Patton, M.Q., 2014. Qualitative Research & Evaluation Methods: Integrating Theory and Practice. SAGE Publications.

Rosado Feger, A.L., 2014. Creating cross-functional strategic consensus in manufacturing facilities. Int. J. Oper. Prod. Manag. 34 (7), 941. https://doi.org/10.1108/IJOPM-08-2012-0299.

Schindler, M., Eppler, M.J., 2003. Harvesting project knowledge: a review of project learning methods and success factors. Int. J. Proj. Manag. 21 (3), 219–228. https://doi.org/10.1016/S0263-7863(02)00096-0.

Schlegel, A., Birkel Hendrik, S., Hartmann, E., 2021. Enabling integrated business planning through big data analytics: a case study on sales and operations planning. Int. J. Phys. Distrib. Logist. Manag. 51 (6), 607–633. https://doi.org/10.1108/ijpdlm-05-2019-0156.

Sengupta, S., Jonsson, P., Dreyer, H.C., Kaipia, R., Choi, T.Y., 2025. Uncertainty regulation and adaptable supply chain planning. Int. J. Oper. Prod. Manag. 45 (11), 1861–1883. https://doi.org/10.1108/IJOPM-07-2025-0645.

Shurrab, H., Jonsson, P., Johansson, M.I., 2022a. Managing complexity through integrative tactical planning in engineer-to-order environments: insights from four case studies. Prod. Plann. Control 33 (9–10), 907–924. https://doi.org/10.1080/09537287.2020.1837937.

Shurrab, H., Jonsson, P., Johansson, M.I., 2022b. A tactical demand-supply planning framework to manage complexity in engineer-to-order environments: insights from an in-depth case study. Prod. Plann. Control 33 (5), 462–479. https://doi.org/10.1080/09537287.2020.1829147.

Singh, S.K., Lee, J.B., 2013. How to use what-if analysis in sales and operations planning. J. Bus. Forecast. 32 (3), 4.

Smith, L., Andraski, J.C., Fawcett, S.E., 2010. Integrated business planning: a roadmap to linking S&OP and CPFR. J. Bus. Forecast 29 (4).

Sousa, R., Voss, C.A., 2008. Contingency research in operations management practices. J. Oper. Manag. 26 (6), 697–713. https://doi.org/10.1016/j.jom.2008.06.001.

Srinivasan, R., Swink, M., 2018. An investigation of visibility and flexibility as complements to supply chain analytics: an organizational information processing theory perspective. Prod. Oper. Manag. 27 (10), 1849–1867. https://doi.org/10.1111/poms.12746.

Strauss, A., Corbin, J., 1998. Basics of Qualitative Research Techniques. Sage Publications, Thousand Oaks, CA.

Swink, M., Kovach, J.J., Roh, J., 2025. Inventory and supply chain planning systems as drivers of supply chain resilience: analyses of firm performance through the COVID-19 pandemic. Prod. Oper. Manag. 34 (8), 2486–2505. https://doi.org/10.1177/10591478251320528.

Teece, D.J., 2007. Explicating dynamic capabilities: the nature and microfoundations of (sustainable) enterprise performance. Strateg. Manag. J. 28 (13), 1319–1350. https://doi.org/10.1002/smj.640.

Tuomikangas, N., Kaipia, R., 2014. A coordination framework for sales and operations planning (S&OP): synthesis from the literature. Int. J. Prod. Econ. 154, 243–262. https://doi.org/10.1016/j.ijpe.2014.04.026.

Vial, G., 2019. Understanding digital transformation: a review and a research agenda. J. Strat. Inf. Syst. 28 (2), 118–144. https://doi.org/10.1016/j.jsis.2019.01.003.

Villena, V.H., Revilla, E., Choi, T.Y., 2011. The dark side of buyer–supplier relationships: a social capital perspective. J. Oper. Manag. 29 (6), 561–576. https://doi.org/10.1016/j.jom.2010.09.001.

Voss, C., Tsikriktsis, N., Frohlich, M., 2002. Case research in operations management. Int. J. Oper. Prod. Manag. 22 (2), 195–219. https://doi.org/10.1108/01443570210414329.

Wallace, T.F., Stahl, R.A., 2008. Sales and Operations Planning: the how-to Handbook: Steelwedge Software.

Walter, A., Ahsan, K., Rahman, S., 2025. Application of artificial intelligence in demand planning for supply chains: a systematic literature review. Int. J. Logist. Manag. 36 (3), 672–719. https://doi.org/10.1108/ijlm-02-2024-0120.

Wang, G., Oh, I.-S., Courtright, S.H., Colbert, A.E., 2011. Transformational leadership and performance across criteria and levels: a meta-analytic review of 25 years of research. Group Organ. Manag. 36 (2), 223–270. https://doi.org/10.1177/1059601111401017.

Wikner, J., Rudberg, M., 2005. Integrating production and engineering perspectives on the customer order decoupling point. Int. J. Oper. Prod. Manag. 25 (7), 623–641. https://doi.org/10.1108/01443570510605072.

Yin, R.K., 2017. Case Study Research: Design and Methods. SAGE Publications, CA.

Zahra, S.A., George, G., 2002. Absorptive capacity: a review, reconceptualization, and extension. Acad. Manag. Rev. 27 (2), 185–203. https://doi.org/10.5465/amr.2002.6587995.