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Sales and operations planning for delivery date setting in engineer-to-order manufacturing: a research synthesis and framework

Swapnil Bhalla [a], Erlend Alfnes [a], Hans-Henrik Hvolby [b] and Olumide Oluyisola [a]

[a]Department of Mechanical and Industrial Engineering, Norwegian University of Science and Technology, Trondheim, Norway; [b]Department of Materials and Production, Aalborg University, Aalborg, Denmark

ABSTRACT

Sales and operations planning (S&OP) has emerged as a planning approach that integrates tactical level decisions across functions and supply chains while aligning day-to-day operations with long-term strategy through these decisions. The extant knowledge on S&OP has evolved primarily based on the needs of mass production contexts, and applications of S&OP in engineer-to-order (ETO) contexts have not been explored by previous research. Arguing that the cross-functionally coordinated planning enabled by S&OP can improve the effectiveness of the challenging and competitively critical tendering process, this paper develops an S&OP framework for the tactical planning process design to support delivery date setting in ETO contexts. The paper adopts a systematic literature review approach for identifying the main tactical planning activities managers in ETO companies should consider while designing the S&OP process and the information inputs required for performing and coordinating these planning activities. The identified planning activities and planning inputs are synthesised to develop the proposed S&OP framework for delivery date setting in ETO contexts. The proposed framework can support managers in assessing which tactical planning activities are strategically essential in their respective companies and redesigning or reconfiguring existing planning processes to address the planning needs of their environment.

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Engineer-to-order; sales and operations planning; tactical planning; delivery date setting; customer enquiry management

1. Introduction

Sales and operations planning (S&OP) is an approach for tactical level planning that has received growing interest from academics and practitioners over the last three decades (Kreuter et al. 2022). S&OP emerged in the 1980s as an extension of aggregate production planning to address problems arising from planning and decision-making in functional silos (Danese, Molinaro, and Romano 2018; Stentoft, Freytag, and Mikkelsen 2020). S&OP emphasises integrating or coordinating the tactical planning activities and planning objectives across the various supply chain functions, e.g. procurement, production, sales, etc., for effectively balancing demand and supply at the tactical level while also aligning the day-to-day operations with long-term strategic plans and competitive priorities (Grimson and Pyke 2007; Pereira, Oliveira, and Carravilla 2020; Thomé et al. 2012b).

Since its conception, S&OP has been adopted in a variety of industrial contexts (Kristensen and Jonsson 2018), and various studies have reported the positive impacts of S&OP adoption on companies' performance (Feng, D'Amours, and Beauregard 2008; Oliva and Watson 2011; Thomé et al. 2012a; Thomé, Sousa, and do Carmo 2014). The adoption of S&OP in different industrial contexts has allowed researchers to observe how the design of the S&OP process is adapted across contexts to achieve the intended performance outcomes (Ivert et al. 2015; Kreuter et al. 2021; Kreuter et al. 2022; Kristensen and Jonsson 2018; Tuomikangas and Kaipia 2014). The principle that planning processes should be designed to fit the characteristics and requirements of specific industrial contexts has been widely emphasised in the planning and control literature (Berry and Hill 1992; Buer et al. 2018b; Jonsson and Mattsson 2003; Newman and Sridharan 1995) and is based on the assumptions of the wider-scoped contingency theory (Donaldson 2001; Ivert et al. 2015; Kristensen and Jonsson 2018; Lawrence and Lorsch 1969). Therefore, contextualising or adjusting the design of the S&OP process according to different industrial characteristics and requirements has been one of the main research streams within S&OP literature (Jonsson, Kaipia, and Barratt 2021; Kreuter et al. 2021; Kreuter et al. 2022).

The recent state-of-the-art reviews on S&OP by Kristensen and Jonsson (2018) and Kreuter et al. (2022)

CONTACT Swapnil Bhalla swapnil.bhalla@ntnu.no

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indicate that one of the major research gaps within the extant S&OP literature is the contextualisation of S&OP design in production contexts operating with the engineer-to-order (ETO) strategy. ETO production contexts, i.e. companies operating with an ETO strategy, produce customised products based on individual customers' requirements, and the adoption of the strategy has been observed across industries supplying high-value, complex products such as industrial machinery, agricultural machinery, ships, ship equipment, etc. (Bertolini et al. 2022; Cannas and Gosling 2021; Gosling and Naim 2009; Zennaro et al. 2019). Due to customer-specific design, engineering, procurement, and production activities, tactical planning is characterised by high complexity and high uncertainty in ETO production contexts (Adrodegari et al. 2015; Alfnes et al. 2021; Løkkegaard et al. 2022; Sylla et al. 2021). The high complexity and uncertainty of tactical planning in ETO contexts amplify the need for coordinated planning across functions, which can be addressed by S&OP (Kreuter et al. 2022; Shurrab, Jonsson, and Johansson 2020b). However, despite these needs of ETO production contexts, the issue of contextualising S&OP design for ETO production has not been investigated in the extant research (Kreuter et al. 2022).

In a step towards addressing the lack of research on S&OP in ETO contexts, the authors' recent case study of an ETO maritime equipment manufacturer identifies customer enquiry management or delivery date setting as one of the main decision areas for S&OP in an ETO manufacturing context (Bhalla et al. 2021). Setting delivery dates in ETO contexts entails (1) estimating the delivery dates to be quoted while tendering for new customer orders or responding to customer enquiries; and (2) assessing the feasibility of delivery dates imposed by customers for potential orders (Carvalho, Oliveira, and Scavarda 2015; Zijm 2000; Zorzini, Stevenson, and Hendry 2012). Setting delivery dates in ETO contexts is a particularly challenging task, and its effectiveness is essential for ETO companies to maintain competitive delivery performance (Amaro, Hendry, and Kingsman 1999; Cannas et al. 2020; Hicks, McGovern, and Earl 2000). Therefore, this paper further explores the contextualisation of S&OP design in ETO contexts, focussing on the tactical planning task of delivery date setting, and addresses the following research question.

> RQ: How should engineer-to-order manufacturers contextualise the design of the sales and operations planning process for effective delivery date setting?

The paper addresses this research question by developing an S&OP reference framework for setting delivery dates while tendering for new customer orders in ETO manufacturing contexts. Delivery date setting is a topic of general relevance for various ETO contexts and has motivated many research contributions supporting practitioners in executing the task effectively. One of these contributions is highlighting that coordinated planning across supply chain functions can help ETO companies in managing the complexity and uncertainty characterising the task of setting delivery dates (Hicks, McGovern, and Earl 2000; Shurrab, Jonsson, and Johansson 2020a, 2020b; Zorzini et al. 2008b; Zorzini, Stevenson, and Hendry 2012). However, the extant literature on delivery date setting lacks guidance on designing a coordinated planning process for setting delivery dates, and developing a process reference framework is one of the main research needs in this area (Bhalla, Alfnes, and Hvolby 2022). The proposed S&OP reference framework identifies the main planning activities of different supply chain functions for setting delivery dates in ETO contexts and the information flows required for coordinating these planning activities.

This paper uses a systematic literature review methodology for developing the S&OP reference framework and answering the research question presented above. The remainder of this paper is organised as follows. Section 2 provides an overview of existing frameworks from the research streams on S&OP and delivery date setting to elaborate on the research gaps motivating this study. Section 3 describes the literature review methodology adopted for developing the S&OP reference framework. Section 4 synthesises the relevant literature for developing the framework. Section 5 discusses potential applications of the proposed framework and identifies future research needs. Section 6 concludes the paper by summarising the paper's contributions.

2. Overview of the extant research

The growing interest in S&OP and the evolving knowledge on the topic have motivated various systematic reviews of the literature on the topic over the last decade, albeit with different focuses (Kreuter et al. 2022; Kristensen and Jonsson 2018; Noroozi and Wikner 2017; Pereira, Oliveira, and Carravilla 2020; Thomé et al. 2012a, 2012b; Tuomikangas and Kaipia 2014). These reviews provide overviews and syntheses of the extant research on S&OP from different perspectives (Jonsson, Kaipia, and Barratt 2021). Among these, the reviews considering the effect of the production strategy on S&OP design, i.e. Kreuter et al. (2022) and Kristensen and Jonsson (2018), find that the extant S&OP research has been contextualised in make-to-stock (MTS) and make-to-order (MTO) production contexts. Due to the differences in the contextual characteristics and planning needs of ETO,

Table 1. Tactical S&OP attributes required in different production contexts.

Tactical S&OP attribute	MTS production	MTO production	ETO production
Planning strategy	Level [10]	Chase [10]	Chase [10]
Aggregation or planning object	Product families or individual products [6, 7, 9, 10, 12]		Individual products [5, 8, 11]
Demand-input for planning	Forecasts [6, 7, 11, 12]		Tenders, confirmed orders or projects [1, 2, 11]
Main planning outputs	Production volumes [10], inventory targets, promotion timing, price changes [12]	Production volumes, sales targets, inventory & backorder targets [6, 7]	Delivery dates for tenders, production plans for confirmed orders or projects [3, 4, 5, 8]

[1] Adrodegari et al. (2015); [2] Alfnes and Hvolby (2019); [3] Alfieri, Tolio, and Urgo (2011); [4] Alfieri, Tolio, and Urgo (2012); [5] Carvalho, Oliveira, and Scavarda (2015); [6] Feng, D'Amours, and Beauregard (2008); [7] Gansterer (2015); [8] Ghiyasinasab et al. (2021); [9] Grimson and Pyke (2007); [10] Olhager (2013); [11] Olhager, Rudberg, and Wikner (2001); [12] Pereira, Oliveira, and Carravilla (2020).

MTO, and MTS production, the design requirements for the S&OP process are different across these contexts (Bhalla et al. 2021; Buer et al. 2018b; Kreuter et al. 2022; Kristensen and Jonsson 2018; Olhager, Rudberg, and Wikner 2001). For instance, S&OP has primarily been considered a forecast-driven planning process in MTS and MTO contexts, while tactical planning in ETO contexts is primarily driven by tenders or customer enquiries and confirmed orders or projects (Adrodegari et al. 2015; Alfieri, Tolio, and Urgo 2011; Feng, D'Amours, and Beauregard 2008; Gansterer 2015; Ghiyasinasab et al. 2021; Hans et al. 2007; Olhager, Rudberg, and Wikner 2001). Table 1 highlights the main differences between the required attributes for tactical S&OP in the different types of production contexts.

Within the topic of S&OP and the broader area of planning and control, conceptual and reference frameworks are valuable artefacts with utility for applications in research as well as practice, e.g. for unifying fragmented knowledge on conceptually related topics (Kreuter et al. 2022; Pereira, Oliveira, and Carravilla 2020; Tuomikangas and Kaipia 2014), for identifying and establishing industry-wide best practices (Adrodegari et al. 2015), for investigating and explaining the impact of context on process design and performance (Kristensen and Jonsson 2018; Thomé et al. 2012b; Zorzini et al. 2008b; Zorzini, Stevenson, and Hendry 2012), for assessing process maturity (Grimson and Pyke 2007), for guiding improvements of process maturity (Danese, Molinaro, and Romano 2018), for mapping, analysing, and designing or redesigning contextually fitting managerial and planning processes (Adrodegari et al. 2015; Shurrab, Jonsson, and Johansson 2020b), etc. Perhaps the most widely cited framework for S&OP is the five-step process model, which lists the main steps to be implemented in companies' S&OP process, namely product portfolio review, forecasting and demand planning, supply planning, pre-S&OP meeting and executive S&OP meeting (Grimson and Pyke 2007; Jacobs et al. 2011; Kristensen and Jonsson 2018; Thomé et al. 2012b; Wallace 2004; Wallace and Stahl 2008). The main activities within different versions of this five-step process model focus on forecast-driven tactical planning. Wing and Perry (2001); Lapide (2005); Grimson and Pyke (2007); Wagner, Ullrich, and Transchel (2014); Goh and Eldridge (2015); Pedroso et al. (2017); Vereecke et al. (2018); and Danese, Molinaro, and Romano (2018) propose S&OP maturity models for assessing the maturity of companies' S&OP processes, and for identifying measures for improving S&OP maturity. Despite the abundance of research on S&OP maturity models, none of the listed studies investigates the applicability of their proposed maturity models in ETO contexts. Other higher-level frameworks, such as the literature synthesis framework developed by Thomé et al. (2012b); the coordination framework proposed by Tuomikangas and Kaipia (2014); and the contingency framework developed by Kristensen and Jonsson (2018), are sufficiently generalisable with dimensions such as organisation, meetings and collaboration, tools and technologies, etc. and these frameworks can provide different theoretical perspectives for studying how S&OP process design in ETO contexts differs from other production environments. More recently, Pereira, Oliveira, and Carravilla (2020) propose a tactical S&OP framework based on the literature on S&OP, aggregate production planning, tactical planning, etc., highlighting the main information flows, decisions and constraints for the tactical S&OP process. Their proposed framework is based on the underlying assumption of a supply chain for standard or non-customised products, rendering various information flows and decisions within the framework irrelevant for S&OP and delivery date setting in ETO manufacturing.

Due to the challenges and complexity of managing ETO operations, planning and control have been among the main research areas within ETO operations and supply chain management literature (Cannas and Gosling 2021; Gosling and Naim 2009; Zennaro et al. 2019). Consequently, numerous planning frameworks have also been proposed in this literature for ETO contexts with different theoretical perspectives underlying these frameworks. In one of the first contributions to planning and control in ETO firms, Bertrand and Muntslag (1993) propose a production control framework to address the lack of fit between the functionality of manufacturing resource planning (MRP II) systems and the requirements of ETO contexts. Little et al. (2000) propose a planning and scheduling reference model for ETO companies based on a similar premise. Both Bertrand and Muntslag (1993) and Little et al. (2000) take a planning system perspective in developing their frameworks. Nam et al. (2018) take a similar perspective, proposing a supply chain planning matrix for designing an advanced planning and scheduling system for ETO shipbuilding. Adrodegari et al. (2015) take a business process perspective and propose a process reference framework for the software requirements of ETO machinery building companies, which consists of activities across the order-fulfilment process. These high-level frameworks are broadly scoped across the order-fulfilment process in ETO contexts, and while they provide insights on a few planning activities relevant for setting delivery dates and S&OP, they lack focus on the information flows relevant for these activities.

Unlike the high-level, broadly scoped frameworks mentioned above, extant literature also provides frameworks that focus specifically on tactical planning and the task of delivery date setting (Kingsman et al. 1996; Shurrab, Jonsson, and Johansson 2020b; Zorzini, Corti, and Pozzetti 2008a). However, these frameworks also lack some necessary elements. For instance, the frameworks proposed by Kingsman et al. (1996) and Zorzini, Corti, and Pozzetti (2008a) focus on fabrication and assembly capacity planning for delivery date setting but do not address engineering capacity planning and procurement planning. As a result, these frameworks lack an integrated or cross-functional perspective that is essential for S&OP in ETO contexts to ensure that lead times for all order-fulfilment activities are considered and to ensure that tactical plans and delivery dates are based on shared information and functional expertise rather than conflicting assumptions (Grabenstetter and Usher 2014; Hicks, McGovern, and Earl 2000; Shurrab, Jonsson, and Johansson 2020a; Zorzini, Stevenson, and Hendry 2012). The framework proposed by Shurrab, Jonsson, and Johansson (2020b), despite its cross-functional perspective, does not address the information flows supporting the tactical planning decisions outlined in their framework.

The overview of literature presented above suggests that an S&OP framework to support delivery date setting in ETO contexts is a knowledge gap in the extant research. We observe that due to a lack of consideration of ETO contexts in the extant S&OP research, existing S&OP frameworks do not address the unique planning needs of these contexts (Kreuter et al. 2022; Shurrab, Jonsson, and Johansson 2020b). Furthermore, tactical planning frameworks developed for ETO contexts are either broadly scoped across the entire order-fulfilment process and lack a focus on setting delivery dates, or lack a cross-functional planning perspective required in S&OP for delivery date setting (Bhalla, Alfnes, and Hvolby 2022). Based on the knowledge gap outlined above, there is a compelling need for developing a reference framework to map, analyse, and design the S&OP process for effectively setting delivery dates in ETO contexts.

3. Methodology

This paper adopts a systematic literature review (SLR) approach to answer this study's main research question and develop a reference framework for contextualising S&OP design for effective delivery date setting. The extant research supporting delivery date setting in ETO contexts is fragmented, and although many studies have addressed different elements of tactical planning in these contexts, an overarching framework is a persisting research gap (Bhalla, Alfnes, and Hvolby 2022). This study aims to identify the planning activities and information flows required in S&OP for setting delivery dates by analysing and synthesising this fragmented body of knowledge. The SLR approach is particularly suitable for integrating and synthesising knowledge from past research to inform industrial practice due to the approach's emphasis on transparency of the literature review process (Thomé, Scavarda, and Scavarda 2016; Tranfield, Denyer, and Smart 2003; Watson and Webster 2020; Webster and Watson 2002). The following subsections describe the review methodology adopted in this paper for developing the S&OP reference framework. The methodology is divided into the three steps typical for SLRs in operations management (Bhalla, Alfnes, and Hvolby 2022; Cannas and Gosling 2021; Kristensen and Jonsson 2018; Thomé, Scavarda, and Scavarda 2016; Tranfield, Denyer, and Smart 2003) – problem formulation (3.1), literature identification and selection (3.2), and analysis and synthesis (3.3).

3.1. Problem formulation

As introduced in sections 1 and 2, this paper is motivated by the empirical observation from previous research that setting delivery dates is a challenging and competitively critical task for ETO manufacturers (Bhalla et al. 2021; Zorzini et al. 2008b; Zorzini, Stevenson, and Hendry 2012), and the lack of frameworks suitable for contextualising the design of the S&OP process for effective delivery date setting in ETO contexts (Bhalla, Alfnes, and Hvolby 2022; Kreuter et al. 2022). The research problem has been translated into the research question for this

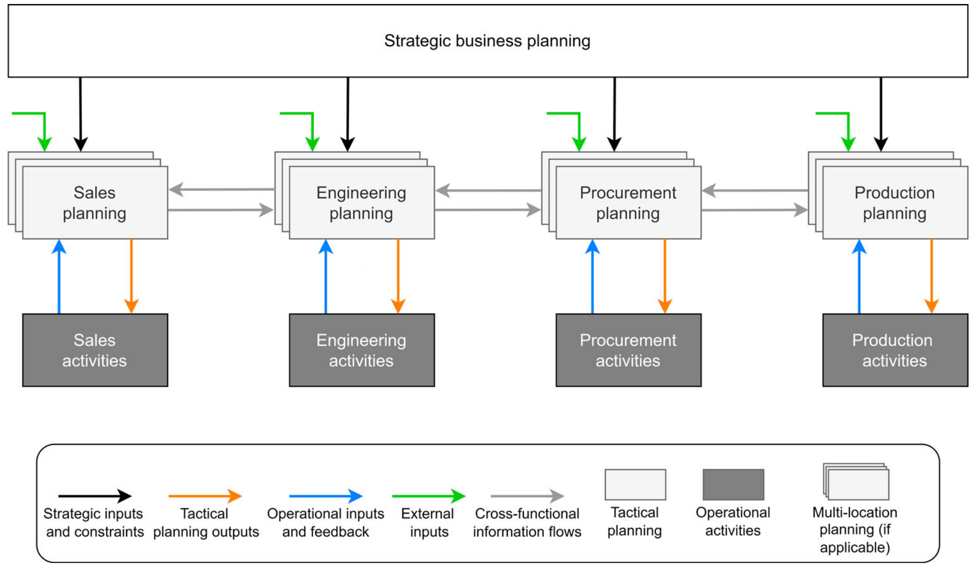

Figure 1. Overall framework for S&OP in ETO contexts (adapted from Pereira, Oliveira, and Carravilla (2020) and Nam et al. (2018)).

paper, as stated in section 1. This problem is addressed in this paper by identifying the planning activities and information flows that ETO companies should consider while designing their S&OP process for effective delivery date setting. The findings are synthesised to propose a reference framework for S&OP in ETO contexts.

The identification and review of literature for identifying the relevant activities and information flows were structured by defining an overall S&OP framework for ETO contexts, as illustrated in Figure 1. This overall framework was defined by adapting the framework from Pereira, Oliveira, and Carravilla (2020), making two main modifications to the original framework. Firstly, the supply chain function of *engineering* was introduced, excluding the *distribution* function, and spatially configuring the supply chain functions of *sales*, *engineering*, *procurement*, and *production* based on the ETO literature (Dekkers 2006; Nam et al. 2018). Secondly, the additional information flow of *operational inputs and feedback* was introduced to account for the uncertain and frequently changing planning environment of ETO contexts, which necessitates considering the current states of operational resources in tactical planning activities (Alfieri, Tolio, and Urgo 2011; Ghiyasinasab et al. 2021). Following Figure 1, the main tactical planning activities or outputs for setting delivery dates were identified under the S&OP subprocesses of *sales planning*, *engineering planning*, *procurement planning*, and *production planning*. As also illustrated in Figure 1, the *information flows* required for these planning activities were identified under the categories of *strategic inputs and constraints*, i.e. outputs of long-term strategic decisions that act as constraints for operations; *external inputs*, i.e. information obtained from actors outside the enterprise, such as suppliers and customers; *operational inputs*, i.e. information about the status and performance of execution and control activities; and *cross-functional information flows*, i.e. information obtained by one planning subprocess or function from another.

3.2. Literature identification and selection

The literature for this review was identified through keyword searches on the Scopus and Web of Science databases and through forward and backward citation searches based on the database search results. The keyword string for searching the two databases was formulated with two blocks. The first block consisted of a wide range of keywords that have been associated in the extant literature with the primary concepts for this study – S&OP and delivery date setting. These included any concepts closely related to, or used synonymously with, either of the primary concepts, e.g. tactical planning, aggregate planning, tactical capacity planning, lead time estimation, etc. The second block of keywords consisted of terms that may be used for referring to ETO contexts, i.e. variations of 'engineer-to-order' and alternative terms, e.g. project manufacturing, customised manufacturing, etc. These included variations of 'make-to-order' for two reasons: (1) some authors use MTO as an umbrella term for collectively referring to all non-MTS contexts, including ETO contexts (Aslan, Stevenson, and Hendry 2012; Kingsman et al. 1996); (2) studies from MTO contexts can also provide insights on planning activities and information flows in ETO contexts, especially for the production function (Adrodegari et al. 2015;

Table 2. Blocks of keywords in the keyword string for literature search.

Block type	Keywords
Concept-related keyword block	'sales and operations planning'; 'sales & operations planning'; 'tactical planning'; 'aggregate planning'; 'capacity planning'; 'production planning'; 'resource planning'; 'lead time estimation'; 'leadtime estimation'; 'delivery date setting'; 'due date setting'; 'customer enquiry management'; 'order acceptance'; 'bid preparation'; 'tendering'; 'delivery date assignment'; 'due date assignment'; 'procurement planning'; 'purchasing planning'; 'sales planning'; 'engineering planning'
Context-related keyword block	'engineer to order'; 'engineer-to-order'; 'engineered to order'; 'engineered-to-order'; 'project manufacturing'; 'project-manufacturing'; 'project production'; 'project-production'; 'project-based production'; 'project based production'; 'project-based manufacturing'; 'project based manufacturing'; 'customized production'; 'customised production'; 'customized manufacturing'; 'customised manufacturing'; 'make to order'; 'made to order'; 'make-to-order'; 'made-to-order'

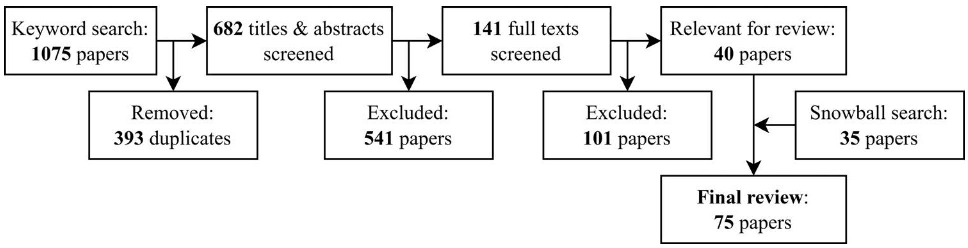

Figure 2. PRISMA flowchart for the process of identifying and selecting literature.

Bhalla, Alfnes, and Hvolby 2022; Sylla et al. 2018). Table 2 shows the keywords in the two blocks of the search string. All keywords in a block were connected by the *or* Boolean operator, while the two blocks were connected by the *and* operator.

The search strings for the databases were formulated to identify papers where the specified keywords appeared in the title, abstract, or author-specified keywords. Searching for publications up to and including May 2022, the searches returned 644 and 431 results on Scopus and Web of Science, respectively, including journal articles, conference papers, and book sections. The citation information (e.g. author(s) of the document, document title, publication year, source type, etc.) for the results from both databases were exported into an EndNote library using RIS (Research Information Systems) format files generated from the databases. After the removal of duplicate results, 682 unique documents remained. The citation information for these documents was exported from the EndNote library into an Excel spreadsheet for record-keeping and documentation of content analysis.

For initial screening, the titles and abstracts of the 682 papers were reviewed to exclude irrelevant papers before the next steps of the review. This screening step led to the exclusion of 541 papers based on one or more of the following criteria: (1) not written in English; (2) not from a peer-reviewed source; (3) research not contextualised or positioned in ETO or MTO production; and (4) research focus on operational or shop-floor level delivery date setting and order-acceptance integrated with detailed scheduling decisions. The next step was to screen the full texts for the remaining 141 papers to assess which of these should be included in the final review. In this full-text assessment, 40 of the 141 papers were found relevant for inclusion in the final review based on two main considerations: (1) the full-text document for the paper is published, and available online; and (2) the paper provides insight into one or more planning activities, or information flows related to delivery date setting, tendering, customer enquiry management, request-for-proposal management, etc.

The final step in identifying relevant literature were the forward and backward citation searches, also known as the snowball search (Thomé, Scavarda, and Scavarda 2016). The reference lists of the 40 papers were screened to identify potentially relevant older papers, and the 'cited by' feature of Google Scholar was used to identify any relevant citations of these papers. Based on this, we identified 35 additional papers that fit the two inclusion criteria presented above, resulting in 75 papers for the final review. Figure 2 illustrates the literature identification process in a PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flowchart adapted from Buer, Strandhagen, and Chan (2018a); Moher et al. (2009).

3.3. *Literature analysis and synthesis*

The content of the 75 papers was analysed by coding relevant text from the literature to the main codes or themes outlined in the overall S&OP framework illustrated in Figure 1, i.e. the planning subprocesses and categories of information inputs. First, the relevant quotes from the papers were coded to one or more of the four planning subprocesses outlined in the framework, i.e. sales-, engineering-, procurement-, and production planning, where each quote identified one or more planning activities for the respective subprocess. Second, quotes identifying one or more planning inputs for a planning activity were coded to these activities and to one of the categories of planning inputs from Figure 1, i.e. strategic constraints, external inputs, operational inputs, or cross-functional inputs.

Among the analysed papers, some of the content contributes explicitly towards answering this study's research question, while others implicitly. Explicit contributions include direct references to specific planning activities, decisions, and planning inputs while describing or discussing case studies, decision-support tools, decision-making methodologies and authors' general observations in the industry. Implicit contributions include quotes that do not mention specific planning activities or planning inputs or mention these without linking them to delivery date setting but allow for logically inferring these. The identified planning activities and inputs were used to populate the overall framework (Figure 1) for creating the final S&OP reference framework.

4. Results

The extant literature provides various insights for contextualising the S&OP design in ETO manufacturing for effective delivery date setting. Based on the content analysis of the reviewed literature, this section identifies the main planning activities and information flows that should be considered in ETO contexts while designing the S&OP process for setting delivery dates. The distribution of the analysed literature across journals and years of publication can be found in Table A1 and Figure A1 in the Appendix.

Table A2 in the Appendix summarises the contributions of the reviewed papers in identifying the planning activities and information inputs for the planning activities for contextualising S&OP design in ETO contexts. As mentioned in subsection 3.3, these activities and information flows are presented in the reviewed literature explicitly or implicitly. Therefore, Table A2 also classifies the contributions of the papers as explicit (E), implicit (I), or partly explicit and partly implicit (E/I). These contributions are further elaborated in the remainder of this section, where each subsection describes the main planning activities and corresponding planning inputs for the four S&OP subprocesses – sales planning (4.1), engineering planning (4.2), procurement planning (4.3), and production planning (4.4).

4.1. Sales planning

Three main tactical planning activities emerge from the reviewed literature for the sales planning subprocess of S&OP for tendering and setting delivery dates in ETO contexts, namely (1) determining which customer enquiries should be pursued, where *customer enquiries* collectively refer to enquiries, tender invitations, sales leads, and requests-for-proposal (RFP) (Aslan, Stevenson, and Hendry 2015; Hans et al. 2007; Hicks, McGovern, and Earl 2000; Shurrab, Jonsson, and Johansson 2020b; Zorzini, Stevenson, and Hendry 2012), (2) setting relative priority levels for customer enquiries (Adrodegari et al. 2015; Ebadian et al. 2009; Shurrab, Jonsson, and Johansson 2020b), and (3) coordinating the preparation of proposals or quotations that are sent to potential customers in response to the enquiries (Carvalho, Oliveira, and Scavarda 2015; Shurrab, Jonsson, and Johansson 2020a). These planning activities and their inputs are described in the following subsections: 4.1.1. Selecting customer enquiries, 4.1.2. Prioritising customer enquiries, and 4.1.3. Responding to customer enquiries. Figure 3 gives an overview of the planning inputs for sales planning, categorising these as strategic inputs, external inputs, operational inputs, and cross-functional inputs using the colour-coding scheme from Figure 1.

4.1.1. Selecting customer enquiries

The reviewed literature emphasises that selecting customer enquiries that a company would pursue is a crucial demand planning decision in ETO contexts, where managers must assess whether it is lucrative to use resources for preparing a proposal (Kingsman et al. 1996; Zorzini et al. 2008b). ETO manufacturing companies typically produce customised products within particular product domains (Adrodegari et al. 2015) with varying degrees of customisation (Alfnes et al. 2021; Cannas et al. 2020). Therefore, a preliminary review of customers' technical and commercial requirements must be conducted to assess if a competitive proposal can be made and its likelihood of success, considering the level of alignment between the company's competitive priorities and the typical order-winning criteria for customers' respective market segments (Adrodegari et al. 2015; Hicks, McGovern, and Earl 2000; Kingsman et al. 1996). This can enable the company's management to determine which orders strategically fit within the context of the company's operations strategy (Amaro, Hendry, and Kingsman 1999; Shurrab, Jonsson, and Johansson 2020b). We identify the main planning inputs for selecting customer enquiries in ETO contexts as the following.

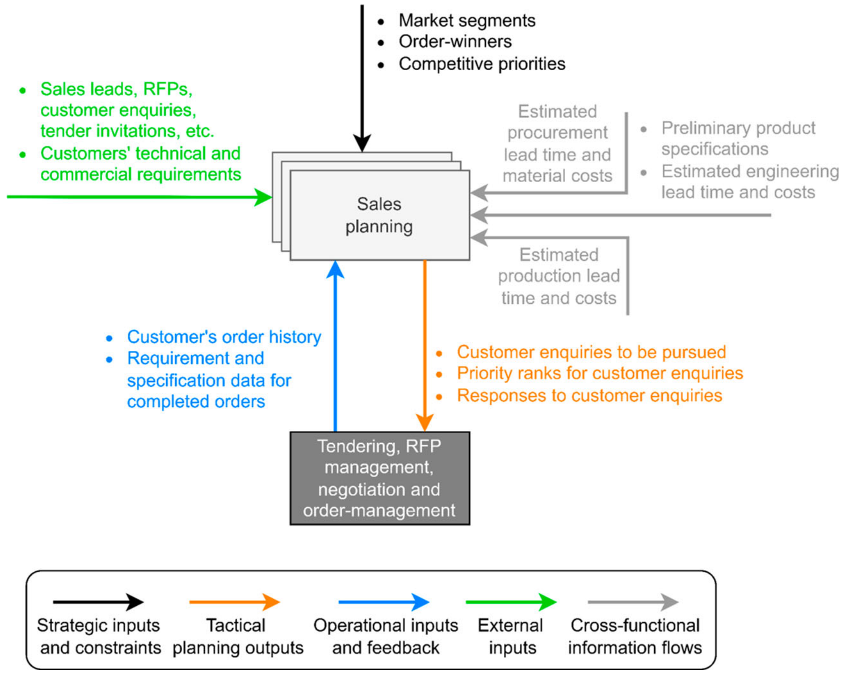

Figure 3. Tactical sales planning – information inputs and planning outputs.

- External inputs – the customer enquiry and customer requirements (Adrodegari et al. 2015; Kingsman et al. 1996; Shurrab, Jonsson, and Johansson 2020b).
- Strategic inputs – the market segmentation strategy, e.g. product-based segmentation, geography-based segmentation, etc.; order-winners, e.g. price, delivery lead time, product features, etc., and the company's competitive priorities (Adrodegari et al. 2015; Amaro, Hendry, and Kingsman 1999; Cannas et al. 2020; Kingsman et al. 1996).

4.1.2. Prioritising customer enquiries

Many ETO companies manage multiple customer enquiries simultaneously, which often compete for the same capacity-constrained managerial resources responsible for coordinating and preparing responses to these enquiries (Adrodegari et al. 2015; Alfnes et al. 2021; Shurrab, Jonsson, and Johansson 2020b). For such instances, ranking the enquiries according to their relative priority level and their level of strategic importance can enable strategic resource allocation to manage these enquiries, where the strategic importance of enquiries may be influenced by factors related to market segmentation, customers' order history, customers' requirements, similarity to previous orders, customer-imposed delivery dates, etc. (Adrodegari et al. 2015; Ebadian et al. 2008; Ebadian et al. 2009; Hans et al. 2007; Kingsman et al. 1996). We identify the following main inputs from the reviewed literature for prioritising customer enquiries.

- External inputs – same as for selecting customer enquiries (4.1.1).
- Strategic inputs – same as for selecting customer enquiries (4.1.1).
- Operational inputs – customer's order history (for assessing strategic relevance of customer) and requirements and specifications for delivered orders (to assess similarity to previous orders) (Adrodegari et al. 2015).

4.1.3. Responding to customer enquiries

The importance of offering competitive product technology, delivery lead times, and prices is widely recognised in the ETO literature (Bertrand and Muntslag 1993; Carvalho, Oliveira, and Scavarda 2015; Cassaigne et al. 1997; Ghiyasinasab et al. 2021; Grabenstetter and Usher 2014; Hans et al. 2007; Zennaro et al. 2019; Zorzini, Corti, and Pozzetti 2008a). Therefore, one of the main sales planning activities in ETO contexts is coordinating the company's response to customer enquiries and providing potential customers with the high-level technical and commercial characteristics of the product, production, and delivery (Adrodegari et al. 2015). The basic technical characteristics are typically based on preliminary engineering (Adrodegari et al. 2015; Sylla et al. 2018; Ulonska and Welo 2016), and the delivery lead time and price can be estimated based on lead time and cost estimates for the main order-fulfilment activities of engineering, procurement, and production functions (Bhalla, Alfnes, and Hvolby 2022; Zorzini et al. 2008b; Zorzini, Stevenson, and Hendry 2012). Based on the reviewed literature, we identify the following main planning inputs for the sales planning function to respond to customer enquiries in ETO contexts.

- Strategic inputs – market segmentation, order-winning criteria (Amaro, Hendry, and Kingsman 1999; Calosso et al. 2003; Cassaigne et al. 1997; Kingsman and Mercer 1997; Kingsman et al. 1993) for assessing the importance of competitive pricing and lead times for different market segments and customers, such that targeted profit margins and slack for delivery lead time can be decided.
- Cross-functional inputs – preliminary product specifications (Adrodegari et al. 2015; Kingsman et al. 1996), detailed design and engineering activities required for order-specific customisation (Adrodegari et al. 2015), estimated lead time and cost for engineering activities (Ghiyasinasab et al. 2021; Grabenstetter and Usher 2013, 2014), estimated lead time and cost for material and component procurement (Hicks, McGovern, and Earl 2000; Zorzini, Stevenson, and Hendry 2012), estimated lead time and cost for production activities including potential overtime and subcontracting costs (Alfieri, Tolio, and Urgo 2011; Carvalho, Oliveira, and Scavarda 2015).

4.2. Engineering planning

Design and engineering activities are critical sources of competitive advantage for many ETO companies (Amaro, Hendry, and Kingsman 1999). Order-specific product customisation is among the main value-adding activities for many ETO companies (Grabenstetter and Usher 2014), which begins with translating the customer requirements into preliminary product specifications in the tendering phase to win customer orders (Adrodegari et al. 2015). ETO companies must ensure that the correct engineering resources are available at the right time for effectively executing engineering activities after order confirmation (Alfnes et al. 2021; Ghiyasinasab et al. 2021). Based on these needs, four main tactical planning activities for the engineering planning function emerge from the reviewed literature, namely (1) defining the preliminary design, features, and technical characteristics of the product (Bertrand and Muntslag 1993; Nam et al. 2018), (2) determining detailed design and engineering activities and relevant resources required for these activities (Adrodegari et al. 2015; Alfnes et al. 2021), (3) estimating the lead times, feasible due dates, and costs for design and engineering activities (Ghiyasinasab et al. 2021; Grabenstetter and Usher 2013, 2014), and (4) identifying if additional engineering capacity or capabilities are required for a customer order (Alfnes et al. 2021; Brachmann and Kolisch 2021; Gosling, Hewlett, and Naim 2017; Shurrab, Jonsson, and Johansson 2020b). These planning activities and their inputs are described in the following subsections: 4.2.1. Defining preliminary product specifications, 4.2.2. Determining detailed engineering activities and resources, 4.2.3. Estimating lead times and costs and setting due dates, and 4.2.4. Identifying needs for external capabilities and additional capacity. Figure 4 summarises the strategic-, external-, operational-, and cross-functional inputs for engineering planning.

4.2.1. Defining preliminary product specifications

For ETO companies competing on the innovativeness and customisability of their products, effectively defining preliminary product specifications in the tendering phase is crucial for winning orders (Amaro, Hendry, and Kingsman 1999; Cannas et al. 2020). Defining preliminary specifications entails understanding customer requirements and translating them into high-level design, features, and technical characteristics of the product (Adrodegari et al. 2015; Alfnes et al. 2021). The extant research reports that the clarity and preciseness of customer requirements in ETO contexts tend to vary across customers based on their technical and functional knowledge of the product (Cannas et al. 2020; Shurrab, Jonsson, and Johansson 2020b). Consequently, close interaction with potential customers can be beneficial in the tendering phase for ETO companies to clarify requirements (Zorzini et al. 2008b). Moreover, customer feedback on preliminary specifications may also be required before order confirmation for products requiring high degrees of newness and innovation (Adrodegari et al. 2015; Alfnes et al. 2021).

New and innovative product technologies are often developed in ETO contexts as part of order-specific engineering activities (Alfnes et al. 2021; Gosling and Naim 2009; Shurrab, Jonsson, and Johansson 2020a). However, ETO companies may also engage in new product development (NPD) initiatives through strategic, order-independent innovations (Cannas et al. 2019; Fang and Wei 2020; Hicks, McGovern, and Earl 2000), e.g. to expand product capabilities to support digital technology applications such as internet-of-things (IoT), real-time monitoring and control for efficient performance, predictive fault detection and maintenance of critical components, etc. (Oluyisola, Sgarbossa, and Strandhagen 2020; Strandhagen et al. 2020; Zheng et al. 2021). Such innovative product features and capabilities may also be offered to customers as part of the preliminary product specifications. On the other hand, customer

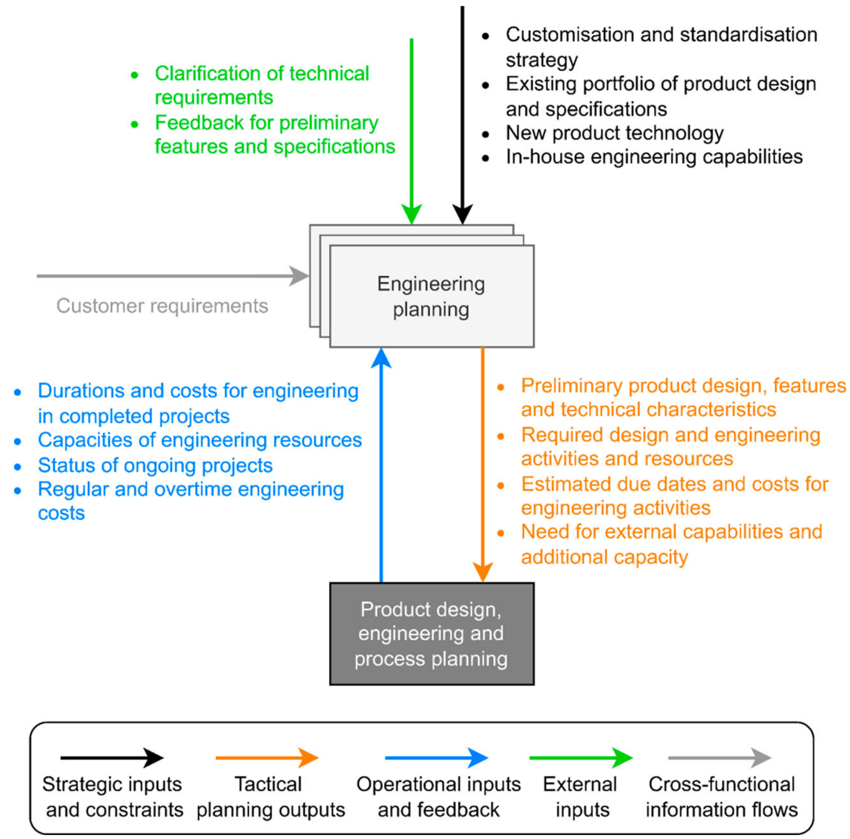

Figure 4. Tactical engineering planning – information inputs and planning outputs.

requirements demanding minimal newness often allow for the reuse of existing design solutions and specifications, which can reduce the time required for defining the preliminary product specifications and increase the reliability of the design offered to the customer (Adrodegari et al. 2015; Grabenstetter and Usher 2013, 2014; Sylla et al. 2018; Ulonska and Welo 2016; Willner, Gosling, and Schönsleben 2016a). As observed in the extant research, the level of order-specific design and customisation required in ETO contexts can vary significantly across market segments and customer orders (Alfnes et al. 2021; Cannas et al. 2020).

Based on the findings from the reviewed literature summarised above, we identify the following main inputs for defining preliminary product specifications.

- Cross-functional input – customer requirements (Adrodegari et al. 2015; Nam et al. 2018) obtained from the sales function.
- Strategic inputs – company's overall strategy for product customisation and standardisation (Fang and Wei 2020; Gosling and Naim 2009; Semini et al. 2014; Willner, Gosling, and Schönsleben 2016a), existing portfolio of product designs and specifications (Adrodegari et al. 2015; Grabenstetter and Usher 2013, 2014; Sylla et al. 2018; Ulonska and Welo 2016; Willner, Gosling, and Schönsleben 2016a), and new product technology (Cannas et al. 2019; Oluyisola, Sgarbossa, and Strandhagen 2020; Strandhagen et al. 2020; Zheng et al. 2021).
- External inputs – clarification of customer requirements and feedback on preliminary product specifications (Alfnes et al. 2021; Shurrab, Jonsson, and Johansson 2020b; Zorzini et al. 2008b).

4.2.2. Determining detailed engineering activities and resources

The order-specific engineering in ETO contexts is a complex transactional and iterative process with substantial uncertainty regarding the specific engineering activities to be undertaken before the detailed product specifications are finalised (Alfnes et al. 2021; Grabenstetter and Usher 2013, 2014). Managers in ETO companies must nevertheless estimate the scope and complexity of these activities and identify the relevant resources for these activities to enable resource and capacity planning for the engineering and design department(s) (Ghiyasinasab et al. 2021; Zijm 2000; Zorzini et al. 2008b). Determining detailed engineering activities and resources entails (1) identifying the design and engineering activities to be performed after order confirmation (Adrodegari et al. 2015) and (2) identifying the design and engineering capabilities required in different disciplines, e.g. mechanical, hydraulic, electrical, etc., and the workload for these activities in terms of, e.g. personnel, person-hours, etc. (Alfnes et al. 2021).

The preliminary product specifications (4.2.1) defined in the tendering phase can be seen as the primary input for determining the detailed engineering activities, since these activities essentially map the course from the preliminary specifications to the final product specifications. In addition, we identify the following planning inputs from the reviewed literature for determining the detailed engineering activities and resources.

- Cross-functional input – customer requirements (Grabenstetter and Usher 2013, 2014) obtained from the sales function.
- Strategic inputs – the company's overall strategy for product customisation and standardisation (Cannas et al. 2020; Dekkers 2006; Johnsen and Hvam 2019) that constrains the extent of order-specific customisation, e.g. all elements of the product may be customisable, or specific modules of the product may be customisable, etc.; and existing portfolio of product designs and specifications that can be reused to fulfil customer requirements (Grabenstetter and Usher 2013, 2014) and reduce the required order-specific engineering activities.

4.2.3. Estimating lead times and costs and setting due dates

As highlighted in subsection 4.1.3, estimated engineering lead times and costs are essential planning inputs for the sales planning function to estimate the overall delivery lead time and delivery date that should be quoted to customers while responding to enquiries. These engineering lead times are also one of the main sources of planning complexity (Grabenstetter and Usher 2014) and uncertainty (Alfnes et al. 2021) in ETO contexts, and while there is an abundance of planning tools and decision-support models for estimating production lead times and costs, there are few contributions in the literature that propose tools for estimating engineering lead times (Bhalla, Alfnes, and Hvolby 2022). Among the handful of contributions in this area, there are two broad categories of approaches proposed for estimating engineering lead times: (1) estimating engineering lead times solely based on the complexity of engineering activities under an infinite capacity assumption (Cannas et al. 2018; Grabenstetter and Usher 2013, 2014), and (2) estimating engineering lead times based on a tactical capacity planning or tactical resource-loading approach under a finite capacity assumption (Brachmann and Kolisch 2021; Ghiyasinasab et al. 2021). While the infinite-capacity approach focuses only on estimating the lead times for engineering activities and relies on historical cost data for estimating engineering costs, the finite-capacity planning approach can integrate the estimation of engineering lead times and costs.

Based on the reviewed literature, we identify two main sets of planning inputs for estimating engineering lead times and costs in the tendering phase in ETO contexts. First, the planning output of the previous engineering planning activity (4.2.2), i.e. the required detailed engineering activities and resources. Second, the operational inputs required for computing the lead time and cost estimates using infinite- or finite-capacity approaches, as listed below.

- Historical data on duration and costs for engineering activities in completed projects (Grabenstetter and Usher 2013, 2014).
- Capacity of engineering personnel and status of ongoing projects (Brachmann and Kolisch 2021; Ghiyasinasab et al. 2021) for estimating lead times based on finite loading.
- Costs of regular and overtime engineering capacity (Brachmann and Kolisch 2021; Ghiyasinasab et al. 2021) for estimating costs of engineering activities.

4.2.4. Identifying needs for external capabilities and additional capacity

Design and engineering capabilities are a vital source of competitive advantage for many ETO manufacturers, especially in contexts where customers value the innovativeness and customisability of products (Alfnes et al. 2021; Amaro, Hendry, and Kingsman 1999; Cannas et al. 2020). For such ETO companies, an important consideration in responding to customer enquiries is the availability of required capabilities in different engineering disciplines to perform the detailed engineering activities necessary to fulfil the customer requirements (Alfnes et al. 2021; Aslan, Stevenson, and Hendry 2015; Gosling, Hewlett, and Naim 2017). Moreover, ETO contexts requiring frequent innovations in product technology necessitate a continual reassessment of in-house capabilities and expertise in engineering to maintain the competitive advantage in product features and innovativeness (Cannas et al. 2020; Gosling, Hewlett, and Naim 2017). Based on these factors, in addition to the detailed engineering activities and resources (i.e. planning output from 4.2.2), we identify the in-house engineering capabilities as the main strategic input for identifying the needs for external engineering capabilities.

Determining the need for additional engineering capacity is an extension of the planning activity of estimating engineering lead times and costs (4.2.3). ETO companies are multi-project contexts where the same capacity-constrained resources execute multiple projects simultaneously (Adrodegari et al. 2015; Barbosa and Azevedo 2019; Hans et al. 2007; Shurrab, Jonsson, and Johansson 2020b). As a result, the regular capacity of in-house engineering resources may not be sufficient for meeting customer-imposed engineering due dates because of these resources being allocated to other ongoing projects, which can necessitate the use of non-regular capacity alternatives such as overtime (Brachmann and Kolisch 2021; Ghiyasinasab et al. 2021). Identifying such non-regular capacity needs as early as in the tendering phase can enable managers in better capacity planning for the engineering function.

4.3. Procurement planning

ETO companies use combinations of standard and non-standard or customer-specific components and modules for producing the final product (Johnsen and Hvam 2019; Zennaro et al. 2019; Zorzini et al. 2008b). Fabrication and assembly activities for various components and modules are outsourced by ETO companies to varying extents, ranging from highly vertically integrated manufacturers that only procure raw materials and basic components to highly vertically disintegrated companies with entirely outsourced production activities (Alfnes et al. 2021; Hicks, McGovern, and Earl 2000; Hicks, McGovern, and Earl 2001; Zorzini, Stevenson, and Hendry 2012). Nevertheless, almost all ETO companies depend on their suppliers for some stages of the order-fulfilment process, which underlines the importance of procurement planning before order confirmation (Hicks, McGovern, and Earl 2000). The primary role of procurement planning in the tendering phase is the early identification of components and sub-assemblies to be procured if an order is confirmed and identifying relevant suppliers and supplier-related constraints for the order-fulfilment process (Dekkers, Chang, and Kreutzfeldt 2013; Hicks, McGovern, and Earl 2000; Shishank and Dekkers 2013). From the reviewed literature, we identify three main tactical planning activities for the procurement planning function in S&OP, namely (1) identifying critical items for a potential customer order, (2) identifying potential suppliers for the critical items, and (3) determining lead time and cost-related constraints for critical items. These planning activities and their planning inputs are described in the following subsections: 4.3.1. Identifying critical items, 4.3.2. Selecting potential suppliers, and 4.3.3. Determining procurement lead times and prices. Figure 5 summarises the strategic-, external-, operational-, and cross-functional inputs for procurement planning.

4.3.1. Identifying critical items

Products produced with an ETO strategy are typically complex, large-sized, and characterised by deep and wide product structures (Zennaro et al. 2019) that consist of components and subsystems with a wide range of characteristics, e.g. some are used in low volumes while others are used in medium to large quantities, some are highly customised while others are standardised, some are technologically advanced while others are not, etc. (Hicks and Braiden 2000; Hicks, McGovern, and Earl 2000). The typically long delivery lead times in ETO contexts allow for externally sourced items to be procured during the order-fulfilment process, i.e. after order confirmation. Nevertheless, factors such as long supplier lead times, the geographical distance of suppliers, few or no alternate suppliers, low flexibility of suppliers, customisation, etc., render some items critical for timely order-fulfilment and delivery precision in ETO contexts (Emblemsvåg 2014; Mwesiumo, Nujen, and Kvadsheim 2021; Shlopak, Rød, and Oterhals 2016; Zorzini et al. 2008b; Zorzini, Stevenson, and Hendry 2012). Some of these factors may also be correlated, e.g. higher levels of customisation are usually associated with higher costs and longer, more uncertain lead times (Alfnes et al. 2021; Hicks, McGovern, and Earl 2000). Identifying such critical components already in the tendering phase can enable managers and planners (1) to consider the supply-related constraints for these items while estimating and quoting delivery dates and prices to customers and (2) to closely monitor the procurement of these items after order confirmation (Zorzini et al. 2008b; Zorzini, Stevenson, and Hendry 2012).

From the reviewed literature, the following main planning inputs for identifying supply-critical items emerge.

- Strategic input – overall outsourcing and offshoring strategy (Hicks, McGovern, and Earl 2000; Sabri, Micheli, and Cagno 2020; Zorzini, Stevenson, and Hendry 2012) that constrains which components and subsystems are sourced from suppliers, and the geographical preferences vis-à-vis suppliers, i.e. localisation versus globalisation of supply.
- Cross-functional inputs – preliminary product specifications (4.2.1) and detailed engineering activities (4.2.2) (Alfnes et al. 2021; Emblemsvåg 2014; Hicks, McGovern, and Earl 2000; Zorzini, Stevenson, and Hendry 2012) that identify subsystems and components that will require order-specific customisation.
- Operational inputs – historical procurement lead times (Hicks, McGovern, and Earl 2000; Zorzini et al.

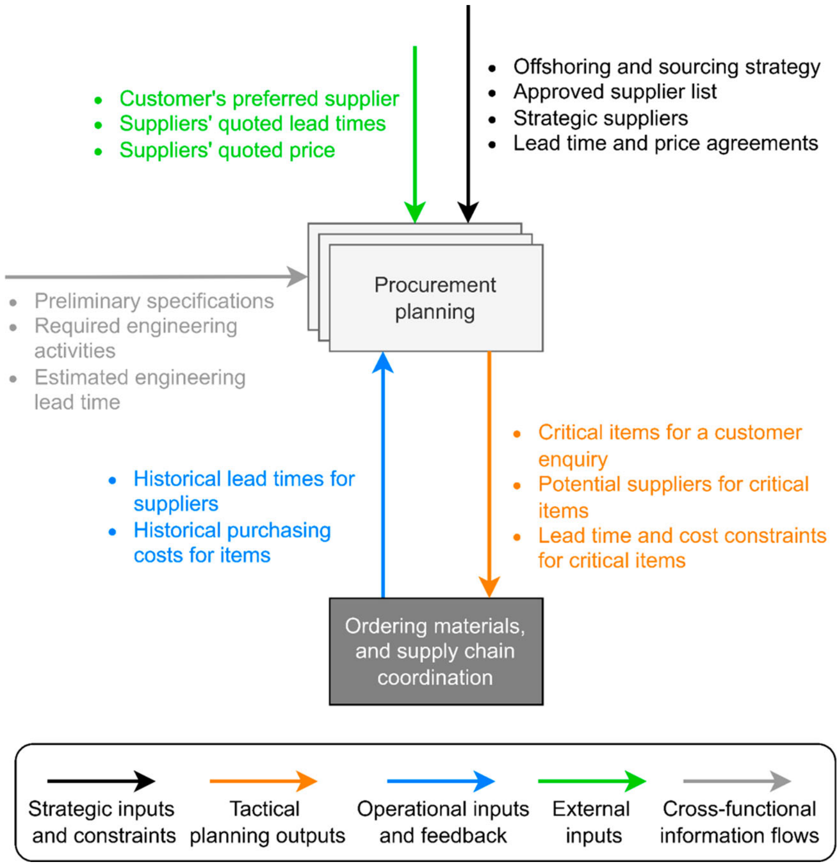

Figure 5. Tactical procurement planning – information inputs and planning outputs.

2008b; Zorzini, Stevenson, and Hendry 2012) that allow for identifying items with potentially long and variable procurement lead time items.

4.3.2. Selecting potential suppliers

The complex structure of ETO products and a large number of sourced components and sub-assemblies used for assembling these products necessitate effective supplier coordination in ETO contexts (Hicks, McGovern, and Earl 2000; Zorzini, Stevenson, and Hendry 2012). Moreover, the suppliers from whom raw materials, components, and sub-assemblies are procured may change in ETO contexts from one customer order or project to another (Alfnes et al. 2021; Mwesiumo, Nujen, and Kvadsheim 2021). For items that are considered critical from a supply planning perspective (4.3.1), potential suppliers must already be identified in the tendering phase such that realistic lead time and price constraints, which are essential planning inputs for estimating and quoting delivery dates and price (4.1.3), can be identified by contacting the potential suppliers (Hicks, McGovern, and Earl 2000; Mello et al. 2017; Zorzini et al. 2008b). Using internally estimated procurement lead times based on historical data and managerial assumptions can expose ETO companies to a significant risk of delays and cost overruns due to the uncertainty of supplier lead times (Alfnes et al. 2021; Hicks, McGovern, and Earl 2000; Shurrab, Jonsson, and Johansson 2020b).

In addition to the identified critical items (4.3.1), we identify the following planning inputs for identifying the potential suppliers based on the reviewed literature.

- Strategic inputs – supplier or vendor list (Mwesiumo, Nujen, and Kvadsheim 2021; Reid, Bamford, and Ismail 2019; Sabri, Micheli, and Cagno 2020) that identifies the approved suppliers for various materials, components, and subsystems; and any strategic suppliers with whom the company has long-term alliances or partnerships for specific items, e.g. due to a supplier's technological expertise, unique product features, etc. (Hicks, McGovern, and Earl 2000; Hicks, McGovern, and Earl 2001; Mello et al. 2017; Mwesiumo, Nujen, and Kvadsheim 2021; Saghiri and Hill 2014).
- External input – customer's preferred supplier(s) for specific items or customer requirements that can exclusively be fulfilled by particular suppliers (Hicks, McGovern, and Earl 2000), which constrain the choice of suppliers.

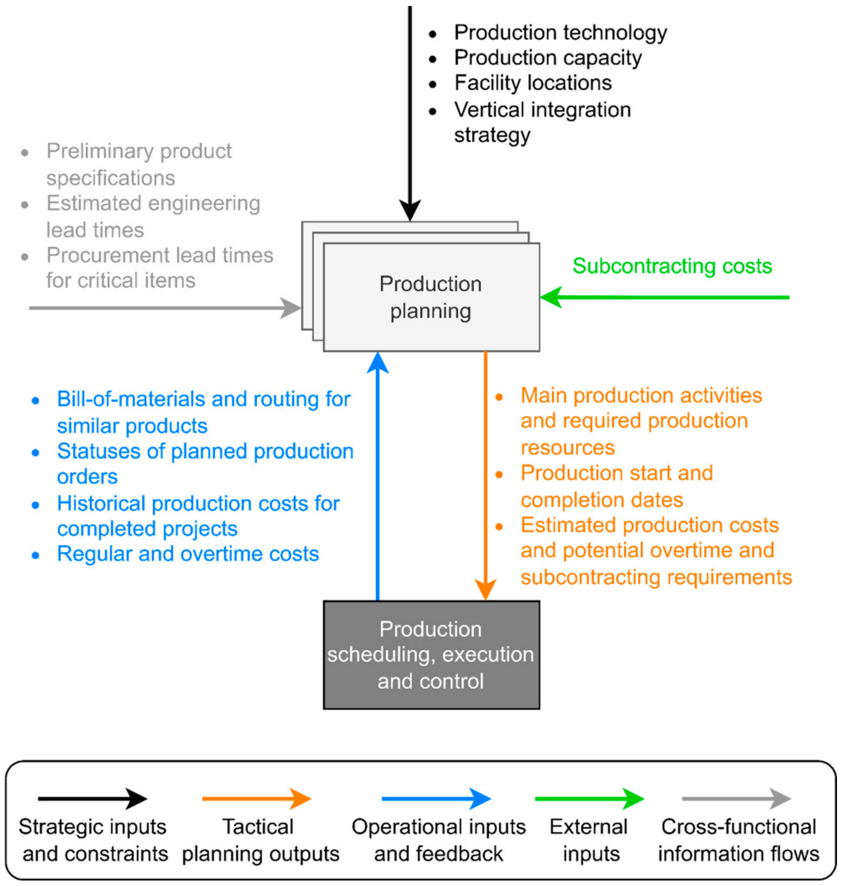

Figure 6. Tactical production planning – information inputs and planning outputs.

4.3.3. Determining procurement lead times and prices

In ETO contexts, procurement lead times and the costs of procured items are usually significant elements of the overall delivery lead time and the overall cost of the product, respectively (Adrodegari et al. 2015; Alfnes et al. 2021; Gourdon and Steidl 2019; Zorzini, Stevenson, and Hendry 2012). Consequently, procurement lead times and costs are indispensable inputs for estimating delivery dates and prices quoted to customers to ensure that products can be delivered to customers within the promised delivery lead times and profitably (Hicks, McGovern, and Earl 2000; Mello et al. 2017). Three main approaches emerge from the extant literature for identifying procurement lead times and costs in the tendering phase emerge, namely (1) estimation based on historical data, (2) identifying lead times and prices from long-term supplier agreements, and (3) identifying lead times and prices by active coordination with suppliers (Calosso et al. 2003; Hicks, McGovern, and Earl 2000; Zorzini et al. 2008b). Based on the reviewed literature, we identify the following planning inputs for determining the procurement lead times and prices.

- Strategic inputs – long-term supplier agreements for lead times and prices (Hicks, McGovern, and Earl 2000; Olhager 2010; Shurrab, Jonsson, and Johansson 2020b), if any.
- Cross-functional inputs – preliminary product specifications (4.2.1) and required detailed engineering activities (4.2.2) for communicating the expected characteristics of customised items to potential suppliers, and the estimated engineering lead times (4.2.3) for communicating the anticipated timeline for availability of the detailed specifications (Dekkers, Chang, and Kreutzfeldt 2013; Hicks, McGovern, and Earl 2000; Shishank and Dekkers 2013; Zorzini, Stevenson, and Hendry 2012).
- External inputs – lead times and prices quoted by suppliers (Alfnes et al. 2021; Calosso et al. 2003; Hicks, McGovern, and Earl 2000; Shishank and Dekkers 2013; Zorzini et al. 2008b; Zorzini, Stevenson, and Hendry 2012).
- Operational inputs – historical data for suppliers' lead times and prices (Hicks, McGovern, and Earl 2000; Shishank and Dekkers 2013; Shlopak, Rød, and Oterhals 2016; Zorzini, Stevenson, and Hendry 2012).

4.4. Production planning

Products that are typically engineered and produced for specific customer orders are usually high-value and heavy-duty electromechanical systems consisting of various subsystems (Cannas and Gosling 2021; Gosling and Naim 2009; Zennaro et al. 2019). Consequently, facilities that manufacture these products require diverse equipment and manual expertise for fabricating the components and assembling the subsystems that comprise these products. Furthermore, since ETO manufacturing contexts are multi-project environments, many customer orders for complex products are simultaneously processed by the specialised, capacity-constrained production resources in these contexts (Adrodegari et al. 2015; Alfnes et al. 2021; Hans et al. 2007). Therefore, capacity constraints for production resources must be considered by managers in ETO contexts while quoting delivery dates and prices for new customer orders to ensure that the customer order can be produced within the promised duration without incurring unanticipated costs due to capacity shortfalls (Alfieri, Tolio, and Urgo 2011; Carvalho, Oliveira, and Scavarda 2015; Shurrab, Jonsson, and Johansson 2020b; Wullink et al. 2004). Based on this need, we identify three main tactical planning tasks for the production planning function within S&OP in the tendering phase, namely (1) identifying the main production activities and resource requirements for a potential customer order, (2) identifying the feasible start and finish dates for production activities or stages, and (3) estimating production costs and non-regular capacity (overtime and subcontracting) requirements. These planning activities and their planning inputs are described in the following subsections: 4.4.1. Identifying the main production activities and resource requirements, 4.4.2. Identifying feasible production start and end dates, and 4.4.3. Estimating production costs and non-regular capacity requirements. Figure 6 summarises the strategic-, external-, operational-, and cross-functional inputs for these production planning activities.

4.4.1. Identifying the main production activities and resource requirements

The tendering phase for customer orders in ETO contexts is characterised by substantial uncertainty regarding the product and process specifications since the detailed product engineering and process planning activities are performed after order confirmation (Adrodegari et al. 2015; Alfieri, Tolio, and Urgo 2012; Alfnes et al. 2021; Carvalho, Oliveira, and Scavarda 2015, 2016; Hans et al. 2007; Reid, Bamford, and Ismail 2019; Shurrab, Jonsson, and Johansson 2020b; Wullink et al. 2004). Nevertheless, managers and planners must plan and tentatively allocate resources and capacity for potential customer orders in the tendering phase to ensure the availability of these resources later, to estimate feasible production due dates, and for timely execution of order-fulfilment activities. To enable this planning or capacity allocation, it is an essential planning activity to identify the main production activities for a potential customer order, e.g. cutting, stamping, machining, welding, assembly, testing, packaging, etc., and the resource requirements for performing them, i.e. personnel and equipment (Adrodegari et al. 2015; Carvalho, Oliveira, and Scavarda 2015; De Boer, Schutten, and Zijm 1997; Reid, Bamford, and Ismail 2019) albeit with high-level, aggregated production stages, workloads, resources, and time-buckets (Adrodegari et al. 2015; Aslan, Stevenson, and Hendry 2012; Zorzini, Corti, and Pozzetti 2008a). The level of aggregation and scope for identifying these resource requirements can vary based on contextual factors such as product complexity, degree of customisation, resource flexibility, etc. (Zorzini, Corti, and Pozzetti 2008a; Zorzini et al. 2008b). For instance, production contexts with fixed bottlenecks may focus on capacity requirements for bottleneck resources, while contexts with varying bottlenecks must consider a broader set of resources and corresponding capacities (Alfnes and Hvolby 2019; Park et al. 1999; Ruben and Mahmoodi 2000; Zorzini, Corti, and Pozzetti 2008a). Similarly, factors such as resource capabilities, capacity flexibility, target resource utilisation, etc., may influence the level of aggregation of resources, capacity, and time-buckets (Ebben, Hans, and Weghuis 2005; Robinson and Moses 2006; Zorzini, Corti, and Pozzetti 2008a). Based on the reviewed literature, we identify the following main planning inputs for identifying the main production activities and resource requirements in the tendering phase.

- Strategic input – current manufacturing process technology, which governs if the fabrication activities will be performed using the same techniques as previous customer orders (Adrodegari et al. 2015; Alfieri, Tolio, and Urgo 2011, 2012) or if new process technology alternatives, e.g. additive manufacturing, have been implemented (Eyers et al. 2021).
- Cross-functional input – preliminary product specifications (4.2.1) (Adrodegari et al. 2015; Alfieri, Tolio, and Urgo 2012; Alfnes and Hvolby 2019; De Boer, Schutten, and Zijm 1997; Nam et al. 2018), based on which the required macro-level production processes can be identified.
- Operational input – existing bill-of-materials (BOM) and production routing from previous orders for similar products (Carvalho, Oliveira, and Scavarda 2015,

2016; De Boer, Schutten, and Zijm 1997; Zorzini et al. 2008b) for estimating the workload or resource requirements for various production resources.

4.4.2. Identifying feasible production start and end dates

Similar to the lead times for engineering and procurement, production lead times are an essential input for the sales planning function to estimate the overall delivery lead time (4.1.3) for customer orders in ETO production contexts (Alfieri, Tolio, and Urgo 2011; Carvalho, Oliveira, and Scavarda 2015; Ghiyasinasab et al. 2021). Estimating the lead time for production essentially entails determining feasible production start and end dates while considering finite-capacity constraints and the availability of resources, materials, and product and process specifications (Ebadian et al. 2008; Hicks and Braiden 2000; Wikner and Rudberg 2005; Zorzini, Stevenson, and Hendry 2012). Among the tactical planning activities for S&OP in ETO contexts that are identified in this review, estimation of production lead times is perhaps the planning activity on which the majority of the extant research has focussed, especially the development of planning and decision-support tools for this activity (Bhalla, Alfnes, and Hvolby 2022). In addition to the identified production activities and resource requirements (4.4.1), the following planning inputs for identifying feasible start and end dates for production activities emerge from the reviewed literature.

- Strategic inputs – vertical integration strategy (Hicks, McGovern, and Earl 2000; Hicks, McGovern, and Earl 2001) that constrains which production activities will be performed in-house, production capacity for in-house production resources (Alfieri, Tolio, and Urgo 2011, 2012; Barbosa and Azevedo 2019; Ebben, Hans, and Weghuis 2005; Micale et al. 2021; Park et al. 1999; Ruben and Mahmoodi 2000; Thürer et al. 2012; Wullink et al. 2004; Zorzini, Corti, and Pozzetti 2008a), and the facility locations for companies with multiple production sites (Yang and Fung 2014) for considering the inter-facility transportation times for components or sub-assemblies.
- Cross-functional inputs – estimated engineering lead times (Ghiyasinasab et al. 2021; Grabenstetter and Usher 2014; Wikner and Rudberg 2005; Zorzini et al. 2008b) that govern the availability of the detailed product and process specifications, and estimated procurement lead times (Alfnes et al. 2021; Hicks, McGovern, and Earl 2000; Zorzini, Stevenson, and Hendry 2012) that govern the availability of raw materials and components.
- Operational inputs – status of planned production orders (Barbosa and Azevedo 2019; Carvalho, Oliveira, and Scavarda 2015; Hans et al. 2007; Thürer et al. 2012) for estimating queueing delays, i.e. durations that production orders must wait for required resources to become available; and existing BOMs and production routing from previous orders for similar products (Adam et al. 1993; Burggraf et al. 2021; Thürer et al. 2012) for estimating the processing times and staging delays, i.e. times when components and subassemblies are waiting for other components to be ready for assembly since complex structures of ETO products contain multiple levels of assemblies (Adrodegari et al. 2015; Hicks and Braiden 2000; Zennaro et al. 2019).

4.4.3. Estimating production costs and non-regular capacity requirements

Estimated production costs are an essential input for the sales planning function to determine the overall product price that must be quoted to customers (4.1.3) in the tendering phase. Based on the reviewed literature, two broad approaches for estimating production costs can be identified. First, these production costs can be estimated based on archived historical data on production costs from previous customer orders for similar products (Adrodegari et al. 2015; Kingsman et al. 1996). Second, these production costs can be estimated based on finite-capacity allocation approaches as an extension of estimating the production lead times (Carvalho, Oliveira, and Scavarda 2015; Ghiyasinasab et al. 2021). Finite-capacity approaches entail explicit consideration of the capacity of production resources, as well as any potential non-regular capacity alternatives, e.g. overtime or subcontracting, that might be required for expediting production to meet customer-imposed delivery dates or for quoting short and competitive delivery dates (Amaro, Hendry, and Kingsman 1999; Carvalho, Oliveira, and Scavarda 2015; Ghiyasinasab et al. 2021; Wullink et al. 2004; Zorzini, Corti, and Pozzetti 2008a). Therefore, when using finite-capacity approaches for estimating production lead times and costs, managers must also identify any non-regular capacity requirements associated with the estimated lead times. Based on the reviewed literature, we identify the following planning inputs for estimating production costs based on historical production costs or estimating these costs and non-regular capacity requirements as an extension of estimating production start and end dates (4.4.2).

- Strategic inputs – vertical integration strategy (Hicks, McGovern, and Earl 2000; Hicks, McGovern, and Earl

2001) that constrains which production activities can be outsourced or subcontracted.

- External inputs – subcontracting costs from potential subcontractors (Carvalho, Oliveira, and Scavarda 2015, 2016; Ebadian et al. 2008; Ghiyasinasab et al. 2021; Wullink et al. 2004) for estimating the potential costs of subcontracted production activities.
- Operational inputs – historical production costs for completed projects (Adrodegari et al. 2015; Kingsman et al. 1996), and costs for regular and overtime capacity of production resources (Carvalho, Oliveira, and Scavarda 2015, 2016; Ghiyasinasab et al. 2021).

4.5. S&OP reference framework for ETO contexts

The tactical planning activities and planning inputs identified in the preceding subsections can be synthesised into an S&OP reference framework for delivery date setting in ETO contexts, as illustrated in Figure 7. The planning activities and planning inputs shown in Figure 7 are identified based on the references summarised in Table A2, and are illustrated separately for sales planning (4.1), engineering planning (4.2), procurement planning (4.3), and production planning (4.4) in Figures 3–6, respectively. The S&OP reference framework shown in Figure 7 synthesises the findings from the literature review for the individual S&OP functional subprocesses into a holistic framework for S&OP in ETO contexts, which is constructed by populating Figure 1 with the relevant planning activities and planning inputs, adapting the presentation methodology from Pereira, Oliveira, and Carravilla (2020).

5. Discussion of the framework and future research needs

Based on a systematic review of the extant literature, this paper has identified the main tactical planning activities that ETO companies should consider in contextualising the design of the S&OP process for effectively setting delivery dates while tendering for new customer orders, and the flow of planning information required for performing and coordinating these activities. The findings have been synthesised into an S&OP reference framework for ETO contexts. The remainder of this section discusses the proposed framework's potential applications or usage areas and future research needs for better supporting practitioners in designing and conducting S&OP in ETO contexts.

5.1. Applications of the proposed framework

The high planning complexity characterising the task of setting delivery dates in ETO contexts has been repeatedly emphasised in the extant literature (Shurrab, Jonsson, and Johansson 2020b; Zorzini, Stevenson, and Hendry 2012). For managing this planning complexity, previous research has underlined the need for cross-functionally coordinated tactical planning in ETO contexts, such that the relevant planning factors are considered while tendering, and the in-house tacit knowledge and expertise of managers are utilised for effective planning (Shurrab, Jonsson, and Johansson 2020a, 2020b; Zorzini et al. 2008b; Zorzini, Stevenson, and Hendry 2012). Despite the emphasis on coordinated planning for effective delivery date setting in previous research, there are no planning frameworks in the extant literature to support ETO practitioners in designing cross-functionally coordinated tactical planning processes, neither in the research stream on delivery date setting (Bhalla, Alfnes, and Hvolby 2022) nor in the stream on tactical S&OP (Kreuter et al. 2022; Kristensen and Jonsson 2018). Therefore, the proposed framework can serve as a *common reference framework* for S&OP and delivery date setting in ETO contexts. Managers in ETO companies could use the framework as a reference for assessing (1) which planning activities are critical or essential for their planning environment, (2) whether their existing tactical planning process addresses those activities, and (3) if there are necessary mechanisms for making the planning inputs available for those activities. Furthermore, given the fragmented nature of the extant research on delivery date setting in ETO contexts (Bhalla, Alfnes, and Hvolby 2022), the use of the proposed framework as a common reference among researchers can help position and scope the future research contributions supporting delivery date setting, similar to the application of their framework demonstrated by Pereira, Oliveira, and Carravilla (2020).

Despite the framework's potential to serve as an S&OP reference for delivery date setting in ETO contexts, some contextual contingencies and limitations must be considered in such a generalisation of the framework. Firstly, the framework is developed with the manufacturing industry as the primary target context. However, the ETO strategy is also adopted in non-manufacturing contexts, such as the construction industry (Cannas and Gosling 2021). Due to the underlying assumptions specific to manufacturing, some framework elements may not be applicable in non-manufacturing ETO contexts. Secondly, the strategic relevance of the elements of the framework is expected to vary across ETO manufacturing contexts based on the characteristics of their planning environments and corresponding planning needs (Buer et al. 2018b; Kristensen and Jonsson 2018; Zorzini, Corti, and Pozzetti 2008a; Zorzini et al. 2008b; Zorzini, Stevenson, and Hendry 2012). Factors such as the degree of product

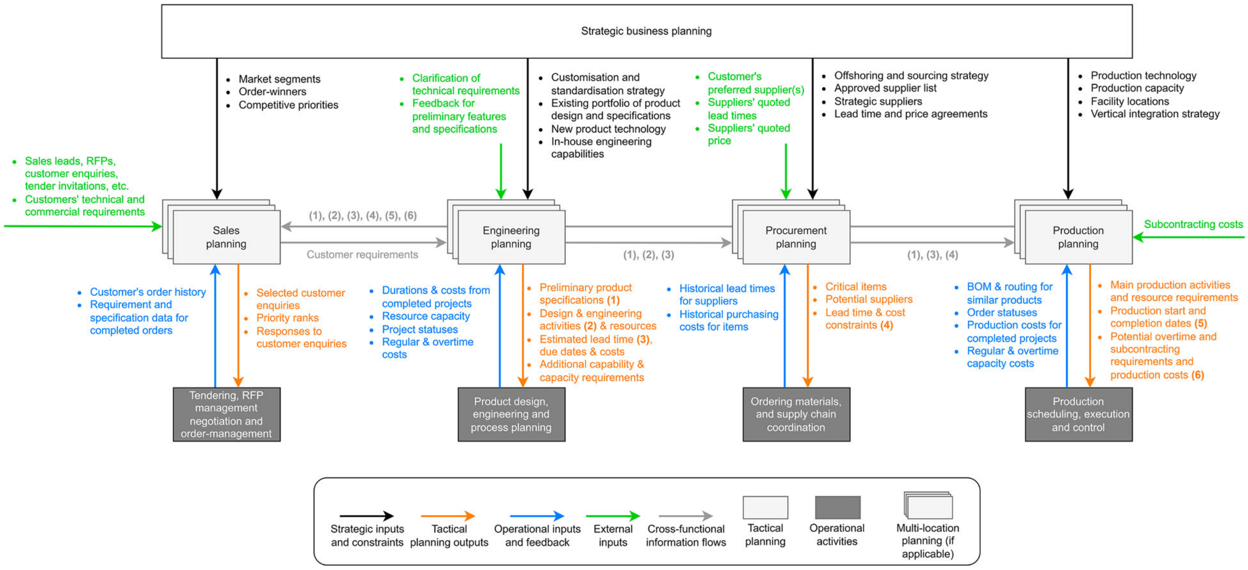

Figure 7. Proposed S&OP reference framework for setting delivery dates in ETO contexts.

customisation, product complexity, order volumes, etc., may amplify the need for cross-functional coordination in tactical planning, while flexibility in capacities of production and engineering functions and the level of technical knowledge of the product and production system across functions may reduce the need for this coordination (Bhalla, Alfnes, and Hvolby 2022; Zorzini et al. 2008b; Zorzini, Stevenson, and Hendry 2012). Companies with high levels of vertical integration may require more emphasis on planning activities for production and engineering functions, while companies with low levels of vertical integration may focus more on planning activities for the procurement function (Hicks, McGovern, and Earl 2000; Hicks, McGovern, and Earl 2001; Zorzini, Stevenson, and Hendry 2012). Furthermore, the context of companies' business- and competitive strategy might influence how specific planning activities and decisions are handled. For instance, companies focusing on expanding their market share might prioritise enquiries from new customers, while other companies might prioritise enquiries from existing customers to sustain existing long-term relationships with customers (Ebadian et al. 2008; Ebadian et al. 2009). In some companies, pre-defined product platforms or templates may be used for expedited or automated specification of preliminary product characteristics in the tendering phase (Fang and Wei 2020; Ulonska and Welo 2016). Due to the variety in characteristics of ETO manufacturing companies found in practice (Alfnes et al. 2021; Amaro, Hendry, and Kingsman 1999; Cannas and Gosling 2021; Gosling and Naim 2009; Hicks, McGovern, and Earl 2001; Willner et al. 2016b), and as exemplified above, the contingency between the contextual factors, the planning needs, and the planning process design are essential to consider while applying or generalising the framework. Moreover, the order-fulfilment process in ETO contexts is influenced by requirements related to compliance with design codes, standards, and product certification practices, which are typically industry-specific and are therefore excluded from the framework. For high-value, complex, and technologically advanced ETO products such as power generation equipment, manufacturing machinery, offshore oil and gas production platforms, etc., the complexity of design and engineering activities is typically managed by using design codes and standards established by different professional societies and national or international standard organisations (Gosling, Hewlett, and Naim 2017; Shapiro 1997) such as ISO (International Organisation for Standardisation), IEC (International Electrotechnical Commission), CEN (European Committee for Standardisation), CENELEC (European Committee for Electrotechnical Standardisation), ANSI (American National Standards Institute), etc. Consequently, many of these ETO products undergo post-production inspection or testing procedures to demonstrate and certify their adherence to the relevant standards, where the relevance of different standards may also depend on the geographical context. Such industry-specific certification procedures and their influence on the order-fulfilment process must be considered while designing the S&OP process in specific contexts. For instance, design and production of ships and ship equipment are governed by the rules and standards established by classification societies such as DNV (Det Norske Veritas), Lloyd's register, etc., and the class certification procedures of these societies impose precedence constraints on shipbuilding projects and ship equipment manufacturing (Alfnes et al. 2021; Emblemsvåg 2014). Therefore, industry-specific regulatory considerations and their impact on S&OP must be incorporated into the framework based on the particular ETO industry or context of application.

The variations in the planning environment characteristics across ETO contexts also suggest another potential usage of the framework for comparative case studies of delivery date setting practices across companies within and across industry sectors. In the extant literature, the handful of multi-case studies on delivery date setting practices are exploratory studies from machinery building companies from a limited set of geographical contexts (Zorzini, Corti, and Pozzetti 2008a; Zorzini et al. 2008b; Zorzini, Stevenson, and Hendry 2012). Despite the valuable contributions of these studies, case research establishing the current status of delivery date setting practices in other industrial and geographical contexts is a gap in the extant research (Bhalla, Alfnes, and Hvolby 2022). The proposed framework can support future case studies on delivery date setting as a *tool for mapping* the tactical planning process for setting delivery dates in ETO companies, identifying variations in companies' focus on planning activities and cross-functional information sharing and the contextual factors influencing these variations. The contingency frameworks for delivery date setting proposed by previous studies of Zorzini et al. (2008b) and Zorzini, Stevenson, and Hendry (2012) identify four high-level design variables for the delivery date setting process, namely delivery date monitoring support, delivery date setting responsibility, coordination, and formalisation. The planning activities and inputs identified in our proposed S&OP framework (Figure 7) provide a more granular set of variables for the design and assessment of the delivery date setting process.

The proposed framework can also be utilised as a basis for *developing maturity models* for delivery date setting practices in ETO contexts. As suggested by numerous contributions within S&OP research and within operations management in general, maturity models are valuable tools for mapping and assessing the current state of business processes and industry practices and for planning strategic process improvements in the studied contexts (Danese, Molinaro, and Romano 2018; Goh and Eldridge 2015; Grimson and Pyke 2007; Pedroso et al. 2017; Vereecke et al. 2018; Wagire et al. 2021; Willner, Gosling, and Schönsleben 2016a). Despite the strategic and competitive importance of the planning task of setting delivery dates (Zorzini et al. 2008b; Zorzini, Stevenson, and Hendry 2012), there are no existing maturity models for delivery date setting practices in ETO contexts (Bhalla, Alfnes, and Hvolby 2022). Furthermore, the existing maturity models for the S&OP process have been developed based on research contextualised in MTS and MTO production contexts (Danese, Molinaro, and Romano 2018; Goh and Eldridge 2015; Grimson and Pyke 2007; Pedroso et al. 2017; Vereecke et al. 2018), and do not consider the unique planning needs for S&OP in ETO production contexts that are highlighted by the framework developed in this paper. The proposed framework can support future research aimed at addressing this gap.

5.2. Research gaps and future research needs

The systematic review of literature conducted to answer this paper's main research question also highlighted several research gaps in the reviewed literature. Based on these research gaps, this subsection suggests research needs that future research should address for supporting practitioners in designing and conducting the S&OP process for effective delivery date setting in ETO contexts.

The first research gap identified in the review concerns the sales planning activities of selecting and prioritising customer enquiries. Over the last three decades, multiple authors and their studies in diverse ETO contexts have highlighted the importance of selecting and prioritising customer enquiries for tendering based on strategic factors (Adrodegari et al. 2015; Hans et al. 2007; Hicks, McGovern, and Earl 2000; Kingsman et al. 1996; Shurrab, Jonsson, and Johansson 2020b; Zorzini et al. 2008b). However, the majority of references for these activities in the extant literature only provide high-level descriptions of these activities without exhaustive accounts of the factors that are or should be considered for these activities. While some of the factors to be considered for selecting and prioritising customer enquiries have been identified or inferred in this paper based on a few references from ETO contexts (Adrodegari et al. 2015; Amaro, Hendry, and Kingsman 1999; Cannas et al. 2020; Hans et al. 2007; Hicks, McGovern, and Earl 2000; Kingsman et al. 1996; Shurrab, Jonsson, and Johansson 2020b; Zorzini et al. 2008b) and MTO contexts (Ebadian et al. 2008; Ebadian et al. 2009), future studies should investigate whether any additional factors should be considered for these activities. Furthermore, the references for these activities in the extant ETO literature do not provide any formal decision-making methodologies for these planning activities. Future research should explore if, similar to MTO contexts (Ebadian et al. 2008; Ebadian et al. 2009), decision models for selecting and prioritising customer enquiries can be developed to support managers in ETO contexts.

The second research gap in the literature review relates to lead time estimation and capacity planning for engineering activities. Among the few quantitative contributions in this area, Grabenstetter and Usher (2013, 2014) use an infinite-capacity approach for estimating engineering lead times by estimating engineering complexity based on historical data and the characteristics of a new engineering project; while Brachmann and Kolisch (2021); Ghiyasinasab et al. (2021) use finite-capacity planning-based approaches for estimating the engineering lead times. While the regression-based infinite-capacity approach from Grabenstetter and Usher (2013, 2014) may be useful for ETO companies with surplus engineering capacity, such an approach may not fulfil the planning needs of companies where the level of engineering capacity utilisation is high. On the other hand, the approaches proposed by Brachmann and Kolisch (2021); Ghiyasinasab et al. (2021) can be useful references for companies with capacity-constrained engineering resources, however, the authors demonstrate and test the proposed approaches using historical data without explicating how the characteristics of a new engineering project are considered in estimating the duration of individual engineering activities and the workloads for individual engineering resources. Future research should explore how hybrid approaches can be developed for estimating the lead times of engineering activities considering both, the capacity constraints for engineering resources and the characteristics of new engineering projects.

The third research gap observed in the literature concerns procurement planning, which is tasked with coordinating the upstream supply chain actors during the tendering phase. Activities such as supplier selection and determining the type of strategically fitting relationships for different suppliers have been traditionally seen as long-term strategic decisions, based on the needs of high-volume production environments (Ellram 1990; Hesping and Schiele 2015, 2016; Kraljic 1983). Recently proposed approaches for selecting suppliers and supplier relationship types in ETO contexts also adopt this view (Sabri, Micheli, and Cagno 2020; Shlopak, Rød, and Oterhals 2016). However, ETO contexts usually procure items order by order, in low volumes (Adrodegari et al. 2015; Buer et al. 2018b; Jonsson and Mattsson 2003), and the suppliers for components of similar products may vary across customer orders (Alfnes et al. 2021; Mwesiumo, Nujen, and Kvadsheim 2021). As a result, ETO companies require tactical-level managerial approaches for periodically or dynamically reassessing procurement strategies and supplier relationships, and prescriptive guidance on the sourcing levers and coordination mechanisms that should be used for different categories of suppliers (Hesping and Schiele 2016). These are knowledge gaps in the extant sourcing literature where research has been primarily motivated by the needs of mass production contexts (Hesping and Schiele 2015). Studies focussing on addressing the tactical-level procurement and supplier coordination needs of ETO companies are required in future research to support managers' procurement planning activities within S&OP and delivery date setting in ETO contexts.

The final set of knowledge gaps and research needs identified in the review are related to lead time estimation and capacity planning for in-house production activities. The majority of the quantitative decision-support tools and models for tactical planning activities in ETO contexts focus on the mutually linked planning activities of tentatively allocating production capacity, estimating production lead times, assessing the feasibility of completing production activities within customer-imposed due dates, etc. (Alfieri, Tolio, and Urgo 2011, 2012; Carvalho, Oliveira, and Scavarda 2015, 2016; Ghiyasinasab et al. 2021; Micale et al. 2021). Despite the variety of tools proposed for these planning activities, there are gaps and shortcomings in the extant planning and decision-support tools that should be addressed to improve their managerial utility in practice (Bhalla, Alfnes, and Hvolby 2022). Planning tools based on formally specified optimisation models and exact solution techniques are valuable for smaller problem instances but become computationally intractable and practically unusable for industrial applications as the product complexity, the number of unique resources, or the required granularity or detail in planning increase (Alfieri, Tolio, and Urgo 2011, 2012; Carvalho, Oliveira, and Scavarda 2015). Efficient heuristic planning methods have been proposed for MTO contexts (Thürer et al. 2012) that are also potentially useful for estimating production lead times in ETO contexts. However, further development and testing are required for such methods to be viable in practice for complex ETO products with multi-level product structures and multiple subsystems that may be fabricated and assembled in parallel (Bhalla, Alfnes, and Hvolby 2022). Therefore, future research on production planning in ETO contexts should focus on developing effective and efficient heuristic planning methods and decision-support tools for addressing the industrial planning needs within tactical-level lead time estimation and capacity planning for production activities.

6. Conclusion

This paper has investigated the research question: How should engineer-to-order manufacturers contextualise the design of the sales and operations planning process for effective delivery date setting? The paper proposes that based on their specific planning environments, ETO companies identify their planning needs for effectively setting delivery dates while tendering for new customer orders, and design or redesign their S&OP process focussing on the activities and information flows that address the identified planning needs. To support this in practice, the paper (1) develops an S&OP reference framework that identifies the planning activities and planning inputs that should be considered in ETO companies for contextualising the S&OP process design for effective delivery date setting, and (2) discusses the industrial application of the framework for designing and analysing the S&OP process. The framework is developed by systematically reviewing literature. The paper also (1) discusses applications of the framework in future research, (2) highlights the research gaps within tactical planning in ETO contexts, and (3) suggests the future research needs to address these gaps and to better support ETO practitioners in designing and conducting the S&OP process. The proposed framework contributes to the literature on two, currently isolated streams of research – the research stream on S&OP that has lacked contextual consideration of ETO production (Kreuter et al. 2022; Kristensen and Jonsson 2018) and the research stream on tactical planning and delivery date setting that has lacked an overall framework for cross-functional coordination and coordinated planning (Bhalla, Alfnes, and Hvolby 2022), as highlighted below.

Previous research on S&OP has primarily been contextualised in MTS contexts in food production, consumer electronics production, automotive manufacturing, production of medical products, cardboard production, process industry, etc. (Danese, Molinaro, and Romano 2018; Grimson and Pyke 2007; Noroozi and Wikner 2017; Oliva and Watson 2011), with some contributions addressing MTO contexts in the electrical and electronics industries (Feng, D'Amours, and Beauregard 2008; Grimson and Pyke 2007) and the automotive supplier industry (Gansterer 2015). Consequently, the extant frameworks developed for supporting S&OP research and practice have been implicitly targeted towards the planning needs of MTS and/or MTO contexts, and do not address the planning needs of ETO contexts. Conversely, the framework proposed in this paper is specifically designed to address the needs of ETO contexts. For instance, the proposed framework is structured based on the ETO supply chain matrix proposed by Nam et al. (2018), as opposed to the general supply chain matrix from Stadtler and Kilger (2008) that was used by Pereira, Oliveira, and Carravilla (2020) to develop their S&OP framework. Furthermore, this paper adopts a customer order or customer enquiry-oriented planning perspective for developing the proposed S&OP framework, which is typical for ETO contexts due to low volumes of customer orders, customer-specific order-fulfilment activities, and relatively long delivery lead times (Adrodegari et al. 2015). This is in contrast to MTO and MTS production contexts, where statistical demand forecasts, contractual sales volumes, and backlogged sales volumes are often essential inputs for S&OP (Feng, D'Amours, and Beauregard 2008; Gansterer 2015; Pereira, Oliveira, and Carravilla 2020), and the planning perspective typically adopted at this level concerns volumes of sales, production, distribution, and procurement, while most order-specific activities are planned and controlled with shorter planning horizons at the operational level (Pereira, Oliveira, and Carravilla 2020). Finally, the framework proposed in this paper includes operational inputs as a planning input category which is absent in the S&OP framework from Pereira, Oliveira, and Carravilla (2020). This inclusion is necessitated by the frequently changing planning environment of ETO production contexts where the current and planned states of operational resources must be considered in tactical planning to increase the feasibility of these plans (Alfieri, Tolio, and Urgo 2011, 2012; Alfnes et al. 2021; Carvalho, Oliveira, and Scavarda 2015, 2016; Ghiyasinasab et al. 2021; Wullink et al. 2004; Zorzini et al. 2008b).

The findings of this study and the proposed framework also contribute to the research stream on tactical planning and delivery date setting in ETO contexts, where an overall framework for cross-functional coordination and coordinated planning has been a gap in the extant literature (Bhalla, Alfnes, and Hvolby 2022). The framework addresses the shortcomings of existing frameworks in this literature stream, underlined in section 2 (Adrodegari et al. 2015; Bertrand and Muntslag 1993; Kingsman et al. 1996; Little et al. 2000; Nam et al. 2018; Shurrab, Jonsson, and Johansson 2020b; Zorzini, Corti, and Pozzetti 2008a), by exhaustively identifying S&OP activities and planning inputs for delivery date setting with a cross-functional perspective.

Based on the research gaps highlighted in recent reviews on S&OP (Kreuter et al. 2022; Kristensen and Jonsson 2018) and delivery date setting (Bhalla, Alfnes, and Hvolby 2022), and to the best of our knowledge, the proposed framework is the first to address the design of S&OP and tactical planning processes in ETO contexts focussing on delivery date setting and tendering from a cross-functional perspective. The development and focus of the framework on tendering are partly motivated by empirical observations from the maritime industry reported by the authors in a previous study (Bhalla et al. 2021), and our subsequent research will focus on demonstrating the application of the framework in industrial cases. In the authors' view, the primary potential for industrial application of the framework lies in its use for supporting the managerial assessment of which planning activities are strategically essential for a company and reconfiguring the design of those planning activities for improving their effectiveness. Future studies can also utilise the framework for defining requirements for decision-support systems and planning functionalities for enterprise planning systems that better address the needs of ETO companies than existing systems (Aslan, Stevenson, and Hendry 2012, 2015). Finally, since the proposed framework focuses on designing S&OP to support delivery date setting, future extensions of the framework can also consider integrating other planning tasks in ETO contexts, e.g. multi-project planning after order confirmation (Adrodegari et al. 2015; Hans et al. 2007), replanning due to engineering changes (Iakymenko et al. 2020), etc., into the scope of the framework.

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Notes on contributors

Swapnil Bhalla is a PhD candidate at the Department of Mechanical and Industrial Engineering, Norwegian University of Science and Technology (NTNU) in Trondheim, Norway. He holds an MSc in Global Manufacturing Management from NTNU and a BEng in Mechanical Engineering from Delhi Technological University in New Delhi, India. He has three years of experience in manufacturing process analysis from the automotive industry in India. In his PhD, he is working on solutions for effective tactical sales and operations planning and delivery date quotation in engineer-to-order manufacturing environments focusing on maritime equipment suppliers. His research interests include information systems, data science and analytics, and decision-support in manufacturing supply chains.

Erlend Alfnes is an associate professor at the Department of Mechanical and Industrial Engineering, Norwegian University of Science and Technology in Trondheim, Norway. He holds a PhD in Manufacturing Logistics. He has 15 years of experience as a manager of national and international research projects. His main research interests include manufacturing planning and control, enterprise resource planning systems, manufacturing strategy, lean manufacturing, and the integration of lean manufacturing and Industry 4.0, and his research activities focus on engineer-to-order industries.

Hans-Henrik Hvolby is a Full Professor at the Centre for Logistics, Aalborg University in Denmark and a visiting professor at the University of Tasmania, Australia. He has previously held visiting professorships at NTNU in Norway and UNISA in Australia. He holds a PhD in Manufacturing Information Systems, has published more than 170 peer-reviewed papers, and serves as an editorial board member of several international journals. For over two decades, he has been the project manager or partner in large research projects raising national and European research funding. His research areas include manufacturing and supply chain planning, manufacturing information systems, logistics and supply chain integration.

Olumide Emmanuel Oluyisola is a cloud operations professional in the logistics-focused software-as-a-service (SaaS) industry. He holds an MSc in Global Production Management and a PhD in Production and Quality Engineering from the Department of Mechanical and Industrial Engineering, NTNU in Trondheim, Norway. He has five years of industrial experience in various roles as a business process analyst, project manager, and technology consultant in the oil & gas and software industries. He has also collaborated on several national research projects. His current research interests include manufacturing planning and control, smart manufacturing systems design, industrial internet-of-things, applied machine learning, and software security.

Data availability statement

The papers used for developing the framework are cited in the manuscript and included in the list of references. Any additional data about the papers can be made available by the authors upon request.

ORCID

Swapnil Bhalla http://orcid.org/0000-0003-4905-2488
Erlend Alfnes http://orcid.org/0000-0002-9892-3916
Hans-Henrik Hvolby http://orcid.org/0000-0002-5574-5216
Olumide Oluyisola http://orcid.org/0000-0001-7944-3776

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Appendix

Table A1 shows the distribution of the 75 reviewed papers across various journals and conference proceedings; Figure A1 shows the distribution of their publication years; Table A2 summarises the papers' contributions to the research question of this study.

Table A1. Distribution of papers across journals and conference proceedings.

Source	Number of papers
International Journal of Production Research	18
International Journal of Production Economics	15
Production Planning and Control	9
Computers in Industry	5
European Journal of Operational Research	3
International Journal of Operations & Production Management	3
IFIP International Conference on Advances in Production Management Systems	3
OR Spectrum	2
Other	17
Total	75

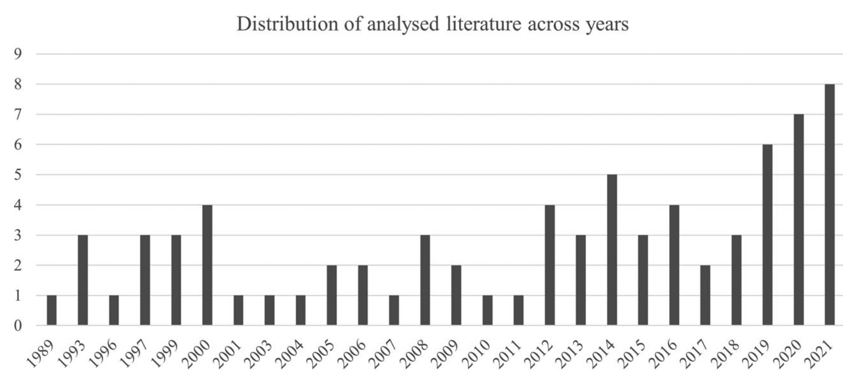

Figure A1. Distribution of papers across years.

Table A2. Overview of the contributions of the analysed literature in addressing the research question.

Reference	Planning activities				Information flow or input				Type of contribution
	Sales	Engineering	Procurement	Production	Strategic	External	Operational	C/F	
Kingsman, Tatsiopoulos, and Hendry (1989)	4.1.3							Sa12	E
Adam et al. (1993)				4.4.2			Pd7		I
Bertrand and Muntslag (1993)	4.1.3	4.2.2, 4.2.3		4.4.1, 4.4.3					E/I
Kingsman et al. (1993)	4.1.3		4.3.3	4.4.3	Sa1, Sa2				E/I
Kingsman et al. (1996)	4.1.1, 4.1.3	4.2.1, 4.2.2	4.3.1	4.4.1, 4.4.3	Sa1, Sa2, Sa3	Sa4, Sa5	Sa7, Pd8	Sa8, Sa12, Sa13	E/I
Cassaigne et al. (1997)	4.1.1, 4.1.3				Sa2	Sa5			I
De Boer, Schutten, and Zijm (1997)				4.4.1, 4.4.2			Pd6, Pd7	Pd10	E/I
Kingsman and Mercer (1997)	4.1.3				Sa1, Sa2				E/I
Amaro, Hendry, and Kingsman (1999)	4.1.1, 4.1.3	4.2.2			Sa1, Sa2, Sa3, En1				I
Easton and Moodie (1999)	4.1.3								E
Park et al. (1999)				4.4.2, 4.4.3	Pd2		Pd7		E
Hicks and Braiden (2000)				4.4.2				Pd12	E
Hicks, McGovern, and Earl (2000)	4.1.1		4.3.1, 4.3.2, 4.3.3		Sa3, Pc1, Pc3, Pc4, En2, En3, Pd4	Sa5, Pc5, Pc6, Pc7	Pc8	Pc10, Pc12	E/I
Ruben and Mahmoodi (2000)				4.4.1, 4.4.2	Pd2		Pd7		E
Zijm (2000)		4.2.1, 4.2.3, 4.2.4		4.4.2, 4.4.3					E
Hicks, McGovern, and Earl (2001)			4.3.2	4.4.1	Pc3, Pd4				I
Calosso et al. (2003)	4.1.3		4.3.3		Sa2	Pc6			I
Wullink et al. (2004)				4.4.2, 4.4.3	Pd2	Pd5			E
Ebben, Hans, and Weghuis (2005)				4.4.1	Pd1, Pd2				I
Wikner and Rudberg (2005)				4.4.2				Pd11	I
Dekkers (2006)		4.2.2			En1				I
Robinson and Moses (2006)				4.4.1	Pd1, Pd2				I
Hans et al. (2007)	4.1.2, 4.1.3	4.2.3		4.4.1, 4.4.2					I
Ebadian et al. (2008)	4.1.2, 4.1.3		4.3.2, 4.3.3	4.4.2, 4.4.3	Sa3, Pc2, Pd2	Sa5, Pd5	Pd7	Sa10, Sa11, Sa12, Sa13, Pd12	E/I
Zorzini, Corti, and Pozzetti (2008a)	4.1.3			4.4.1, 4.4.2, 4.4.3	Sa2, Pd1, Pd2		Pd7		E
Zorzini et al. (2008b)	4.1.1	4.2.1	4.3.1, 4.3.2, 4.3.3	4.4.1, 4.4.2		En5, Pc6	Pd6		I
Ebadian et al. (2009)	4.1.2, 4.1.3				Sa3	Sa5		Sa12, Sa13	E
Gosling and Naim (2009)		4.2.1, 4.2.2			En1				I
Olhager (2010)			4.3.3		Pc4				I
Alfieri, Tolio, and Urgo (2011)				4.4.1, 4.4.2	Pd1, Pd2		Pd6, Pd7	Pd10	E/I
Alfieri, Tolio, and Urgo (2012)				4.4.2	Pd1, Pd2		Pd6, Pd7	Pd10	E/I

(*continued*).

Table A2. Continued.

Reference	Planning activities				Information flow or input				Type of contribution
	Sales	Engineering	Procurement	Production	Strategic	External	Operational	C/F	
Aslan, Stevenson, and Hendry (2012)	4.1.3								E
Thürer et al. (2012)				4.4.2	Pd2		Pd7		E
Zorzini, Stevenson, and Hendry (2012)	4.1.3		4.3.1, 4.3.2, 4.3.3	4.4.2	Pc1	Pc6, Pc7	Pc8, Pc9	Sa11, Pc10, Pc11, Pd12	E/I
Dekkers, Chang, and Kreutzfeldt (2013)			4.3.2, 4.3.3		Pc1			Pc10	I
Grabenstetter and Usher (2013)	4.1.3	4.2.1, 4.2.2, 4.2.3			En1, En2		En7, En8	Sa10, En11	E/I
Shishank and Dekkers (2013)			4.3.2, 4.3.3		Pc1	Pc6, Pc7	Pc8, Pc9	Pc10	E/I
Emblemsvåg (2014)			4.3.1					Pc10, Pc11	I
Grabenstetter and Usher (2014)	4.1.3	4.2.1, 4.2.2, 4.2.3			En1, En2		En7, En8	Sa10, En11	E/I
Saghiri and Hill (2014)			4.3.2		Pc3				E/I
Semini et al. (2014)		4.2.2			En1				I
Yang and Fung (2014)				4.4.2	Pd3				I
Adrodegari et al. (2015)	4.1.1, 4.1.2, 4.1.3	4.2.1, 4.2.2, 4.2.3		4.4.1, 4.4.2, 4.4.3	Sa1, Sa2, Sa3, En2, Pd1, Pd2	Sa4, Sa5	Sa6, Sa7, Pd8	Sa8, Sa9, En11, Pd10	E/I
Aslan, Stevenson, and Hendry (2015)	4.1.3	4.2.4		4.4.1	En4, Pd1, Pd2				E/I
Carvalho, Oliveira, and Scavarda (2015)	4.1.3			4.4.1, 4.4.2, 4.4.3	Pd2	Pd5	Pd6, Pd7, Pd9	Sa12, Sa13	E
Carvalho, Oliveira, and Scavarda (2016)				4.4.1, 4.4.2, 4.4.3	Pd2	Pd5	Pd6, Pd7, Pd9		E
Shlopak, Rød, and Oterhals (2016)			4.3.1, 4.3.2		Pc3		Pc8, Pc9		I
Ulonska and Welo (2016)		4.2.1			En2				E
Willner, Gosling, and Schönsleben (2016a)	4.1.3	4.2.1			En1, En2			Sa10, En11	E
Gosling, Hewlett, and Naim (2017)		4.2.2, 4.2.4			En1, En4				I
Mello et al. (2017)			4.3.2, 4.3.3			Pc6, Pc7			I
Cannas et al. (2018)		4.2.3			En1, En2			En11	E
Nam et al. (2018)		4.2.1		4.4.1				En11, Pd10	E/I
Sylla et al. (2018)	4.1.3	4.2.1			En2	Sa5		En11	E
Alfnes and Hvolby (2019)	4.1.3	4.2.1	4.3.1, 4.3.2	4.4.1, 4.4.2	En2, Pd2	Sa5, Pc6	Pd7	Sa11, Sa12, Pc10, Pd10	E
Barbosa and Azevedo (2019)	4.1.3	4.2.3		4.4.2	Sa1, En1, En2, Pd2	Sa4, Sa5	En8, En9, Pd7		E/I

(*continued*).

Table A2. Continued.

Reference	Planning activities				Information flow or input				Type of contribution
	Sales	Engineering	Procurement	Production	Strategic	External	Operational	C/F	
Cannas et al. (2019)		4.2.1, 4.2.2			En1, En2, En3				I
Johnsen and Hvam (2019)		4.2.2			Sa5, En1			En11	I
Reid, Bamford, and Ismail (2019)			4.3.2		Pc2				E
Zennaro et al. (2019)	4.1.3			4.4.2					E
Cannas et al. (2020)	4.1.1	4.2.1, 4.2.2, 4.2.4			Sa1, Sa2, Sa3, En1, En2				I
Fang and Wei (2020)		4.2.1			En1, En2, En3				I
Oluyisola, Sgarbossa, and Strandhagen (2020)		4.2.1			En3				I
Sabri, Micheli, and Cagno (2020)			4.3.1, 4.3.2		Pc1, Pc2, Pc3, Pc4		Pc8, Pc9		I
Shurrab, Jonsson, and Johansson (2020b)	4.1.1, 4.1.2	4.2.1, 4.2.4	4.3.2, 4.3.3		Sa2, Sa3, En4, Pc2, Pc3	Sa4, Sa5, En5	En8		E/I
Shurrab, Jonsson, and Johansson (2020a)	4.1.3	4.2.1, 4.2.3, 4.2.4	4.3.2, 4.3.3	4.4.1, 4.4.2, 4.4.3	Sa1, Sa2, En1, Pc1, Pd1, Pd2		Sa6, En8, En9, Pc8, Pc9, Pd7		E/I
Strandhagen et al. (2020)		4.2.1			En3				I
Alfnes et al. (2021)	4.1.3	4.2.1, 4.2.3, 4.2.4	4.3.1, 4.3.2, 4.3.3	4.4.1, 4.4.2	En1, En2, En4, Pc1	Sa5, En5, En6, Pc6	En8, En9, Pc8	Sa10, Sa11, Sa12, En11	E/I
Brachmann and Kolisch (2021)		4.2.3, 4.2.4			En4		En8, En9, En10		E
Burggraf et al. (2021)				4.4.2			Pd7		I
Eyers et al. (2021)				4.4.1	Pd1				I
Ghiyasinasab et al. (2021)		4.2.3, 4.2.4		4.4.2, 4.4.3	Pd2	Pd5	En8, En9, En10, Pd7, Pd9		E
Micale et al. (2021)				4.4.2	Pd2		Pd7		E
Mwesiumo, Nujen, and Kvadsheim (2021)			4.3.1, 4.3.2		Pc2				I
Zheng et al. (2021)		4.2.1			En3				I

Planning activities and information inputs

4.1.1: Selecting customer enquiries; **4.1.2**: Prioritising customer enquiries; **4.1.3**: Responding to customer enquiries; **4.2.1**: Defining preliminary product specifications; **4.2.2**: Determining detailed engineering activities and resources; **4.2.3**: Estimating lead times and costs and setting due dates; **4.2.4**: Identifying needs for external capabilities and additional capacity; **4.3.1**: Identifying critical items; **4.3.2**: Selecting potential suppliers; **4.3.3**: Determining procurement lead times and prices; **4.4.1**: Identifying the main production activities and resource requirements; **4.4.2**: Identifying feasible production start and end dates; **4.4.3**: Estimating production costs and non-regular capacity requirements.

Sales planning inputs – **Sa1**: Market segmentation; **Sa2**: Order-winning criteria; **Sa3**: Competitive priorities; **Sa4**: Sales leads, requests-for-proposals, customer enquiries, etc.; **Sa5**: Customers' technical and commercial requirements; **Sa6**: Customers' order history; **Sa7**: Requirement and specification data for completed orders; **Sa8**: Preliminary product specifications; **Sa9**: Required detailed design and engineering activities; **Sa10**: Estimated engineering lead time; **Sa11**: Procurement lead times and costs; **Sa12**: Production start and completion dates; **Sa13**: Overtime and subcontracting needs and production costs.

Engineering planning inputs – **En1**: Product customisation and standardisation strategy; **En2**: Existing portfolio of product design and specifications; **En3**: New product technology; **En4**: In-house engineering capabilities; **En5**: Clarification of customer's technical requirements; **En6**: Feedback for preliminary features and specifications; **En7**: Durations and cost data from completed projects; **En8**: Capacity of engineering personnel; **En9**: Statuses of ongoing projects; **En10**: Costs of regular and overtime engineering capacity; **En11**: Customer requirements.

Procurement planning inputs – **Pc1**: Offshoring and sourcing strategy; **Pc2**: Approved supplier list; **Pc3**: Strategic suppliers; **Pc4**: Supplier agreements for lead times and prices; **Pc5**: Customer's preferred supplier(s); **Pc6**: Supplier's quoted lead time; **Pc7**: Supplier's quoted price; **Pc8**: Historical lead times for suppliers; **Pc9**: Historical purchasing costs for items; **Pc10**: Preliminary product specifications; **Pc11**: Required detailed design and engineering activities; **Pc12**: Estimated engineering lead time.

Production planning inputs – **Pd1**: Production technology; **Pd2**: Production capacity; **Pd3**: Production facility locations; **Pd4**: Vertical integration strategy; **Pd5**: Subcontracting costs; **Pd6**: Existing bill-of-materials and routing for similar products; **Pd7**: Production status of ongoing projects; **Pd8**: Production cost data for completed projects; **Pd9**: Regular and overtime production capacity costs; **Pd10**: Preliminary product specifications; **Pd11**: Estimated engineering lead time; **Pd12**: Procurement lead times.