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Swapnil Bhalla

Sales and Operations Planning for Delivery Date Setting in Engineer-to-Order Manufacturing

Doctoral thesis

NTNU
Norwegian University of Science and Technology
Thesis for the Degree of Philosophiae Doctor
Faculty of Engineering
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Summary

Engineer-to-Order (ETO) production entails designing or redesigning, engineering, fabricating, and assembling products for specific customer orders. Companies manufacturing big-sized, high-value, and heavy-duty industrial products such as machine tools, power generation equipment, agricultural machinery, maritime equipment, etc., are perhaps the largest group of adopters of the ETO strategy (Adrodegari et al. 2015; Cannas and Gosling 2021; Gosling and Naim 2009; Zennaro et al. 2019). Adopting the ETO strategy allows these companies to deliver highly customized, technologically competitive, and innovative solutions to fulfill specific customer requirements (Hicks, McGovern, and Earl 2000). However, operating with the ETO strategy also introduces significant complexity and uncertainty to planning tasks in these contexts (Alfieri, Tolio, and Urgo 2012; Alfnes et al. 2021; Carvalho, Oliveira, and Scavarda 2016; Shurrab, Jonsson, and Johansson 2020b).

Due to customer-specific design, engineering, procurement, and production activities, the duration of the order-fulfillment process, i.e., delivery lead time, is typically long in ETO contexts. Estimating these long delivery lead times is a complex planning task since there is a wide range of factors influencing the lead times for different order-fulfillment activities. Furthermore, product and process specifications are often uncertain until the late stages of the order-fulfillment process in ETO contexts because of customer-specific design and engineering activities, further adding to the challenges of estimating the delivery lead times. While it is challenging to plan, estimate, and quote reliable delivery lead times in ETO contexts, the reliability of the quoted lead times is a critical factor for ETO companies in maintaining their delivery precision and competitiveness (Amaro, Hendry, and Kingsman 1999; Cannas et al. 2020; Grabenstetter and Usher 2014; Hicks, McGovern, and Earl 2000). The planning task of estimating these lead times and order delivery dates, known as delivery date setting, has motivated numerous academic studies over the past decades. However, ETO companies still struggle with effectively setting delivery dates while tendering for new customer orders.

The extant research on delivery date setting suggests that cross-functional coordination, i.e., coordination across functions such as sales, engineering, procurement, production, etc., positively influences the effectiveness of ETO companies' delivery date setting process (Shurrab, Jonsson, and Johansson 2020a, 2020b; Zorzini, Corti, and Pozzetti 2008; Zorzini et al. 2008; Zorzini, Stevenson, and Hendry 2012). The planning concept known as Sales and

Operations Planning (S&OP) is a widely advocated approach for improving cross-functional coordination and overcoming functional silos in planning processes. S&OP has been effective in various non-ETO production contexts (Kristensen and Jonsson 2018; Thomé et al. 2012b; Tuomikangas and Kaipia 2014). However, the application of S&OP for cross-functionally coordinated planning in ETO contexts has not been explored previously, and recent reviews on S&OP call for studies to fill this gap (Kreuter et al. 2022; Kristensen and Jonsson 2018). Motivated by the need for (1) improving cross-functional coordination in delivery date setting and (2) exploring S&OP applications in ETO contexts, this doctoral study has investigated *how ETO manufacturers can design their S&OP process for effectively quoting delivery dates*. To this end, the study has addressed three main research questions using case studies from the maritime equipment manufacturing industry and two systematic reviews of the existing literature.

RQ1: *How do the characteristics of an engineer-to-order manufacturer influence the design requirements for sales and operations planning?*

The first research question aimed to understand how S&OP design requirements are influenced by an ETO manufacturer's contextual characteristics. This question was answered through a single case study of a maritime equipment supplier, with some additional insights from a systematic literature review. The findings indicate that the influence of ETO environments' contextual characteristics on S&OP design requirements is significant and complex. Long product delivery lead times and order-driven engineering, procurement, and production activities imply that S&OP design requirements in ETO contexts starkly differ from the S&OP process designs traditionally advocated and implemented in mass production contexts, where S&OP primarily addresses forecast-driven production and inventory planning for product families. Low production volumes and long delivery lead times impose that S&OP should be order-driven. Various order-specific activities and parallel or simultaneous execution of order-fulfillment activities for various orders impose that S&OP is performed with a multi-project perspective with material availability constraints and capacity constraints from production and engineering resources. Diverse and highly specialized production resources impose higher levels of detail and granularity in planning capacity for production resources. The results from the case study highlight that delivery date setting is one of the main tactical planning tasks S&OP should support in ETO contexts. A synthesis of previous research provides various factors influencing coordination needs for delivery date setting in the S&OP process, e.g., product complexity, degree of customization, contextual uncertainty, etc., that managers must consider while designing their S&OP process.

RQ2: *What are the available tools, methods, and frameworks for setting delivery dates within sales and operations planning in engineer-to-order manufacturing?*

The second research question aimed to map the state of the art of the artifacts supporting delivery date setting in ETO contexts. This question was addressed through a systematic literature review on delivery date setting. The review shows that most of the contributions in the extant research have focused on developing planning and decision-support tools, e.g., optimization models, mathematical models, planning heuristics, etc. However, most of these contributions have focused on estimating production lead times, while the estimation of procurement and engineering lead times have been overlooked. The extant literature also provides some frameworks for guiding planning process design. However, these do not address the cross-functional planning needs of ETO contexts since most of these frameworks are based on make-to-order production contexts. The review reveals the need for developing process reference frameworks for delivery date setting as one of the items on the agenda for future research, motivating the final research question of this study.

RQ3: *What are the main sales and operations planning activities and information flows for delivery date setting in engineer-to-order contexts?*

The third research question aimed to identify the main cross-functional planning activities and information flow that should be considered in ETO manufacturing companies while designing the S&OP process for setting delivery dates. This question was addressed by systematically reviewing the literature on planning in ETO contexts. The review identifies 13 main S&OP activities for delivery date setting in ETO contexts clustered under the broad S&OP subprocesses of sales planning, engineering planning, procurement planning, and production planning. Sales planning selects and prioritizes customer enquiries and coordinates with different functions to formulate a response for the potential customer. Engineering planning defines the product’s preliminary specifications and assesses the complexity, workload, and duration of the detailed engineering activities required after order confirmation. Procurement planning identifies critical suppliers and subcontractors and the time required for procuring items from these actors. Production planning assesses the workload and duration of the production activities. The review identifies various information flows associated with each

S&OP activity, such that each information flow provides a set of planning inputs for a particular planning activity. The planning activities and information flows are synthesized into an S&OP framework for delivery date setting in ETO contexts. The proposed framework can support practitioners in mapping, analyzing, and designing or redesigning their delivery date setting process with an emphasis on cross-functional coordination, which previous empirical studies have found to improve the effectiveness of delivery date setting. Two case studies of maritime equipment suppliers are presented to illustrate the framework's application for mapping and analyzing planning activities in the delivery date setting process. The granularity of the framework is expected to enable practitioners to assess the relevance of specific planning activities and information flows for their particular contexts.

The findings of the doctoral study (1) highlight the significance and complexity of the influence of ETO environments' contextual characteristics on S&OP design requirements and underline how S&OP requirements in ETO contexts differ from other production contexts; (2) provide the state of the art of artifacts supporting delivery date setting at the S&OP level in ETO contexts and highlight the various knowledge gaps that should be addressed to improve state of the art and better support the planning task in practice; (3) emphasize the need for planning frameworks to guide the design of the S&OP process for delivery date setting; (4) present the main planning activities and information flows that managers in ETO companies should consider while designing their S&OP process for delivery date setting; (5) highlight how the required planning activities and information flows may vary across ETO contexts.

While many ETO companies, in practice, commit to delivery dates without planning the resources and capacity required to meet those delivery promises, the thesis argues that planning is essential for ensuring that promised delivery dates are feasible to meet. While order-promising without planning may occasionally be necessary for winning orders in low-demand markets, managers in ETO contexts must not accept this as the standard operating procedure to avoid overtime, subcontracting, and delay penalty costs in high-demand periods. To this end, the S&OP framework proposed by this doctoral study can aid ETO companies in systematically designing their delivery date setting and tendering process.

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I have been surrounded by some wonderful people over the last four years who have supported me in different ways in completing this doctoral work. This dissertation would be incomplete without expressing my gratitude to them, and this note is dedicated to just that.

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Trondheim, December 2022

Swapnil Bhalla

List of Appended Papers and Declaration of Authorship

Paper	Title	Declaration of Authorship
1	Bhalla, Swapnil, Erlend Alfnes, Hans-Henrik Hvolby, and Olumide Emmanuel Oluyisola. 2021. "Requirements for Sales and Operations Planning in an Engineer-to-Order Manufacturing Environment." In *Advances in Production Management Systems. Artificial Intelligence for Sustainable and Resilient Production Systems*, edited by Alexandre Dolgui, Alain Bernard, David Lemoine, Gregor von Cieminski and David Romero, 371-80. Cham: Springer. doi: https://doi.org/10.1007/978-3-030-85910-7_39.	Bhalla conceptualized the paper and collected the data with Alfnes. Bhalla wrote the paper with feedback from Alfnes, Hvolby, and Oluyisola.
2	Bhalla, Swapnil, Erlend Alfnes, and Hans-Henrik Hvolby. 2022. "Tools and practices for tactical delivery date setting in engineer-to-order environments: a systematic literature review." *International Journal of Production Research*:1-33. doi: https://doi.org/10.1080/00207543.2022.2057256.	Bhalla conceptualized the paper and conducted the review. Bhalla wrote the paper with feedback from Alfnes, and Hvolby.
3	Bhalla, Swapnil, Erlend Alfnes, Hans-Henrik Hvolby, and Olumide Emmanuel Oluyisola. 2022. "Sales and operations planning for delivery date setting in engineer-to-order manufacturing: a research synthesis and framework." *International Journal of Production Research*:1-31. doi: https://doi.org/10.1080/00207543.2022.2148010.	Bhalla conceptualized the paper and conducted the review. Bhalla wrote the paper with feedback from Alfnes, Hvolby, and Oluyisola.
4	Bhalla, Swapnil, Erlend Alfnes, and Hans-Henrik Hvolby. 2022a. "Sales and Operations Planning for Delivery Date Setting in Engineer-to-Order Maritime Equipment Manufacturing: Insights from Two Case Studies." In *Advances in Production Management Systems. Smart Manufacturing and Logistics Systems: Turning Ideas into Action*, edited by Duck Young Kim, Gregor von Cieminski and David Romero, 321-8. Cham: Springer. doi: https://doi.org/10.1007/978-3-031-16411-8_38.	Bhalla conceptualized the paper and collected the data. Bhalla wrote the paper with feedback from Alfnes, and Hvolby.

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1 Introduction

This chapter provides the industrial background and research motivation for this doctoral study of sales and operations planning for delivery date setting in engineer-to-order manufacturing, presents the study's research aim and research questions, clarifies the scope of the study, and outlines the overall structure of this dissertation.

1.1 Industrial Background

Maritime equipment suppliers, i.e., companies designing, developing, and producing equipment for ships and other floating entities, are an essential part of global maritime supply chains and are among the largest contributors to economic activity and employment in Norway (Haugland, Abrahamoglu, and Jakobsen 2021; Mellbye, Helseth, and Jakobsen 2017). These companies have historically operated with high profits. However, they have experienced a significant decline in operating profits and overall demand for equipment following the dramatic impacts of the oil price-crash in 2014-15 on the global shipbuilding industry (Haugland, Abrahamoglu, and Jakobsen 2021; Organisation for Economic Co-operation and Development (OECD) 2018; Steidl and Yildiran 2017; Strandhagen et al. 2020). Adding to their challenges, Norwegian maritime equipment suppliers also face fierce competition from equipment suppliers from countries with lower labor costs (Haugland, Abrahamoglu, and Jakobsen 2021).

While these changes affecting the Norwegian equipment suppliers continue to depend on the overall maritime industry, they pose substantial pressure on these equipment suppliers to be effective and efficient in maintaining or improving the profitability and competitiveness of their operations (Haugland, Abrahamoglu, and Jakobsen 2021; Helseth, Mellbye, and Jakobsen 2018). The need for effective and efficient operations under various exogenous challenges has placed planning and control at the center of the managerial focus of maritime equipment suppliers since effective planning and control "can contribute to competitive performance by lowering costs and providing greater responsiveness to the market" (Jacobs et al. 2011, 12).

Planning and control collectively refer to "closed-loop processes that determine the need for material and capacity to address expected demand, execute the resulting plans, and update planning and financial information to reflect the results of execution" (APICS 2011). For manufacturing contexts such as maritime equipment production, this entails “planning and controlling all aspects of manufacturing, including managing materials, scheduling machines and people, and coordinating suppliers and key customers” (Jacobs et al. 2011, 1). Decisions and activities within manufacturing planning and control are often classified hierarchically into three levels – *strategic, tactical*, and *operational* (Anthony 1965; APICS 2011; Pereira, Oliveira, and Carravilla 2020; Stevenson 2015), where these levels differ in terms of their:

- planning horizons: long range (e.g., some years), medium range (e.g., a few months to more than a year), and short range (e.g., a day to a few weeks).
- decision scope: enterprise-wide, multi-functional or cross-functional, and function or department-specific.
- organizational level: executive or top-management level, middle-management level, and supervisory or execution or operative level.

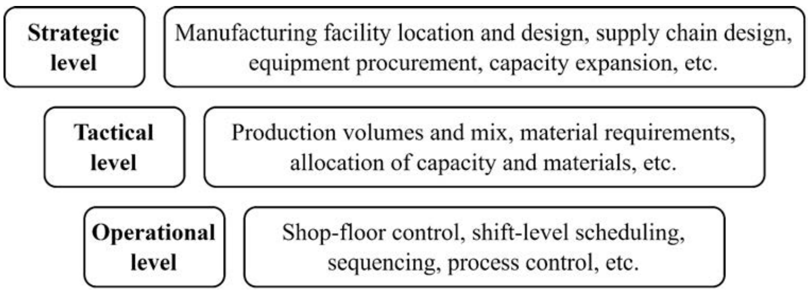


Figure 1.1 Typical activities at the hierarchical levels of manufacturing planning & control (Beckman and Rosenfield 2008; Jacobs et al. 2011; Stevenson 2015)

Figure 1.1 shows typical manufacturing planning and control decisions and activities at the three levels in the hierarchical framework. The strategic level concerns long-term executive decisions that set a manufacturing enterprise's overall competitive priorities and performance objectives and the structural and infrastructural design decisions that identify the resources and capabilities required to meet those objectives (Beckman and Rosenfield 2008; Jacobs et al. 2011). The tactical level concerns medium-range planning tasks that develop plans for matching supply and demand in terms of volume and product mix, identifying the quantities and timing of material and capacity requirements for meeting expected or confirmed customer demand (Jacobs et al. 2011, 2-3; Pereira, Oliveira, and Carravilla 2020). Strategic performance objectives act as performance measures or planning objectives for tactical-level planning tasks executed within the constraints set by structural and infrastructural decisions at the strategic level. Tactical-level plans, in turn, set the targets and constraints for operational-level activities concerned with monitoring or controlling the day-to-day execution of production and procurement activities such as work-center or machine-specific scheduling and sequencing of jobs, follow-up of procured raw-materials and components, etc. Therefore, tactical-level planning is the link between the day-to-day operations of a manufacturing enterprise and its long-term operations strategy (Grimson and Pyke 2007; Kreuter et al. 2022; Pereira, Oliveira, and Carravilla 2020). Under a given context of operations strategy, tactical planning activities act as the managerial lever for maximizing the supply-demand balance and competitiveness (Feng, D'Amours, and Beauregard 2008; Kristensen and Jonsson 2018; Tuomikangas and Kaipia 2014).

For maritime equipment manufacturers, one of the most challenging tactical-level planning tasks is estimating lead times and quoting delivery dates while tendering for new customer orders. Maritime equipment, such as engines, power generators, propulsion and maneuvering systems, lifting systems, etc., are complex, high-value electromechanical products. These are typically customized and produced to fulfill specific customers' requirements in relatively low volumes instead of being mass-produced with standardized product configurations (Alfnes et al. 2021; Zennaro et al. 2019). The order-fulfillment process for maritime equipment includes customer-specific design and engineering activities to address product customization based on customer requirements. Most detailed engineering activities are performed after order confirmation, and the scope and complexity of these activities are usually uncertain during the tendering phase (Alfnes et al. 2021; Haugland, Abrahamoglu, and Jakobsen 2021). Many of the components and sub-assemblies for maritime equipment are sourced from sub-suppliers and may require order-specific procurement due to customized specifications, high inventory-related costs, etc. (Mwesiumo, Nujen, and Kvadsheim 2021; Oluyisola, Salmi, and Strandhagen 2018). Consequently, the lead times for procuring some components from sub-suppliers are uncertain in the tendering phase. Furthermore, the production process's specifications, workload, and duration are also uncertain at this stage (Alfnes et al. 2021). Therefore, effectively estimating delivery lead times and setting delivery dates for new orders, which is an inherently complex task because of the various order-fulfillment activities to be considered, is made further challenging because of the uncertainties in the durations of these activities. The *effectiveness* of the delivery date setting can be measured in terms of three main performance indicators – the average delay in delivery of orders relative to the delivery lead time; the percentage or fraction of delayed orders; and the percentage or fraction of tenders that lead to confirmed orders, also known as the strike rate (Zorzini et al. 2008). Quoting too short delivery lead times can lead to delayed orders and poor delivery precision, or higher costs may be incurred to ensure timely deliveries. On the other hand, quoting delivery lead times that are too long can lead to uncompetitive quotes, which may negatively influence the likelihood of winning an order.

This doctoral study was initiated as part of *RESPONS*, an industrial innovation project financed by the Research Council of Norway. Innovation projects for the industrial sector (*innovasjonsprosjekt i næringslivet* – IPN), such as *RESPONS*, are company-led research and development projects that create new knowledge or insights leading to value creation for the participating companies in the form of new or improved products, services, or production processes (The Research Council of Norway 2021, 2022). The *RESPONS* project focused on developing knowledge to improve planning processes and was led by a globally known and successful supplier of customized maritime propulsion and maneuvering equipment. Quoting delivery dates while tendering for new orders was reported as a planning challenge by the company's executives during the early stages of the project, emphasizing the lack of appropriate planning functionality for capacity planning. Furthermore, there was no clear structure in the company's planning and decision-making process for setting delivery dates. The reported challenges were also evident in the production and order data from the company's enterprise planning system, which revealed that the delivery lead times varied significantly over time and across customer orders, even for orders with similar types and sizes of equipment. These observations, coupled with similar challenges reported in the literature from other industrial contexts producing complex and customized products described in 1.2, served as the motivation for pursuing delivery date setting as the main research topic of this doctoral study.

1.2 Research Motivation

The manufacturing strategy of producing order-specific customized products, widely known as the Engineer-to-Order (ETO) strategy, is not unique to the maritime industry. The ETO strategy has been adopted in other sectors producing heavy-duty and high-value products such as machine tools, power generation equipment, agricultural machinery, etc. (Adrodegari et al. 2015; Cannas and Gosling 2021; Gosling and Naim 2009; Zennaro et al. 2019). Similar to maritime equipment suppliers, other industrial contexts adopting the ETO strategy also report challenges related to the planning complexity and uncertainty characterizing the task of setting delivery dates. Delivery date setting entails (1) identifying delivery dates quoted or promised to customers, e.g., in tendering, bidding, responding to customer enquiries or requests-for-proposal (RFPs), etc.; or (2) assessing the feasibility of meeting delivery dates imposed by customers (Carvalho, Oliveira, and Scavarda 2015; Hicks, McGovern, and Earl 2000; Zorzini, Stevenson, and Hendry 2012). Due to its competitive importance in winning orders, and the industrial challenges related to it, the task of setting delivery dates in ETO contexts has attracted substantial research attention in the extant literature with various types of contributions from researchers, e.g., multi-case studies of delivery date setting practices in different industry sectors (Shurrab, Jonsson, and Johansson 2020a; Zorzini, Corti, and Pozzetti 2008; Zorzini et al. 2008; Zorzini, Stevenson, and Hendry 2012), process frameworks to formalize parts of the tactical planning process for setting delivery dates (Adrodegari et al. 2015; Kingsman 2000; Kingsman et al. 1996), decision-support tools for tactical planning activities for setting delivery dates (Carvalho, Oliveira, and Scavarda 2015, 2016; Ghiyasinasab et al. 2021; Grabenstetter and Usher 2014), etc.

One of the valuable contributions of previous research is the finding that formalized and coordinated planning across different functions and upstream supply chain actors are best practices for managing the planning complexity and uncertainty of setting delivery dates in ETO contexts (Zorzini et al. 2008; Zorzini, Stevenson, and Hendry 2012). The order-fulfillment process in ETO contexts includes order-specific engineering, procurement, and production activities. As a result, factors influencing the duration of these activities also affect the overall delivery lead time for customer orders, e.g., scope and complexity of engineering activities (Grabenstetter and Usher 2013, 2014), customization requirements for procured components and geographical distances for suppliers (Alfnes et al. 2021; Hicks, McGovern, and Earl 2000; Zorzini, Stevenson, and Hendry 2012), available production capacity (Carvalho, Oliveira, and Scavarda 2015, 2016), etc. Furthermore, many of these factors are uncertain in the tendering phase (Alfieri, Tolio, and Urgo 2012; Alfnes et al. 2021; Hans et al. 2007), and expert managerial estimates of various factors and lead times play an essential role in setting delivery dates (Hicks, McGovern, and Earl 2000). Since these factors concern the activities of different functions – the information, expertise, and tacit knowledge of managers required for estimating these factors are scattered across these functions and in the upstream supply chain for critical procured items. Therefore, coordinated planning across functions and critical suppliers facilitates utilizing all available and relevant information and expertise in the planning process. Furthermore, under the multitude of factors influencing delivery lead times, formalizing the planning process for setting delivery dates systematizes that the factors or constraints relevant to estimating delivery lead times are considered. Formalizing the planning process may entail making the process explicit by establishing, e.g., predefined procedures, decision rules, roles and responsibilities of the actors involved, information and activity flows among the different actors, etc.

The performance benefits of cross-functional coordination are not limited to ETO manufacturing contexts and improving the effectiveness of delivery date setting. Thomé, Sousa, and Scavarda do Carmo (2014) highlight that several studies have documented the positive influence of cross-functional coordination on firms' performance since Lawrence and Lorsch (1969) defined the main concepts for analyzing this effect more than 50 years ago. The industrial contexts of these studies include a variety of manufacturing firms with a wide range of characteristics (Parente, Pegels, and Suresh 2002; Stank, Daugherty, and Ellinger 1999; Thomé et al. 2012a; Thomé, Sousa, and Scavarda do Carmo 2014). In many of these instances, companies achieved cross-functional coordination in tactical planning using sales and operations planning (S&OP), which is a widely known approach for coordinated tactical planning across functions and suppliers (Kreuter et al. 2022; Kristensen and Jonsson 2018; Pereira, Oliveira, and Carravilla 2020; Thomé et al. 2012b). S&OP focuses on balancing supply and demand at the tactical planning level by breaking down functional planning silos and integrating planning objectives across functions to minimize the negative impacts of function-specific planning with mutually conflicting objectives (Jonsson, Kaipia, and Barratt 2021; Oliva and Watson 2011; Stentoft, Freytag, and Mikkelsen 2020).

The benefits of cross-functional planning using S&OP have been widely advocated with supporting evidence in various academic and practitioner journals (Thomé et al. 2012b; Tuomikangas and Kaipia 2014). However, findings from recent literature reviews on S&OP (Kreuter et al. 2022; Kristensen and Jonsson 2018) indicate the weakness of the existing research on the topic for ETO contexts, as also pointed out by Shurrab, Jonsson, and Johansson (2020b). In their study focusing on context-based S&OP design, Kristensen and Jonsson (2018) find no research on how the characteristics of ETO contexts influence the design of the S&OP process. Kreuter et al. (2022) further corroborate this, highlighting that the application of S&OP for cross-functional tactical planning in ETO contexts appears "particularly suitable" due to high planning complexity; however, no studies in the extant literature have explored the application of S&OP in ETO contexts. Given the challenges of estimating lead times and delivery dates in ETO contexts, it is interesting to explore how the S&OP process can be designed to facilitate cross-functional planning and effective delivery date setting. For planning processes to be effective in a context, it is essential to design the processes to fit the contextual characteristics and planning needs, as highlighted by numerous contingency theory on planning and control (Buer et al. 2018; Ivert et al. 2015; Kreuter et al. 2021; Kristensen and Jonsson 2018; Stevenson, Hendry, and Kingsman 2005). Therefore, the potential to improve the effectiveness of delivery date setting using S&OP in ETO contexts serves as the main motivation for this research.

1.3 Research aim and questions

Motivated by the industrial challenges of maritime equipment manufacturers and the research gaps highlighted in the literature, this doctoral research investigates how S&OP can be designed for effective delivery date setting in ETO contexts. The overall aim of the study is to:

Create knowledge on how engineer-to-order manufacturers can design their sales and operations planning process for effectively quoting delivery dates.

Based on this overall aim, three main research questions have guided the design of this doctoral research. These are presented and briefly described below.

RQ1*: How do the characteristics of an engineer-to-order manufacturer influence the design requirements for sales and operations planning?*

The first research question aims to understand how the design requirements for S&OP are influenced by the contextual characteristics of an ETO manufacturer. As highlighted earlier, this is a research gap due to the lack of S&OP research in ETO contexts. Understanding how an ETO manufacturer's planning environment affects S&OP design is essential for understanding how S&OP can facilitate effective delivery date setting in ETO contexts.

RQ2*: What are the available tools, methods, and frameworks for setting delivery dates within sales and operations planning in engineer-to-order manufacturing?*

The second research question aims to map the current state of the art of delivery date setting in ETO contexts by identifying and analyzing the knowledge and artifacts developed by the extant research on the topic. Since this doctoral research aims to develop knowledge for improving the effectiveness of delivery date setting in ETO contexts, it is essential to map the current state of the art to establish and concretize the research needs in this area and position the contributions of this doctoral study to the extant research. The answers to this research question further justified the need for exploring the use of S&OP for setting delivery dates and led to the formulation of the third research question.

RQ3*: What are the main sales and operations planning activities and information flows for delivery date setting in engineer-to-order contexts?*

The third and final research question aims to identify the main cross-functional planning activities and information flows that should be considered in ETO manufacturing companies while designing the S&OP process for setting delivery dates. The findings for this research question result in a reference framework that can be used as managerial design decision-support in ETO companies – for designing their S&OP process or reassessing the design of their existing planning process for setting delivery dates for new customer orders.

1.4 Research scope

This doctoral research is positioned within operations management, which focuses on "the systematic direction of the processes involved in the sourcing, production, and delivery of products and services" (APICS 2011). Operations management is a cross-disciplinary field (Karlsson 2016, 12; Sousa and Voss 2008) that concerns designing, planning, scheduling, and controlling the resources used for creating and delivering services and products (Slack, Brandon-Jones, and Johnston 2013). The contributions of this study are specifically targeted towards the ETO operations management body of knowledge, which has been a growing focus area within operations and supply chain management research (Cannas and Gosling 2021; Gosling and Naim 2009). The outcomes of this study also contribute to the S&OP body of literature by developing knowledge on S&OP for ETO manufacturing contexts, which have been overlooked in the extant S&OP research (Kreuter et al. 2022).

ETO manufacturing contexts typically manage each customer order as a project while managing and executing many such projects simultaneously (Adrodegari et al. 2015; Hans et al. 2007; Strandhagen et al. 2020; Zennaro et al. 2019). In some respect, setting delivery dates and estimating delivery lead times in ETO manufacturing contexts resembles estimating project durations in the project management terminology (PMI 2013). However, the contributions of this study are not targeted toward the general project duration estimation literature, which is a separate body of research within the project management field with a broader scope of applications also in non-manufacturing contexts such as construction, software, etc. Instead, this study focuses on estimating the duration of manufacturing projects undertaken by ETO companies, which requires a combination of planning approaches from the production management and project management bodies of knowledge.

This research is theoretically founded in the concept of strategic fit (Buer et al. 2018; Ivert et al. 2015; Kreuter et al. 2021; Kristensen and Jonsson 2018; Stevenson, Hendry, and Kingsman 2005), which can be considered an extension of the contingency theory (Donaldson 2001; Lawrence and Lorsch 1969; Sousa and Voss 2008). The strategic fit concept, applied to planning processes, dictates that they should be designed to align with their planning context or environment. While studying the influence of the characteristics of an ETO maritime equipment supplier on the design requirements for S&OP (RQ1), the research scope has been limited to market-related, product-related, and process and resource-related factors adapted from Buer et al. (2018). This study has not explicitly considered the effects of cultural, geographical, and organizational factors on S&OP design requirements.

This research is motivated by the challenges observed in a maritime equipment manufacturing context operating with an ETO strategy. Consequently, the literature reviewed for identifying the relevant tools, methods, frameworks, planning activities, and information flows (RQ2 and RQ3) is primarily contextualized in ETO manufacturing. ETO contexts, in this study, refer to manufacturing companies where product design, engineering, and production activities, albeit partially, are a part of the order-fulfillment process. ETO manufacturing contexts have been further sub-categorized in previous research based on the degree of product customization or the customer-specificity of products (Alfnes et al. 2021; Cannas et al. 2019, 2020; Willner et al. 2016). However, this doctoral study does not narrow its industrial focus to any specific ETO sub-category based on the level of customization.

1.5 Thesis outline

This thesis is divided into two parts. The first part comprises the main report, and the second is the collection of papers. The main report is organized as follows.

Chapter 1, i.e., this chapter, introduces the project and this thesis. The chapter has presented the industrial background for the researched problem, described the theoretical motivation for the research, introduced the research objective and questions, and outlined the research scope of the doctoral study.

Chapter 2 provides the necessary theoretical background for the topics relevant to this study and positions this doctoral research within the existing research on delivery date setting and sales and operations planning.

Chapter 3 presents the research design of this doctoral study. It describes how the methodology of this doctoral study combines the systematic literature review and case research approaches to address the study's research objective and questions and highlights the measures taken to ensure research quality.

Chapter 4 presents the main results and findings of the study. The results from the appended papers are summarized and linked to the main research questions of this doctoral study. The chapter also discusses the results and highlights this thesis' contributions to theory and the practical implications of the results.

Chapter 5 concludes the main report with a summary of the results and findings. The chapter also presents the concluding remarks, underlines some limitations of the doctoral study, and highlights areas for future research.

The second part of the thesis consists of the following four papers written to disseminate this doctoral thesis' results.

1. Bhalla, Swapnil, Erlend Alfnes, Hans-Henrik Hvolby, and Olumide Emmanuel Oluyisola. 2021. "Requirements for Sales and Operations Planning in an Engineer-to-Order Manufacturing Environment." In *Advances in Production Management Systems. Artificial Intelligence for Sustainable and Resilient Production Systems*, edited by Alexandre Dolgui, Alain Bernard, David Lemoine, Gregor von Cieminski and David Romero, 371-80. Cham: Springer. doi: https://doi.org/10.1007/978-3-030-85910-7_39.

2. Bhalla, Swapnil, Erlend Alfnes, and Hans-Henrik Hvolby. 2022. "Tools and practices for tactical delivery date setting in engineer-to-order environments: a systematic literature review." *International Journal of Production Research*:1-33. doi: https://doi.org/10.1080/00207543.2022.2057256.

3. Bhalla, Swapnil, Erlend Alfnes, Hans-Henrik Hvolby, and Olumide Emmanuel Oluyisola. 2022. “Sales and operations planning for delivery date setting in engineer-to-order manufacturing: a research synthesis and framework.” *International Journal of Production Research*:1-31. doi: https://doi.org/10.1080/00207543.2022.2148010.

4. Bhalla, Swapnil, Erlend Alfnes, and Hans-Henrik Hvolby. 2022a. "Sales and Operations Planning for Delivery Date Setting in Engineer-to-Order Maritime Equipment Manufacturing: Insights from Two Case Studies." In *Advances in Production Management Systems. Smart Manufacturing and Logistics Systems: Turning Ideas into Action*, edited by Duck Young Kim, Gregor von Cieminski and David Romero, 321-8. Cham: Springer. doi: https://doi.org/10.1007/978-3-031-16411-8_38.

2 Theoretical Background

This chapter provides background on the main conceptual domains within operations management that provide the theoretical frame of reference and motivation for the research problem addressed in this study – ETO manufacturing, delivery date setting, and S&OP.

2.1 Engineer-to-order manufacturing

ETO manufacturing refers to producing customized goods for specific customer orders and requirements (Alfnes et al. 2021; Hicks, McGovern, and Earl 2000). The ETO production strategy has been adopted across the globe in various companies and supply chains producing high-value industrial products such as manufacturing and construction machinery, power generation equipment, ships and ship equipment, equipment for offshore oil and gas operations, etc. (Cannas and Gosling 2021; Gosling and Naim 2009; Zennaro et al. 2019). Companies operating with this strategy perform customer order-driven production of products that are partially or entirely designed and engineered according to specific customers' requirements (Alfnes et al. 2021; Cannas et al. 2020). Consequently, the planning and execution of most sales, engineering, procurement, and production activities in ETO manufacturing contexts are based on actual customer orders rather than forecasts (Adrodegari et al. 2015; Olhager 2003).

The ETO strategy is often described using the concept of the customer order decoupling point (CODP), also known as the order penetration point (OPP). The CODP signifies the extent to which a customer order penetrates the process of conception of a product, from concept design and engineering to material procurement, fabrication, assembly, and shipment (Gosling, Hewlett, and Naim 2017; Olhager 2003; Wikner and Rudberg 2005). The CODP for a product distinguishes engineering and production activities that are generic or anticipation-driven from those that are customer order-specific (Berry and Hill 1992; Cannas et al. 2019; Gosling, Hewlett, and Naim 2017; Olhager 2003; Wikner and Rudberg 2005). Order-specific design and engineering activities allow manufacturers to offer customized solutions that address individual customers' needs and requirements, creating a competitive advantage on the performance dimensions of flexibility and innovativeness (Amaro, Hendry, and Kingsman 1999; Cannas et al. 2020; Semini et al. 2014). Simultaneously, postponing procurement and production until after the receipt of confirmed customer orders allows manufacturers to reduce inventories of components and finished goods (Cannas et al. 2020; Semini et al. 2014). Reducing the order-specificity of these activities enables manufacturers to compete on the performance dimensions of price, delivery time, and delivery precision; however, the uncertainty of the material and capacity requirements increases due to the dependency of product specifications on individual customers (Alfnes et al. 2021; Amaro, Hendry, and Kingsman 1999; Cannas et al. 2020; Semini et al. 2014). While the extent of customer-specific engineering, procurement, and production may vary across different ETO companies, their product segments, individual customer orders, etc. (Cannas et al. 2019, 2020; Semini et al. 2014), there are some typical characteristics of ETO manufacturing contexts that are listed below.

- Big-sized, high-value, and heavy-duty products, e.g., ships and maritime equipment, industrial and agricultural machinery, power systems, offshore equipment, etc., with complex product structures or bill-of-materials that contain various levels of subassemblies and a wide range of components (Zennaro et al. 2019).
- An order-fulfillment process comprising of non-physical activities such as tendering, design, engineering, process planning, etc., and physical activities such as procurement, fabrication, assembly, testing, etc. (Adrodegari et al. 2015; Amaro, Hendry, and Kingsman 1999; Bertrand and Muntslag 1993; Wikner and Rudberg 2005).
- Each customer order is managed as a project, and the order-fulfillment activities of multiple projects are planned and executed simultaneously under resource and capacity constraints (Adrodegari et al. 2015; Brachmann and Kolisch 2021; Ghiyasinasab et al. 2021; Hans et al. 2007).
- Order-driven customization of products produced in low volumes, with long order-fulfillment or delivery lead times ranging from a few months to more than a year (Alfnes et al. 2021; Carvalho, Oliveira, and Scavarda 2015).
- Overlapping engineering, procurement, and production activities (Iakymenko et al. 2020; Semini et al. 2014), which creates uncertainty in capacity requirements, material requirements, and activity durations for procurement and production planning (Alfieri, Tolio, and Urgo 2012; Carvalho, Oliveira, and Scavarda 2016; Hans et al. 2007; Hicks, McGovern, and Earl 2000).
- Different levels of vertical integration of supply chains, ranging from highly integrated manufacturers with a wide range of in-house manufacturing capabilities to design and project management firms that outsource most physical activities (Adrodegari et al. 2015; Hicks, McGovern, and Earl 2000; Hicks, McGovern, and Earl 2001).

2.2 Sales & operations planning and the production context

In a hierarchical planning and control framework (Figure 1.1), tactical-level planning activities are tasked with defining preliminary, aggregate plans for activities of different functions. These plans are usually defined considering rough quantities and durations for the material flows and resources, typically with planning horizons ranging from a few months to more than a year (Pereira, Oliveira, and Carravilla 2020; Stadtler and Kilger 2008). S&OP is a widely known and advocated approach for tactical planning. It emphasizes cross-functionally integrated tactical planning to balance supply and demand while aligning a company's day-to-day operations with its competitive priorities and long-term strategic plans (Grimson and Pyke 2007; Pereira, Oliveira, and Carravilla 2020; Thomé et al. 2012b). The S&OP approach emerged as an extension of aggregate production planning in the 1980s as a response to functionally siloed planning and decision-making, which were negatively impacting the effectiveness of plans as well as companies' overall performance due to the conflicting planning objectives or priorities of different functions (Danese, Molinaro, and Romano 2018; Stentoft, Freytag, and Mikkelsen 2020). Instead of creating uncoordinated and functionally siloed tactical plans, S&OP emphasizes creating a coordinated set of plans that enable coordination or integration across the activities of different functions such as sales, procurement, finance, distribution, engineering, production, etc. (Kreuter et al. 2022; Pereira, Oliveira, and Carravilla 2020). This thesis uses the terms *coordination* and *integration* interchangeably. These terms refer to "the quality of the state of collaboration that exists among departments that are required to achieve unity of effort by the demands of the environment" (Lawrence and Lorsch 1969, 11).

Since its conception in the 1980s, S&OP has been adopted in various industrial contexts (Kristensen and Jonsson 2018). In these contexts, researchers have reported performance improvements after S&OP adoption on a wide range of performance dimensions (Kreuter et al. 2022), e.g., financial performance – revenue and profit (Nemati, Madhoshi, and Ghadikolaei 2017), operational performance – quality, flexibility, and delivery (Thomé, Sousa, and Scavarda do Carmo 2014; Thomé, Sousa, and do Carmo 2014), supply chain performance – lead time, stock-outs, and inventory (Goh and Eldridge 2019, 2022), etc. Various studies find that the S&OP-driven improvements in firms' performance can be attributed to S&OP's ability to coordinate or integrate plans across the different supply chain functions such as marketing, sales, procurement, production, distribution, etc. (Feng, D'Amours, and Beauregard 2008, 2010; Feng et al. 2013; Oliva and Watson 2011; Thomé et al. 2012a; Thomé, Sousa, and Scavarda do Carmo 2014; Thomé, Sousa, and do Carmo 2014). While the performance benefits of S&OP and coordinated planning have been observed across a wide range of industrial contexts, the design of the S&OP process that facilitates these performance outcomes varies across companies based on the characteristics of their planning environment and corresponding planning needs (Kristensen and Jonsson 2018). Planning processes should be designed to fit specific industrial contexts' characteristics and planning needs (Berry and Hill 1992; Buer et al. 2018; Jonsson and Mattsson 2003; Newman and Sridharan 1995). This notion of *strategic fit* is widely accepted and emphasized in the planning and control literature and has its foundations in the wider-scoped contingency theory (Donaldson 2001; Ivert et al. 2015; Kristensen and Jonsson 2018; Lawrence and Lorsch 1969). Consequently, contextualizing the design of the S&OP process, i.e., designing and adjusting the S&OP process according to the contextual characteristics of companies' planning environments, has been one of the main streams of research within the extant S&OP literature (Kreuter et al. 2022; Kristensen and Jonsson 2018).

Recent literature reviews by Kreuter et al. (2022) and Kristensen and Jonsson (2018) reveal that despite the diversity of contexts where S&OP has been applied and studied, the extant S&OP research is contextually weak vis-à-vis ETO production. Previous S&OP research has been conducted primarily in mass production or make-to-stock (MTS) production contexts in food production, consumer electronics industry, automotive manufacturing, medical product manufacturing, cardboard industry, process industry, etc. (Danese, Molinaro, and Romano 2018; Grimson and Pyke 2007; Noroozi and Wikner 2017; Oliva and Watson 2011), with few contributions in make-to-order (MTO) contexts from the automotive supplier industry (Gansterer 2015) and the electrical and electronics sectors (Feng, D'Amours, and Beauregard 2008; Grimson and Pyke 2007). Consequently, the existing literature on contextualizing S&OP design is inadequate in guiding the design of the S&OP process in ETO contexts (Kreuter et al. 2022; Shurrab, Jonsson, and Johansson 2020b). The planning needs of ETO manufacturers are significantly different from MTS and MTO contexts. The differences in planning needs of these contexts dictate that ETO manufacturers require unique S&OP process designs developed with a focus on their planning needs. For instance, the extant literature presents the S&OP process in MTS and MTO contexts as a primarily forecast-driven planning process (Feng, D'Amours, and Beauregard 2008; Gansterer 2015; Olhager, Rudberg, and Wikner 2001; Pereira, Oliveira, and Carravilla 2020). In contrast, tactical planning in ETO contexts is primarily based on tenders or sales enquiries from potential customers and confirmed customer orders (Adrodegari et al. 2015; Alfieri, Tolio, and Urgo 2011; Alfnes et al. 2021; Carvalho, Oliveira, and Scavarda 2015; Ghiyasinasab et al. 2021; Hans et al. 2007; Olhager, Rudberg, and Wikner 2001). To highlight the main differences between the planning needs across MTS, MTO, and ETO production contexts, Table 2.1 summarizes some of the high-level attributes required for S&OP.

Table 2.1 Required S&OP attributes for tactical planning in different production contexts (adapted from paper #3)

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 and confirmed orders [1, 2, 11]
Main planning outputs	Production volumes [10], inventory targets, promotion timing, and price changes [12]	Production volumes, sales targets, inventory, and backorder targets [6, 7]	Delivery dates for tenders and production plans for confirmed orders [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)

The first attribute in Table 2.1, i.e., planning strategy, governs how the production volumes are set relative to the demand level in different periods. The level strategy implies a stable production rate over the planning horizon, while the chase strategy implies changing the production volume to match demand (Olhager and Selldin 2007; Olhager 2013; Olhager, Rudberg, and Wikner 2001). The level of aggregation or the planning object defines the planning granularity, governing whether plans are made considering individual products or with similar products aggregated into product families. The demand-input defines the source of demand that is considered for planning. Finally, the planning output essentially defines the purpose of the planning process, i.e., what should the planning process produce.

Kreuter et al. (2022) highlight the need for research to guide S&OP design in ETO companies and call for future research to investigate S&OP applications in these contexts. They emphasize that the application of S&OP in “ETO settings appears to be particularly suitable” due to the high complexity of tactical planning where cross-functional planning is necessary to balance supply and demand. Their call for ETO-focused S&OP studies is also supported by previous research by Parente, Pegels, and Suresh (2002). They find it more critical for ETO companies than other production contexts to overcome functional silos and improve cross-functional coordination. Furthermore, numerous ETO-focused studies concerning tactical planning also emphasize the need for cross-functional planning in ETO contexts (Shurrab, Jonsson, and Johansson 2020a, 2020b; Zorzini et al. 2008; Zorzini, Stevenson, and Hendry 2012).

The research need for investigating S&OP applications in ETO contexts motivated this doctoral study's first research question (RQ1), which explores the design requirements for S&OP in an ETO manufacturing context. Based on the findings from RQ1 and as introduced in Chapter 1, this doctoral study investigates the application of S&OP in ETO contexts for the tactical planning task of setting delivery dates. This task is described in the subsequent section.

2.3 Delivery date setting in engineer-to-order contexts

The time that elapses between the receipt of a customer order and the delivery of the product, i.e., the delivery lead time (Chapman et al. 2016, 15), is one of the critical measures of delivery performance for ETO manufacturers (Amaro, Hendry, and Kingsman 1999; Cannas et al. 2020; Grabenstetter and Usher 2014). The customer-driven order-fulfillment process in ETO companies renders the delivery lead times inherently long. Consequently, reducing these lead times and reliably estimating them are the two essential aspects of improving delivery performance and customer service for ETO manufacturers (Hicks, McGovern, and Earl 2000). The latter, i.e., the task of estimating delivery lead times for potential customer orders, is referred to as delivery date setting. It entails (1) estimating the delivery date or lead time to be quoted while tendering for new customer orders and (2) assessing the feasibility of meeting customer-imposed delivery dates (Carvalho, Oliveira, and Scavarda 2015; Hicks, McGovern, and Earl 2000; Zijm 2000; Zorzini, Stevenson, and Hendry 2012). Delivery date setting is a competitively critical planning task for ETO manufacturers due to its importance in improving and sustaining delivery performance (Zorzini et al. 2008). Estimating delivery lead times and delivery dates is particularly challenging in ETO companies due to the planning complexity and uncertainty that characterize these contexts (Alfnes et al. 2021; Shurrab, Jonsson, and Johansson 2020b; Zorzini et al. 2008; Zorzini, Stevenson, and Hendry 2012).

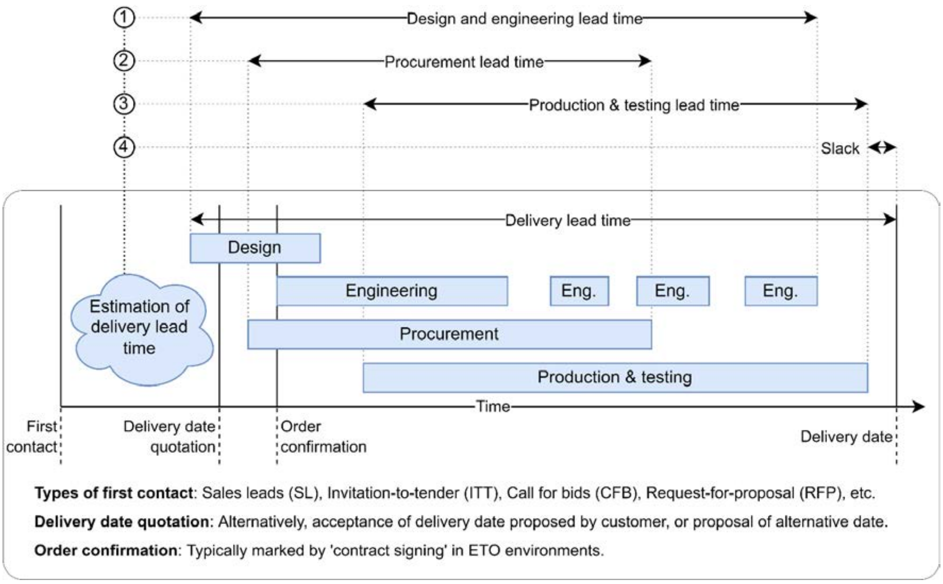


Figure 2.1 Typical order-fulfillment timeline in ETO manufacturing contexts (adapted from paper #2)

The delivery lead time for a customer order in ETO contexts comprises lead times for different order-fulfillment activities – design and engineering lead times, procurement lead times, production and testing lead times, and commissioning and installation lead times (Adrodegari et al. 2015; Alfnes et al. 2021; Semini et al. 2014) as illustrated in Figure 2.1. Estimating the lead times for these activities is a complex task because various factors influence them, and it is essential to consider these factors for the lead time estimates to be reliable. These factors include order-specific engineering needs, engineering resource requirements, available engineering capacity, order-specific material requirements, material availability, suppliers' lead times, order-specific production activities, available production capacity, etc. (Adrodegari et al. 2015; Brachmann and Kolisch 2021; Carvalho, Oliveira, and Scavarda 2015; Ghiyasinasab et al. 2021; Grabenstetter and Usher 2013; Zorzini, Corti, and Pozzetti 2008; Zorzini, Stevenson, and Hendry 2012). Due to the parallel execution of the different order-fulfillment activities, the lead times for these activities often overlap (Cannas et al. 2019; Iakymenko et al. 2018), adding to the complexity of estimating the overall delivery lead times. Moreover, some of these factors, e.g., engineering needs, production activities, material requirements, etc., are often uncertain in the tendering phase in ETO contexts. Design and engineering lead times are uncertain as they depend on exogenous factors such as customers' technical knowledge of the product, customers' change behavior, etc. These dependencies make it difficult to predict how many iterations of product engineering will be required before the product specifications are finalized (Shurrab, Jonsson, and Johansson 2020b). Due to incomplete product and process specifications in the tendering phase, procurement and production functions lack information, such as material and capacity requirements, based on which they can tentatively plan procurement and production activities and estimate the respective lead times (Alfnes et al. 2021). As a result of the high planning complexity and uncertainty, estimating the lead times for individual order-fulfillment activities and the overall delivery lead time is one of the most challenging planning tasks in ETO contexts. For managing the complexity and uncertainty of delivery date setting, previous research suggests three practices that can support ETO companies in minimizing the negative impacts of high complexity and uncertainty on their delivery precision. These can be listed as follows.

- **Coordination across functions and the supply chain**: cross-functional coordination refers to information sharing and coordinated decision-making and planning across different functions. It contributes to mitigating the performance risks that emerge from conflicting priorities of different functions and the scatteredness of planning information and estimation expertise across functions (Hendry and Kingsman 1989, 1993; Kingsman et al. 1993; Konijnendijk 1994; Zorzini, Corti, and Pozzetti 2008; Zorzini et al. 2008). Similarly, supply chain coordination, i.e., information-exchange and collaborative decision-making and planning with suppliers and subcontractors, can mitigate the performance risks that emerge from unrealistic assumptions regarding suppliers' lead times, capacity availability, etc. (Alfnes et al. 2021; Hicks, McGovern, and Earl 2000; Zorzini, Stevenson, and Hendry 2012).
- **Formalization of the delivery date setting process design**: establishing a formal or systematic process for setting delivery dates entails specifying the different actors involved in the process, delineating the roles or activities performed by each actor, and explicating the underlying decision-making procedures and decision-rules. Systematizing the process in this way enables a shared view of the process and decision-making priorities across different actors, thus reducing its reliance on tacit knowledge, and allows for the continual assessment and improvement of the delivery date setting process (Adrodegari et al. 2015; Zorzini, Corti, and Pozzetti 2008; Zorzini et al. 2008; Zorzini, Stevenson, and Hendry 2012).
- **Application of software tools for planning and decision-support**: the use of decision-support and planning tools facilitates planners and managers in effectively and systematically considering the wide range of factors relevant for estimating the delivery

lead times and dates to be quoted while tendering for new orders (Adrodegari et al. 2015; Carvalho, Oliveira, and Scavarda 2015; Corti, Pozzetti, and Zorzini 2006; Grabenstetter and Usher 2014).

These practices provided the theoretical framework for answering this doctoral study's second research question (RQ2), which maps the current state of the art within existing research on delivery date setting in ETO contexts. Each contribution in literature was mapped to one or more of these practices. Such a mapping allowed for discovering that there were no holistic planning frameworks in this literature to support ETO manufacturers in designing a formalized and cross-functionally coordinated tactical planning process for setting delivery dates. This research gap, which served as motivation for this doctoral study's third and final research question (RQ3), is elaborated in the subsequent section.

2.4 Sales & operations planning for delivery date setting

The extant literature establishes cross-functional coordination and formalization in tactical planning as practices that positively influence the effectiveness of delivery date setting in ETO contexts. Despite this, the literature has lacked a holistic reference framework or model that can guide ETO companies in designing such a planning process. Reference frameworks are conceptual artifacts that have been valuable in manufacturing planning and control research and practice with various applications. These applications include unifying fragmented knowledge (Kreuter et al. 2022; Pereira, Oliveira, and Carravilla 2020; Tuomikangas and Kaipia 2014), establishing best practices for industry sectors (Adrodegari et al. 2015), investigating and explaining contextual influence on the design and performance of processes (Kristensen and Jonsson 2018; Thomé et al. 2012b; Zorzini et al. 2008; Zorzini, Stevenson, and Hendry 2012), assessing and improving maturity of processes (Danese, Molinaro, and Romano 2018; Grimson and Pyke 2007), mapping, analyzing, and designing contextually-fitting processes (Adrodegari et al. 2015; Shurrab, Jonsson, and Johansson 2020b), etc. While various planning frameworks for ETO contexts have been proposed in the extant literature, they cannot be used as reference frameworks for tactical planning and delivery date setting for different reasons. For instance, high-level planning frameworks proposed by Adrodegari et al. (2015); Bertrand and Muntslag (1993); Little et al. (2000); and Nam et al. (2018) are scoped across the entire order-fulfillment process. Due to their broad scope, they only partially address the tactical planning activities and information flows relevant to delivery date setting.

Frameworks focusing on tactical planning and delivery date setting have also been proposed in the extant literature by Kingsman et al. (1996); Shurrab, Jonsson, and Johansson (2020b); and Zorzini, Corti, and Pozzetti (2008). However, these frameworks also have some shortcomings. The frameworks of Kingsman et al. (1996); and Zorzini, Corti, and Pozzetti (2008) are not cross-functional and only address tactical capacity planning for fabrication and assembly. Shurrab, Jonsson, and Johansson (2020b) do not address the information flow for cross-functional planning in their tactical planning framework.

Various frameworks have also been proposed in the extant S&OP literature. However, most elements of these frameworks lack applicability in ETO contexts due to the lack of consideration of ETO companies' planning needs in developing these frameworks. For instance, the widely cited five-step S&OP process framework identifies the main S&OP activities as 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). However, all the variations of this framework focus on forecast-driven tactical planning. Various process maturity models can also be found in the extant S&OP literature (Danese, Molinaro, and Romano 2018; Goh and Eldridge 2015; Grimson and Pyke 2007; Lapide 2005; Pedroso et al. 2017; Vereecke et al. 2018; Wagner, Ullrich, and Transchel 2014; Wing and Perry 2001). However, none of these have been developed or tested in ETO contexts. The S&OP literature synthesis framework from Thomé et al. (2012b), the S&OP coordination framework from Tuomikangas and Kaipia (2014), and the S&OP contingency framework proposed by Kristensen and Jonsson (2018) can be generalized to ETO contexts since they consider broader S&OP dimensions such as organization, meetings and collaboration, tools and technologies, etc. However, these are primarily useful as theoretical frameworks for studying variations in S&OP design across production contexts rather than as prescriptive reference frameworks for guiding S&OP process design in a specific industrial context. Among the recent contributions within S&OP, Pereira, Oliveira, and Carravilla (2020) develop a holistic framework that identifies the planning activities and information flow in S&OP. However, since their framework is developed based on the extant S&OP literature, many of its activities and information flows are irrelevant to ETO contexts.

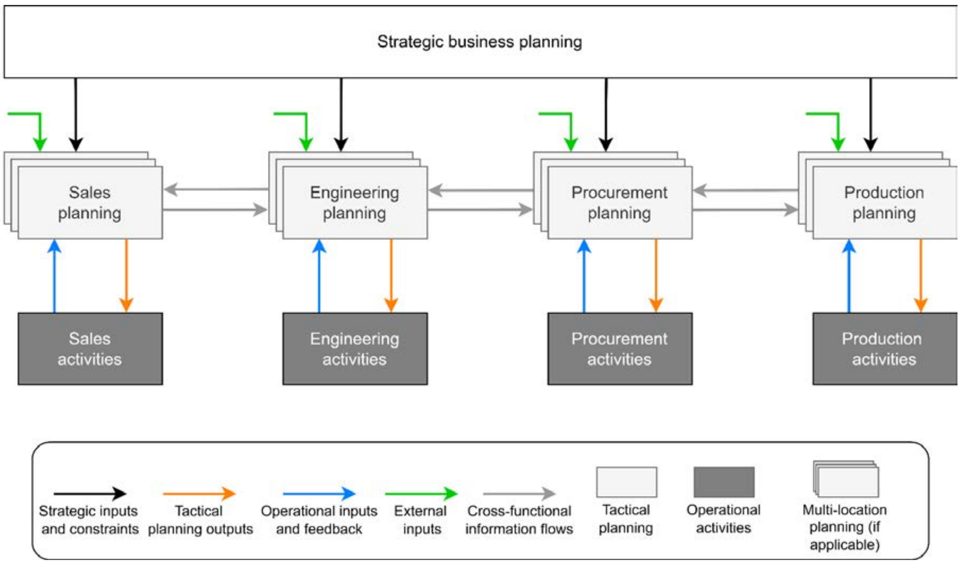


Figure 2.2 Overall structure for an S&OP framework for ETO contexts (paper #3) - adapted from Pereira, Oliveira, and Carravilla (2020) and Nam et al. (2018)

The overview of frameworks from the extant literature presented above highlights how the need for a framework to guide S&OP process design for effective delivery date setting in ETO contexts is not addressed by existing literature. This research gap motivated this doctoral study's third and final research question (RQ3), which is addressed by developing an S&OP reference framework for delivery date setting in ETO contexts. For developing this framework, an overall structure of the framework was defined by adapting the underlying assumptions in the S&OP framework from Pereira, Oliveira, and Carravilla (2020) to fit the characteristics of ETO contexts. Firstly, the *distribution* function was replaced by the *engineering* function. Then, the *sales*, *engineering*, *procurement*, and *production* functions were reorganized based on Nam et al.'s (2018) ETO supply chain matrix. Next, in addition to *strategic inputs*, *external inputs*, and *cross-functional inputs* from Pereira, Oliveira, and Carravilla (2020), the planning input category of *operational inputs* was introduced to account for the unpredictable and frequently changing planning environment of ETO companies. These attributes of ETO contexts necessitate that the current states of operational resources are considered in tactical planning (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. 2008). The resulting structure, which is shown in Figure 2.2, served as the theoretical framework for identifying and logically organizing the relevant planning activities and information flows for S&OP in an ETO context.

2.5 Summary

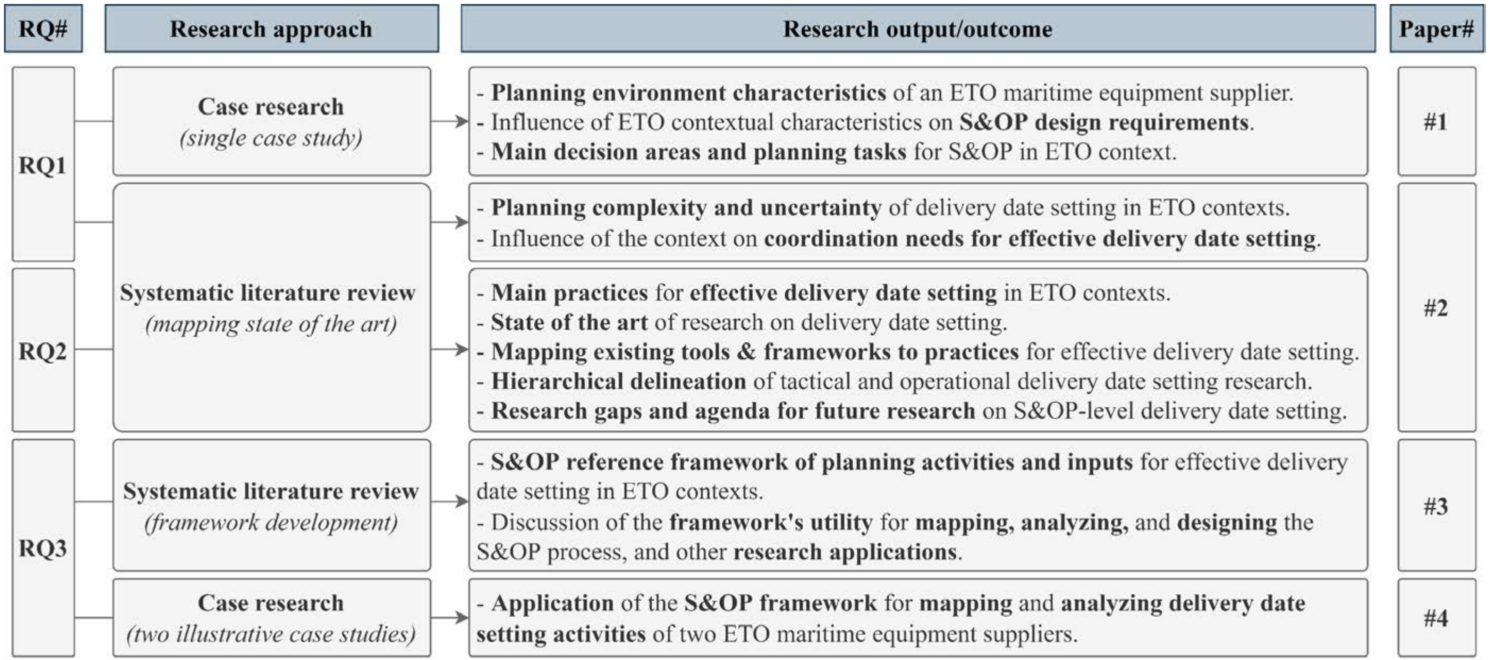
The importance of cross-functional coordination for effective delivery date setting presents it as a good use case for investigating the application of S&OP in an ETO context. Despite the emphasis on coordinated tactical planning for effective delivery date setting, and the capability of S&OP to improve cross-functional coordination and integrate plans of different functions, due to the lack of S&OP research in ETO contexts, the research streams on delivery date setting and S&OP have remained mutually disconnected. Furthermore, the extant delivery date setting literature lacks an overarching reference framework to guide the design of a formalized and cross-functionally coordinated tactical planning process for setting delivery dates (Bhalla, Alfnes, and Hvolby 2022). This doctoral project is positioned at the intersection of the research areas of tactical-level delivery date setting and S&OP that have hitherto had mutually separate research streams. However, as argued in this doctoral study, integrating knowledge from these streams of research offers promising opportunities for improving the effectiveness of delivery date setting in ETO manufacturing contexts.

3 Research design

This chapter presents the research design of this doctoral study. First, section 3.1 presents the overall research methodology, describing the main research approaches and methods used in different phases of the study for answering the RQs and discussing the methodological considerations behind selecting these approaches. Then, section 3.2 discusses the various aspects of research quality, highlighting the steps taken to address each quality aspect in this doctoral study.

3.1 Research methodology

This doctoral study utilized two main research approaches for answering the RQs – case research and systematic literature review. The case research approach uses case studies as the units of analysis. It is particularly effective for (1) studying phenomena in their natural settings by observing practice, (2) answering *why*, *what*, and *how* questions with a comprehensive grasp of a phenomenon's complexity and other characteristics, and (3) conducting exploratory investigations to understand phenomena about which little or no formalized knowledge exists (Benbasat, Goldstein, and Mead 1987; Meredith 1998; Voss, Johnson, and Godsell 2016). A systematic literature review is a research approach that "locates existing studies, selects, and evaluates contributions, analyzes and synthesizes data, and reports the evidence in such a way that allows reasonably clear conclusions to be reached about what is and is not known" (Denyer and Tranfield 2009, 671). Systematic literature reviews are not merely an inventory and critique of previous research but respond to specific RQs with a review process that is more well-defined, transparent, and rigorous than traditional narrative reviews (Cronin, Ryan, and Coughlan 2008; Thomé, Scavarda, and Scavarda 2016). Figure 3.1 provides an overview of the research design for this study, outlining the approach(es) used for answering each RQ and the corresponding research outputs and papers. The remainder of this section explains why these approaches were applied in the different phases of the doctoral study to generate the research outcomes and results.



RQ1: How do the characteristics of an ETO manufacturer influence the design requirements for S&OP?
RQ2: What are the available tools, methods, and frameworks for setting delivery dates within S&OP in ETO manufacturing?
RQ3: What are the main S&OP activities and information flows for delivery date setting in ETO contexts?

Figure 3.1 Overview of the research approaches used for addressing each research question

As pointed out in section 1.1, this doctoral study began as part of a research and innovation project aimed at creating new knowledge or insights that can enable improvements in the planning processes of the project's industrial partner – a maritime equipment supplier operating with an ETO strategy. Therefore, in the initial phases of the doctoral research, various factory tours and discussions with executives were conducted to observe the company's operations, understand the company's characteristics, and explore the planning challenges that could also be interesting doctoral research topics. Based on these exploratory discussions, delivery date setting was identified as a challenging tactical planning task for the company, which literature also suggested to be a research topic relevant to the broader research area of ETO operations management.

The extant literature on delivery date setting in ETO contexts suggested that the tactical planning process for setting delivery dates would be more effective if planning is cross-functionally coordinated instead of functionally siloed. Consequently, the literature on S&OP was explored to identify any relevant insights for designing the tactical planning process for setting delivery dates, revealing that none of the extant S&OP research had been conducted in ETO contexts. The need for coordination in delivery date setting and the ETO-contextual gap in S&OP research led to the formulation of this study's first research question (**RQ1**): *How do the characteristics of an engineer-to-order manufacturer influence the design requirements for sales and operations planning?*

The first sub-study of this doctoral research was a single case study aimed at answering RQ1. A single-case research design was chosen for this study to enable an in-depth investigation of an ETO planning environment's characteristics and their influence on S&OP design. The industrial partner was selected as the case for this in-depth study to capitalize on the access to data for mapping the characteristics of the case company. The company had partnered in previous research projects with the *Production Management* research group at NTNU, where this doctoral research was undertaken. As a result, transcripts from various interviews and workshops conducted previously by other researchers were available in the group's archives. The already established contact with the company through the ongoing research project facilitated access to recent product and production data, such as bill-of-materials, production routings, planned and actual dates for production orders, etc. This data and the observations from factory visits were used for mapping the characteristics of the case company's planning environment on three main dimensions adapted from Buer et al. (2018) – product characteristics, process and resource characteristics, and market characteristics. These characteristics were validated through semi-structured interviews with the master planner and planning department head, conducted remotely during the travel restrictions imposed due to the COVID-19 pandemic. These interviews were recorded and transcribed, and the transcripts were verified with the interviewees.

The mapped characteristics of the case company were qualitatively analyzed using the 'strategic fit' concept as a theoretical fundament to identify five main S&OP design requirements generated by these characteristics, explicitly linking each requirement to one or more of the company's characteristics. These requirements partially answer RQ1 and are reported in paper #1. This sub-study showed that in addition to delivery date setting, multi-project planning and spare parts planning were the two other main planning tasks for S&OP in the studied ETO case. Nevertheless, as a scoping measure, delivery date setting was maintained as the focus in the later sub-studies of the doctoral research.

The second sub-study of this doctoral research was a systematic literature review. The review aimed at mapping the state of the art of tactical-level delivery date setting and answering this study's second research question (**RQ2**): *What are the available tools, methods, and frameworks for setting delivery dates within sales and operations planning in engineer-to-order manufacturing?* The systematic literature review approach is a particularly effective research tool for mapping, analyzing, and synthesizing previous research through a transparent and rigorous process and laying the foundation for further research by uncovering research gaps and needs (Watson and Webster 2020; Webster and Watson 2002). Moreover, systematic reviews also support practitioners by establishing a base of reliable and actionable knowledge (Tranfield, Denyer, and Smart 2003). A detailed description of the literature identification and analysis methodology for this systematic literature review can be found in paper #2. In addition to answering RQ2, this sub-study also contributed to RQ1. The sub-study provided (1) a description of how the characteristics of ETO contexts contribute to the complexity and uncertainty characterizing delivery date setting and, therefore S&OP; and (2) additional insights about the influence of the planning environment's characteristics on the coordination needs to be considered while designing the S&OP process.

The third and fourth sub-studies in the doctoral research aimed at answering the third and final research question (**RQ3**): *What are the main sales and operations planning activities and information flows for delivery date setting in engineer-to-order contexts?* This research question was addressed through an S&OP reference framework of the planning activities and information flow for delivery date setting. The framework was first theorized in the third sub-study using the systematic literature review approach. Then, the fourth sub-study demonstrated the framework's application and adaptability using case studies. The framework was applied for mapping and analyzing the delivery date setting activities in case studies of two maritime equipment suppliers. The second sub-study (paper #2) indicated that despite the literature emphasizing cross-functional coordination's positive influence on the effectiveness of delivery date setting, there were no existing reference frameworks for designing a coordinated S&OP process for delivery date setting in ETO companies. The need for an ETO-focused S&OP reference framework was further reinforced by the lack of S&OP studies in ETO contexts (Kreuter et al. 2022). Therefore, developing an S&OP reference framework appeared to be a suitable contribution to addressing this gap.

The choice of using the systematic literature review approach for developing the S&OP reference framework was primarily based on the considerations of the generalizability of the framework and the efficiency of data collection. For the framework to be generalizable across different ETO industry sectors, it was essential to consider the characteristics and planning needs of various sectors in developing the framework. This doctoral study was conducted in Norway, where most entities operating with the ETO strategy are part of the maritime industry, e.g., shipbuilding companies and shipyards, EPC (engineering, procurement, and construction) yards, ship equipment suppliers, offshore equipment suppliers, etc. Consequently, access to other industry sectors would have entailed obtaining access to companies or case studies from other countries or continents. Considering the expected duration of a large-scale, multi-geography, multi-industry case study and the timeframe for the doctoral research, using secondary data and information from published literature was the more pragmatic alternative. Furthermore, the extant literature on ETO contexts has been based on a wide range of industry sectors (Cannas and Gosling 2021; Gosling and Naim 2009; Zennaro et al. 2019), which provided a further precedent for relying on literature to develop the framework. Paper #3 describes how literature was identified, analyzed, and synthesized to develop the framework.

As mentioned above, this doctoral research's fourth and final sub-study used case studies to demonstrate that the S&OP reference framework can be adapted and applied across different ETO contexts. This sub-study was designed as an in-depth two-case study, where both the case companies were maritime equipment suppliers. The number of cases for this study was kept low to enable adequate depth and detail in each case study while overcoming the lack of generalizability of findings from a single case study. The first case company in this sub-study was the industrial partner supplying maritime propulsion and maneuvering equipment to the shipbuilding industry (henceforth referred to as ProCo), also used as the case study for the first sub-study. The second case company was a handling equipment supplier for maritime applications (henceforth referred to as HanCo). The choice of the two case companies was based on the theoretical replication logic (Yin 2018, 55), where the delivery date setting activities in the two cases were expected to have different focuses due to the differences in the vertical integration strategies of the two companies. Furthermore, choosing two cases from the same industry sector and in the same geographical region allowed for controlling the variations in the external contexts of the companies, e.g., demand trends, compliance requirements, etc.

The data gathered during the first sub-study was reused for mapping and analyzing the delivery date setting activities for ProCo. The data required from HanCo was collected through two semi-structured interviews with the company's chief operating officer (COO) and from internal documents shared by the COO describing the main planning activities and overall planning hierarchy and planning challenges in the case company. The delivery date setting activities performed in the two cases were analyzed using the S&OP framework as a reference or checklist of activities. The analysis found that some activities were performed as expected, some were performed by different actors than in the framework, and some were not performed. The differences between the activities in the framework and the findings from the cases were discussed and could be explained by contextual factors that were (1) specific to the cases or (2) general characteristics of the industry sector.

3.2 Research quality

Research quality is a multi-faceted concept that concerns (1) the relevance of the research topic and the significance of the contribution, (2) the validity of the research, and (3) the reliability of the results and findings (Karlsson 2016). This section highlights the attributes and elements of this doctoral research that justify its quality.

3.2.1 Relevance

The first quality requirement, i.e., industrial relevance or managerial value of research, was essential for this doctoral study to fulfill since the study was funded as part of a larger research project targeted at creating knowledge and innovations that can improve industrial practice. Consequently, as described earlier, the project's industrial partner's challenges were used as the point of departure for defining the research topic. A wide range of published literature was surveyed in the early stages of the doctoral study. This activity allowed for (1) ascertaining the knowledge gaps in delivery date setting, tactical planning, and S&OP in ETO contexts and (2) ensuring that the topic was worth researching, making a theoretical contribution, and was relevant to the academic community. Finally, the relevance of the developed S&OP framework was assessed through a workshop with executives from the industrial partner – the COO, the Vice President of Engineering, the Master Planner, and the Project Planner. The framework was presented and described to the participants, followed by a discussion of (1) how the company's delivery date setting process compared to the representation in the framework and (2) the framework's relevance for ETO companies in designing and analyzing their delivery date setting process.

3.2.2 Validity

The second quality aspect, i.e., the validity of the research, concerns how well the research has been conducted. Research validity is typically assessed on the criteria of construct validity, internal validity, and external validity (Karlsson 2016, 30-1). *Construct validity* concerns if the correct operational measures are used for measuring the concepts of interest. *Internal validity* concerns if the study assumes or demonstrates the correct causalities between variables and does not overlook any factors that could explain the causal relationships. *External validity* concerns if the results or findings are generalizable in contexts other than the ones studied (Yin 2018, 42). The first two aspects of validity were crucial for the case studies, but the external validity aspect was also relevant for the overall framework development.

In the case studies, multiple sources of information were used, wherever feasible, while collecting case data to map the companies' characteristics and their delivery date setting activities to maximize the construct validity. Semi-structured interviews were used to complement field observations, secondary interview transcripts, company documents, historical production data, public reports, and information from companies' websites. Furthermore, the key interviewees were asked to review the case manuscripts.

In this doctoral research, maximizing the internal validity in the case studies was most important in instances where inferences were made about past events based on interviews and documentary evidence. The internal validity was ensured in these instances by adopting the tactic of explanation building – explicitly describing the line of reasoning and evidence behind the assumed causality between variables.

Given that the first case study used a single case research design, a strong theoretical foundation was essential for maximizing the external validity of the findings from the study (Yin 2018, 45-6). Therefore, the comprehensive list of planning environment variables from Buer et al. (2018) was used as the theoretical framework for mapping the planning environment characteristics of the case company in paper #1. Furthermore, the proposed design requirements for S&OP were explicitly linked to specific attributes of the company's planning environment, thus making it possible to assess the relevance of the requirements in other S&OP contexts.

The development of the S&OP reference framework proposed in this doctoral research has been primarily based on a systematic literature review. This choice of approach for developing the framework enhances the generalizability of the framework since extant literature from a variety of ETO contexts has been used to gain insights based on which the framework's elements were identified. Furthermore, paper #3 also highlights various context-specific considerations that may be necessary for adapting the framework to fit the needs of particular ETO companies. Moreover, in paper #4, a two-case study design was chosen to demonstrate the adaptability of the framework where the cases are selected based on the theoretical replication logic, further justifying the generalizability of the framework across ETO contexts.

3.2.3 Reliability

The third aspect of research quality, i.e., reliability, concerns the objectivity of the research such that the researcher's biases do not influence the results and conclusions, and other researchers can reach the same conclusions by replicating the research steps (Karlsson 2016, 31). Interview protocols were established, and a document database was maintained for all relevant documents and transcripts used as case evidence to maximize the case studies' reliability, as recommended by Yin (2018, 46). Furthermore, the method and process of analyzing the cases have been explicitly reported in the two case-based papers (#1 and #4) to facilitate the replication of the studies. Similarly, various tactics were adopted to maximize the reliability of the systematic literature reviews. Papers #2 and #3 describe how the literature was identified, screened, and selected for these reviews. The descriptions include the keywords and search string, databases used, inclusion and exclusion criteria, and the number of papers included and excluded in different steps using PRISMA flowcharts (Preferred Reporting Items for Systematic Reviews and Meta-Analyses). Both papers also describe the clustering and coding process of the literature and the theoretical frameworks used for this. The results and findings are tabulated in both papers, with explicit references to the relevant literature.

4 Main results

This chapter presents the results and findings from the four sub-studies comprising this doctoral research. First, based on the results from papers #1 and #2, section 4.1 addresses RQ1, describing how the characteristics of an ETO context influence the design requirements for S&OP. Then, based on results from paper #2, section 4.2 addresses RQ2, summarizing the state of the art of tools, methods, and frameworks for supporting delivery date setting in ETO contexts and the research needs in this area. Based on results from papers #3 and #4, Section 4.3 presents the S&OP reference framework of planning activities and information flow for delivery date setting and the results from the case studies conducted to illustrate the adaptability of the framework. Section 4.4 discusses the results and findings of the doctoral research, and sections 4.5 and 4.6 present the research's theoretical contributions and practical implications.

4.1 Influence of ETO characteristics on S&OP design requirements (RQ1)

The influence of the characteristics of an ETO context on the S&OP design requirements was primarily investigated in this doctoral research through a single case study of an ETO maritime propulsion and maneuvering equipment manufacturer (ProCo), as described in chapter 3. The company's characteristics were mapped along three main dimensions, i.e., product characteristics, process and resource characteristics, and market characteristics, as shown in Table 4.1. By jointly considering the company's product, process, and market characteristics as factors for designing the S&OP process and using the strategic fit concept as a theoretical lens, five main high-level requirements for S&OP design were identified. These requirements were explicitly linked to one or more of the company's planning environment characteristics to clarify which specific characteristics are theorized to impose these requirements. These five requirements are listed below, and Figure 4.1 links the requirements to the characteristics of the case company.

(1) S&OP should support reliable delivery date setting in the project sales phase by ensuring the feasibility of executing the project within the set delivery date while meeting cost constraints/objectives.
(2) S&OP should allocate production resources to projects while ensuring the feasibility of time-phased plans on relevant resources or resource groups.

(3) S&OP should allocate engineering and production capacity to confirmed projects such that each project can be executed within time and cost constraints and objectives and such that the schedule for one project does not negatively impact the time or cost performance of other projects.

(4) S&OP should allocate internal fabrication capacity to project-specific production and spare part production such that mutual disruptions between these activities can be minimized.

(5) S&OP should support effective spare part demand planning and inventory control by facilitating cross-functional collaborative forecasting and planning of production and procurement.

Table 4.1 Characteristics of ProCo's planning environment (paper #1)

Product characteristics:

- Customized and standard propeller and thruster systems for ships, consisting of heavy-duty mechanical, hydraulic, and electronic subsystems.
- Big-sized product with deep and wide bill-of-materials (BOM) with up to eight levels.
- Long product life (over 25 years) and maintenance regulations make after-sales maintenance, repair, and spare parts sales an important part of SHIPRO's business.

Process & resource characteristics:

- The fulfillment of each customer order for new equipment is managed as a project, and several such projects are managed and executed simultaneously.
- Functionally laid-out job-shop production for fabrication of components and steel structures; fixed positions for sub-assemblies and the final assembly.
- Customer order-based steel-structure fabrication, sub-assembly, and final assembly.
- Fabrication of machined components is partly customer order- or project-based and partly based on spare part demand forecasts.
- Various specialized single-axis and multi-axis CNC-machines (computer numerical control) for component fabrication – only a few components (less than 10%) have alternate routings.
- Production lead time for the same product varies significantly across different projects due to variations in the composition of the order-book or project-portfolio.
- High variability in customization requirements across projects – less than 100 engineering hours are typically used for order-specific configuration for standard equipment orders, whereas customized equipment may require twice-thrice the number of engineering hours and multiple iterations before drawings are finalized.

Market characteristics:

- High variability in annual demand and production volumes – have varied between 200 and 500 thrusters per year in the last five years.
- High variability in product mix – depends on the demand for types of new vessels.
- Delivery dates are contractually committed – which necessitates reliable estimation of delivery lead time during the project sales phase to ensure high delivery precision.
- High responsiveness in spare parts – promised delivery lead time for spare parts is three weeks with a 95% service level target.
- Stock-keeping-units (SKUs) with a wide range of demand and supply characteristics in the spare part portfolio, e.g., low vs. high annual demand; sporadic vs. stable demand; replenishment lead time of few days vs. several weeks, etc.

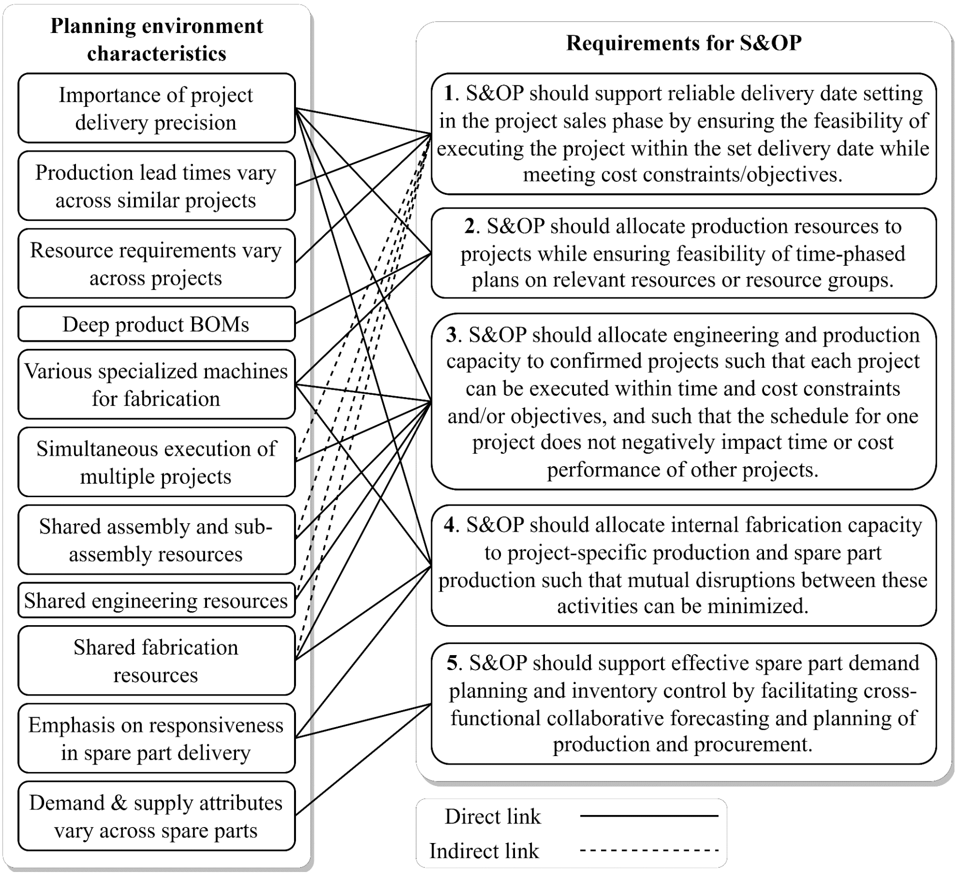


Figure 4.1 S&OP design requirements linked to the characteristics of the studied ETO context (adapted from paper #1)

The results from the single case study presented above were complemented by relevant findings from the second sub-study, i.e., paper #2, which was a systematic literature review. The review provides a detailed description of the complexity and uncertainty characterizing delivery date setting, and thus S&OP, in ETO contexts. Furthermore, paper #2 synthesizes findings from multiple case studies in the extant literature (Zorzini, Corti, and Pozzetti 2008; Zorzini et al. 2008; Zorzini, Stevenson, and Hendry 2012) into a conceptual model of contextual factors affecting the coordination needs in delivery date setting and S&OP in ETO contexts, as shown in Figure 4.2.

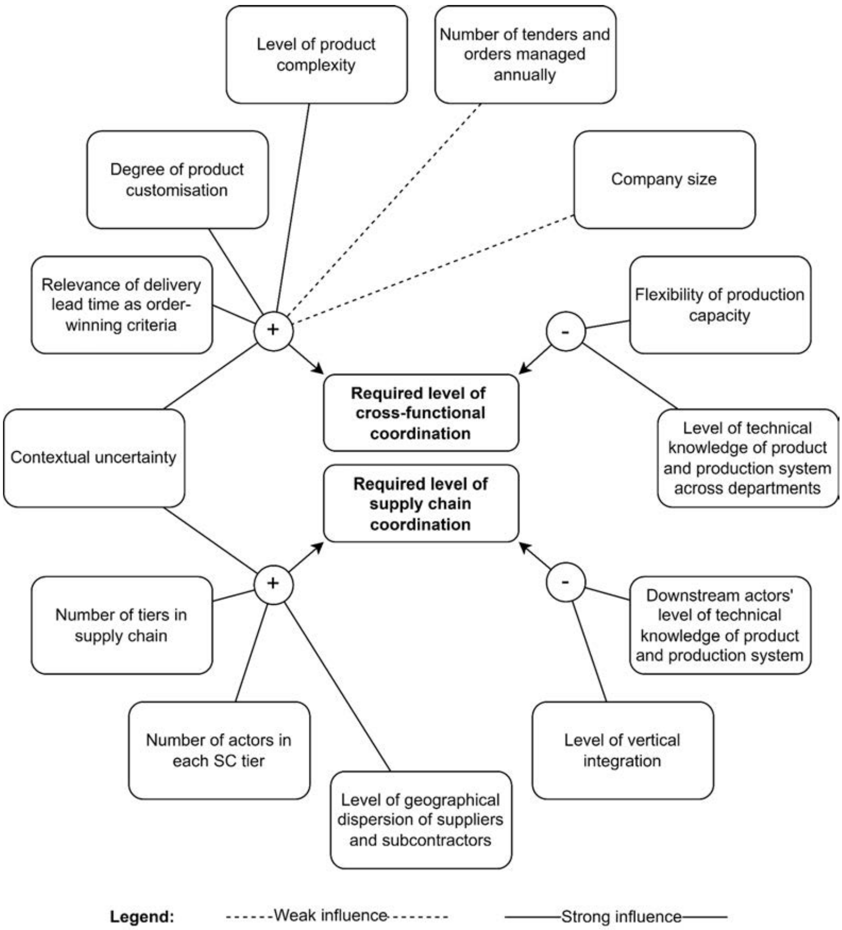


Figure 4.2 Conceptual model of contextual factors influencing coordination needs (paper #2)

4.2 Delivery date setting tools, methods, and frameworks in ETO contexts (RQ2)

The second RQ of this study, which was aimed at mapping the state of the art of artifacts, i.e., tools, methods, and frameworks, to support delivery date setting in ETO contexts, was addressed in paper #2 through a systematic review of the extant literature. Furthermore, this sub-study also identified various research gaps in this area and proposed a research agenda to address these gaps.

Paper #2 identifies five main categories of artifacts (tools, methods, and frameworks) supporting delivery date setting from the reviewed literature. The reader is referred to paper #2 for a detailed review of contributions within each category. The five categories are briefly presented below.

- ***Process models and frameworks***, i.e., schematics explicating or formalizing activities, relevant actors, information flows between activities and actors, and decision mechanisms that may otherwise remain tacit or informal and hinder process improvement (Kalpic and Bernus 2002). Process frameworks are valuable tools for formalizing the delivery date setting process and improving coordination by acting as references for the planning information that should be exchanged between different actors, i.e., functions in an enterprise, echelons of a supply chain, etc.
- ***Optimization models***, i.e., mathematical formulations with explicitly stated objective function(s) and constraints, such that the solutions to the model provide decision-support for delivery date setting, e.g., linear programming models (Özdamar and Yazgaç 1997), mixed-integer programming models (Calosso et al. 2003), dynamic programming models (Kapuscinski and Tayur 2007), stochastic programming models (Alfieri, Tolio, and Urgo 2012), etc., where the solutions may be obtained through exact solution methods (Carvalho, Oliveira, and Scavarda 2015), or heuristics (Wullink et al. 2004; Yang and Fung 2014) and metaheuristics (Manavizadeh et al. 2013).
- ***Mathematical models***, i.e., analytically derived or regression analysis-based polynomial models that represent lead times or delivery dates as functions of other variables and parameters (Grabenstetter and Usher 2014; Ioannou and Dimitriou 2012; Thürer et al. 2012).
- ***Tactical planning heuristics***, i.e., ad-hoc methods for tactical capacity planning or resource-loading developed using the domain- and context-specific knowledge to circumvent the complexity of formulating and solving optimization models (Corti, Pozzetti, and Zorzini 2006; Thürer et al. 2012).
- ***Decision-making methodologies and decision-support systems***, i.e., miscellaneous procedures and conceptual descriptions of software systems developed for supporting tasks and decisions related to delivery date setting, e.g., a strike rate analysis methodology for managing the trade-off between quoted prices and lead times (Hendry and Kingsman 1993; Kingsman 2000; Kingsman and Mercer 1997; Kingsman, Tatsiopoulos, and Hendry 1989; Kingsman et al. 1996; Kingsman et al. 1993), a bottleneck resource-focused capacity planning decision-support system (Park et al. 1999), a customer attractiveness analysis methodology for prioritizing customer enquiries (Ebadian et al. 2009), etc.

The identified artifacts were mapped to one or more of the three main application areas, as introduced in subsection 2.3 – cross-functional and supply chain coordination, formalization of the delivery date setting process design, and planning and decision-support. A summary of the contributions in literature and their mapping to the relevant application areas can be found in *Table 3* and *section 3* in paper #2.

The review revealed that the majority of contributions in the extant literature have been in the area of planning and decision-support tools for production, with only a few addressing the needs of cross-functional planning and planning in non-production functions, i.e., sales, procurement, and engineering. Furthermore, most of the optimization models, mathematical models, and planning heuristics proposed in the reviewed literature were found to lack specific real-world contexts or industrial challenges motivating their development. Among the few contributions addressing the formalization of the delivery date setting process, most of the proposed process models and frameworks are context-specific and lack generalizability. Designing and developing widely applicable process models, frameworks, and planning systems for ETO contexts has been difficult due to the diversity or lack of homogeneity across ETO companies (Hicks and Braiden 2000; Zorzini et al. 2008). Nevertheless, the context-specific process models proposed in the extant literature can serve as initial references for developing more generalizable process frameworks.

Based on the research gaps identified in paper #2, some of which have been highlighted above, the paper suggests various research needs as the agenda for future research. These are listed below.

(1) Development of process models and reference frameworks to support the formalization of the delivery date setting process design.
(2) Exploration of mapping or process modeling methodologies.
(3) Case research in new ETO industrial contexts and geographical locations.
(4) ETO typologies or taxonomies based on delivery date setting requirements.
(5) Development of delivery date setting maturity models.
(6) Exploration of Industry 4.0 technology applications for coordination improvements.
(7) Development of cross-functional planning and decision-support tools.
(8) Testing of engineering lead time estimation tools proposed in the literature.
(9) Development of ontologies for effective planning and decision-support systems.
(10) Development of efficient heuristic algorithms for optimization formulations.

(11) Documentation of managerial decision-support needs and need-based development of planning and decision-support tools.
(12) Development of tactical capacity planning heuristics considering practical aspects.

The need for developing process models and reference frameworks to support the formalization of the delivery date setting process (#1 in the list above) motivated the development of an S&OP reference framework in paper #3, as described in the subsequent section (4.3).

4.3 S&OP activities and information flows (RQ3)

This doctoral study's third and final RQ aimed to address the dearth of S&OP research within ETO contexts (Kreuter et al. 2022; Kristensen and Jonsson 2018) and the lack of a reference framework for guiding practitioners in designing the delivery date setting process (paper #2). These gaps were addressed by developing an S&OP reference framework for delivery date setting. The framework was developed in paper #3 by identifying the main S&OP activities and information flow for delivery date setting through a systematic literature review and synthesizing these into the proposed framework. The application and adaptability of the framework were illustrated in paper #4 through two case studies.

The planning activities and information flows were first identified in paper #3 for the individual planning functions of sales, engineering, procurement, and production. These are summarized in Figure 4.3, Figure 4.4, Figure 4.5, and Figure 4.6, respectively. The planning activities and information flows were integrated into a holistic S&OP reference framework, as shown in Figure 4.7. The proposed framework can be used as a reference for mapping, analyzing, and designing or redesigning ETO companies' tactical planning process for setting delivery dates from an S&OP perspective, which emphasizes cross-functional coordination in the planning process. Other potential applications of the framework have been discussed in paper #3, highlighting that company- and industry-specific characteristics and planning needs should be considered while applying the framework in practice. This may lead to some of the framework's elements being highly important in a specific context while others are irrelevant. To demonstrate how the level of detail in the framework facilitates analysis of the delivery date setting process at a granular level, paper #4 applies the framework for mapping and analyzing the delivery date setting activities in two case studies. The mapping of the activities in the cases is summarized in Table 4.2. A descriptive comparison of the delivery date setting activities in the two cases can be found in paper #4.

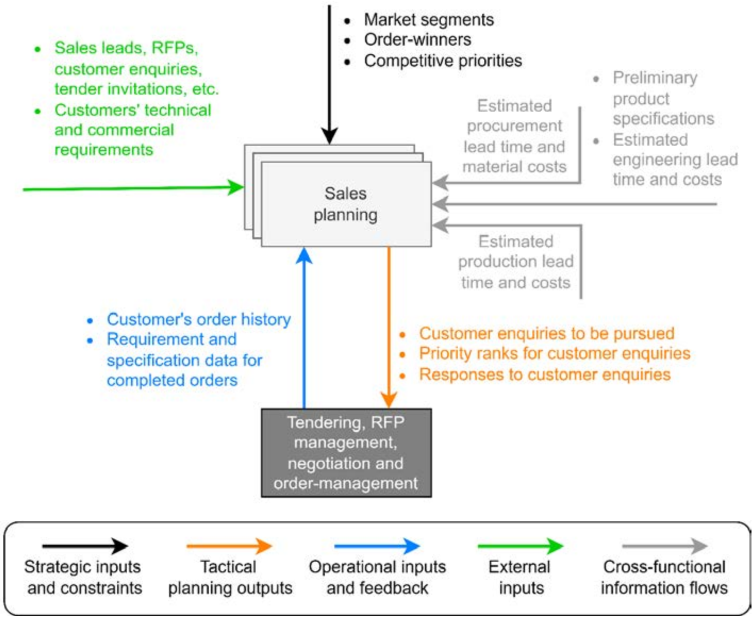


Figure 4.3 Sales planning activities and information inputs (paper #3)

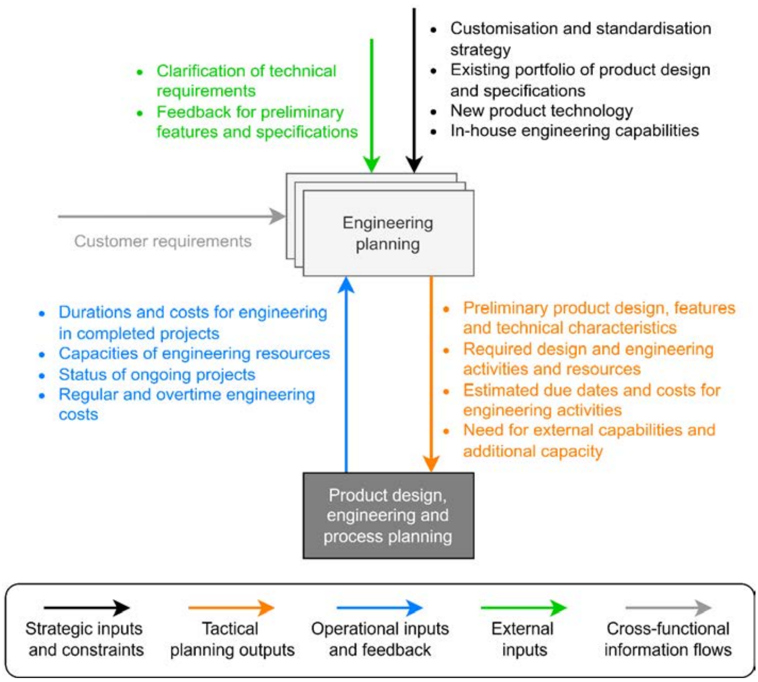


Figure 4.4 Engineering planning activities and information inputs (paper #3)

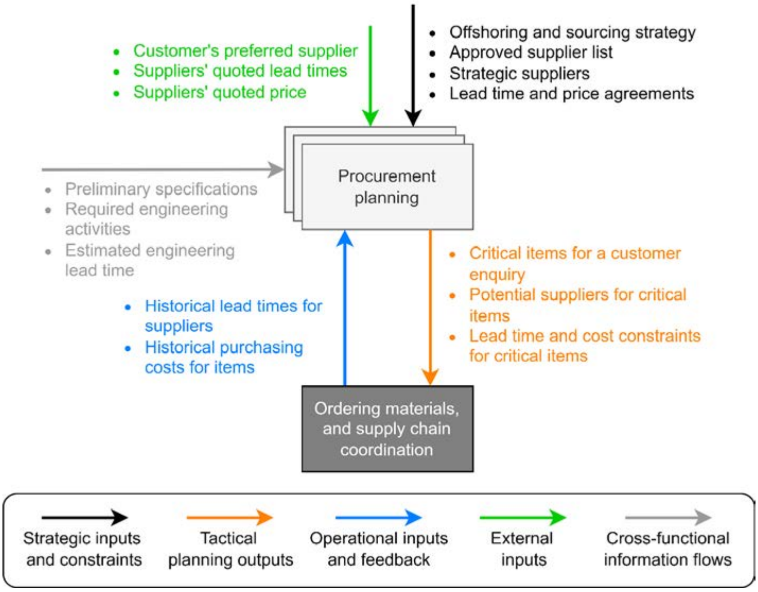


Figure 4.5 Procurement planning activities and information inputs (paper #3)

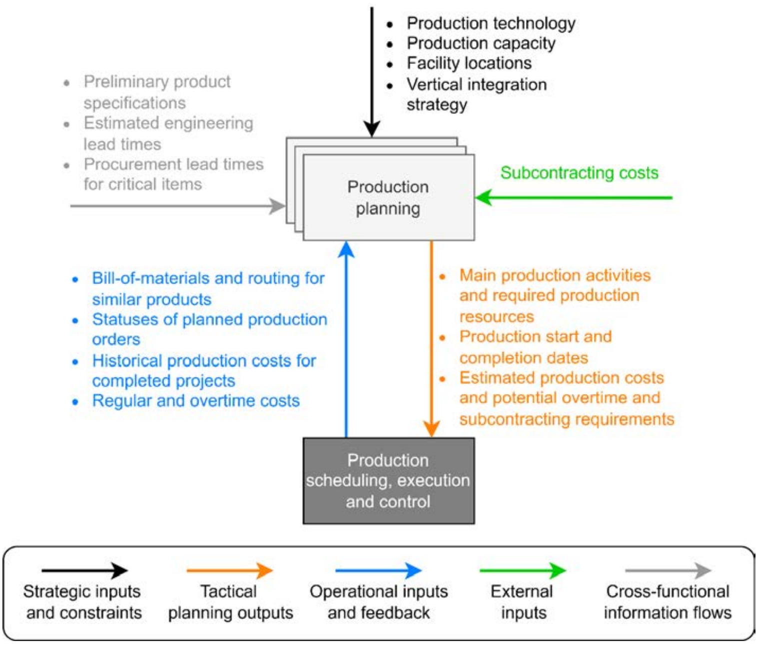


Figure 4.6 Production planning activities and information inputs (paper #3)

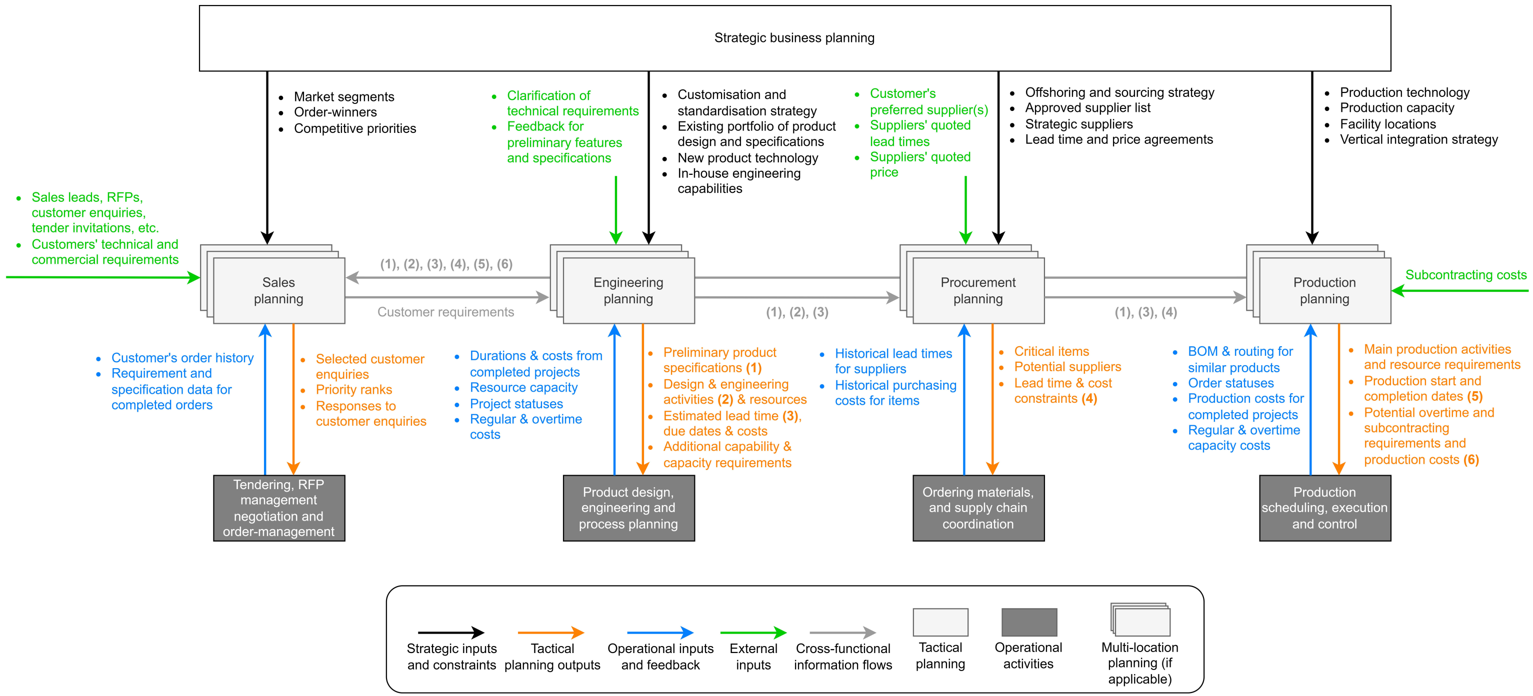


Figure 4.7 S&OP reference framework for delivery date setting in ETO contexts (paper #3)

Table 4.2 Delivery date setting activities in two case companies mapped using activities in the S&OP reference framework (paper #4)

	S1	S2	S3	E1	E2	E3	E4	Pc1	Pc2	Pc3	Pd1	Pd2	Pd3
ProCo	--	--	✓	✓*	--	--	--	✓#	✓#	✓#	✓#	✓#	--
HanCo	--	--	✓	✓*	✓*	--	✓*	--	--	--	--	--	--

Legend:
✓: evidence of activity found in case — *: activities performed by sales department
--: evidence of activity not found — #: activities performed for some orders only

S1: select enquiries; **S2**: prioritize enquiries; **S3**: responding to customer enquiries; **E1**: define preliminary specs; **E2**: determine engineering activities & resources; **E3**: estimate engineering lead times & costs; **E4**: identify external capability & capacity needs; **Pc1**: identify critical items; **Pc2**: select potential suppliers; **Pc3**: determine procurement lead times & prices; **Pd1**: identify main production activities & resource requirements; **Pd2**: identify feasible production start & end dates; **Pd3**: estimate production costs & non-regular capacity req.

Findings from the case studies, which were both from the maritime equipment manufacturing industry, revealed that the low demand in the shipbuilding and maritime industry over the last decade has led to a reduced focus on planning before order confirmation. In both companies, delivery dates are primarily quoted based on historical lead times. Engineering capacity, material procurement lead times, and production capacity are not considered in most orders until after order confirmation. This reduced focus on planning before order confirmation makes the effectiveness of the companies' current delivery date setting process dependent on the market conditions, and the delivery dates estimated with the current approach may not be reliable in higher demand conditions.

The S&OP framework was presented to executives at ProCo in a workshop aimed at getting their feedback and assessing the framework's industrial relevance, as mentioned in 3.2.1. The feedback from the participants indicated that they perceived the framework as a valuable tool for companies to identify opportunities for improving their tendering and delivery date setting process. ProCo's COO suggested that "the framework can be developed into a checklist of activities" to review the current state of the delivery date setting process in ETO companies, emphasizing that such an activity would be particularly interesting for a COO. The participants acknowledged that different sets of planning activities are expected to be relevant for different types of ETO companies; nevertheless, the framework covered a wide range of activities to be usable in various contexts. The participants highlighted that one of the main elements missing from the framework was the activity of *contractual review*, which is typically an essential step before order confirmation in ETO contexts. The participants emphasized that this activity is critical for ETO companies that often use order-specific contracts rather than standard ones and, therefore, could be incorporated into the future development of the framework.

4.4 Discussion of results

So, how should ETO companies design their S&OP process for effectively setting delivery dates? It is possible to offer some recommendations and insights on the subject based on a four-year doctoral study and the results reported in the previous sections.

Firstly, it is essential to acknowledge the wide variety of ETO contexts that can be found in practice, ranging from manufacturing facilities producing specialized industrial machinery and equipment to shipyards and engineering, procurement, and construction yards. As a result of this variety, the planning needs and required planning tools are bound to vary across these different contexts. Therefore, the primary task in designing the S&OP process for setting delivery dates in any ETO context should be to map the characteristics of the planning environment and identify the main planning needs based on the mapped characteristics. Papers #1 and #2 highlight the main contextual characteristics and their influence on planning and coordination needs. Previous literature on delivery date setting (Zorzini et al. 2008; Zorzini, Stevenson, and Hendry 2012) and planning and control in general (Buer et al. 2018; Oluyisola et al. 2022) provides additional insights on the mapping of planning environment characteristics and their influence on planning needs.

The second essential task in designing the S&OP process for delivery date setting is determining the main planning activities required to address the planning needs and the main planning inputs required for performing said activities. The doctoral project has developed an S&OP reference framework to aid this task in practice that identifies a wide range of planning activities and inputs relevant to delivery date setting in different ETO contexts based on a systematic review of literature in paper #3. ETO companies can use the proposed framework as a reference list of activities and information flows to select the most important ones for their planning needs based on their planning environments' characteristics. Paper #4 illustrates a preliminary application of the S&OP framework for mapping the planning activities for setting delivery dates in two case companies.

The third and final task in designing the S&OP process for delivery date setting is selecting, designing, developing, and implementing the tools and mechanisms required for performing or supporting the main planning activities and information flows. Relevant tools include decision-support systems and planning methods that enable managers and other decision-makers to utilize the available planning inputs for effective decision-making and planning. Managers can thus base plans on available data and explicit information rather than relying entirely on their experience and tacit knowledge. Mechanisms primarily refer to the modes through which planning inputs and information are obtained by managers and decision-makers or exchanged between different actors, e.g., integrated enterprise systems; periodic or need-based planning meetings; shared web applications for planning; etc. The doctoral study's results can facilitate the selection of relevant tools and mechanisms. Paper #2 provides a review of the state of the art of available tools, methods, and frameworks for delivery date setting. Paper #3 provides a framework to support ETO companies in individuating the specific planning activities and information flow that may require decision-support tools and information-sharing mechanisms. Furthermore, both papers (#2 and #3) highlight several gaps that future research should address to better support ETO companies in selecting or developing necessary tools and mechanisms. The existing tools and methods reviewed in paper #2 can be linked to particular planning activities in the S&OP framework from paper #3, as exemplified below.

- Ghiyasinasab et al. (2021) and Brachmann and Kolisch (2021) demonstrate with their models how sales planning can integrate information from different functions to estimate the overall lead time for responding to customer enquiries.
- Grabenstetter and Usher (2013, 2014) demonstrate how engineering planning can utilize historical data and the characteristics of a new customer order for estimating the engineering lead times.
- Ebadian et al. (2008) demonstrate how procurement planning can select potential suppliers and subcontractors, albeit through an MTO case.
- Alfieri, Tolio, and Urgo (2011, 2012); Carvalho, Oliveira, and Scavarda (2015, 2016), among many others, demonstrate how production planning can determine the feasible start and end dates for production activities.

Given this doctoral study’s aim and focus, the above recommendations mainly concern planning process design. Nevertheless, as highlighted in 4.2, developing a process reference framework is only one of many gaps to be addressed for supporting practitioners. Based on the findings of the systematic literature reviews and case studies, it is possible to offer additional insights that would allow academia to support the delivery date setting practice better.

One of the insights gained during this doctoral study is that enterprise planning systems do not have the planning functionalities required by ETO manufacturing companies to set delivery dates effectively. Examples include capacity planning functionality for engineering departments, capacity planning functionality for production departments with aggregate time buckets and forward loading, scenario-based planning functionality to differentiate between tenders or potential customer orders and confirmed orders, etc. Aslan, Stevenson, and Hendry (2012, 2015) have previously highlighted the shortcomings of these systems, which were also observable in the two case studies. Nevertheless, these systems continue to be essential for these manufacturers, especially relatively large ETO companies, to manage myriads of activities, materials, and business processes. Academia can support ETO companies and planning system suppliers focusing on the ETO industry by developing and demonstrating planning and decision-support tools for delivery date setting. However, the extant research in this area also exhibits various gaps that future research should address. For instance, most research on planning and decision-support tools has only addressed production planning for setting delivery dates. There are only a few examples of decision-support tools that integrate planning for engineering, procurement, and production in estimating delivery dates. Further testing and developing these few tools in other contexts is essential to assess their broader applicability.

While there are various studies on planning and decision-support tools in the extant delivery date setting literature, few of the developed tools in the extant literature were motivated by industrial problems or needs of specific contexts. This trend has, over time, broadened the gap between the theoretical developments within delivery date setting and the needs of practitioners. To address this, research in this area requires more practical problem-solving studies that are empirically grounded in specific industrial contexts. Moreover, from the viewpoint of supporting the industry, future research may benefit from developing effective tactical planning heuristics for delivery date setting rather than aiming to develop exact optimization-based planning and decision-support tools. The computational complexity and solving times of optimization-based tools grow drastically with the number of activities, projects, degree of parallelism, etc., especially for larger ETO enterprises. As a result, carefully developed heuristics based on managers' domain-specific knowledge may be more successful and useable in practice.

This doctoral research integrates two research streams that were, hitherto, mutually dissociated, i.e., delivery date setting and S&OP. Previous research on delivery date setting has developed a variety of artifacts to support ETO companies. Still, there has been no overarching framework to guide the design of a cross-functional planning process for delivery date setting, despite findings from previous research highlighting the importance of cross-functional coordination for its effectiveness. Meanwhile, coordination improvements through S&OP have been repeatedly reported in the literature, although none of the reported applications are from ETO contexts. This study has used S&OP as a set of principles for designing the delivery date setting process, thus only exploring the application of S&OP for a specific planning task in ETO contexts. However, as discussed in paper #3, we do not see this as the only potential application for S&OP in ETO contexts, and other applications remain to be explored.

4.5 Contributions to theory

This doctoral study makes various theoretical contributions that address gaps in the extant knowledge. These contributions to theory are highlighted in this section, and Table 4.3 provides an overview of the main contributions from the appended papers.

Table 4.3 An overview of the main theoretical contributions

Main contribution	**Paper**			
	1	**2**	**3**	**4**
Identifying planning environment characteristics and main S&OP design requirements for an ETO manufacturer	x			
Highlighting the differentiation b/w tactical-level and operational-level delivery date setting		x		
Mapping state of the art of delivery date setting tools, methods, and frameworks applicable in ETO contexts		x		
Conceptual model of factors influencing coordination needs for delivery date setting in ETO contexts		x		
Developing an S&OP reference framework for delivery date setting activities and information flows in ETO contexts			x	
Illustrating an application of the S&OP reference framework				x
Identifying research gaps and proposing agenda for future research on S&OP and delivery date setting in ETO contexts		x	x	

The first contribution of this doctoral research is identifying the high-level requirements for the design of the S&OP process in an ETO context and identifying the main planning tasks or decisions that S&OP should support in such a setting. These results from paper #1 contribute to the S&OP body of knowledge, where ETO contexts have been entirely overlooked in previous research (Kreuter et al. 2022; Kristensen and Jonsson 2018). These results are the basis for linking the two topics central to this doctoral study, i.e., delivery date setting and the S&OP concept.

The second contribution of this doctoral study is the explicit differentiation between delivery date setting as a tactical decision taken by managers with medium to long planning horizons and delivery date setting as a short-term operational decision on the shop floor. As clarified in paper #2, among studies in MTO contexts, delivery date setting has been considered a tactical planning task by some (Ebadian et al. 2008; Ebadian et al. 2009) and as an operational planning task by others (Li and Ventura 2020; Oğuz, Salman, and Yalçın 2010). However, delivery date setting in ETO contexts has been unequivocally considered a tactical planning task. Clarifying this distinction is essential for scoping the development and selection of tools and frameworks for delivery date setting in ETO contexts. The artifacts focusing on operational decision-making can be excluded, and those addressing tactical decision-making, albeit in MTO contexts, can be considered for relevant insights. The review and selection of literature in paper #2 also demonstrate the application of this inclusion and exclusion logic, where the excluded literature is explicitly listed for the transparency of the review.

The third contribution of this research has been to systematically map the current state of the art of artifacts, i.e., tools, methods, and frameworks, available for supporting ETO companies in setting delivery dates. Before the publication of paper #2, the research on the topic was fragmented and lacked a set of specific research gaps to guide further research on delivery date setting. As highlighted in paper #2, while various previous reviews partly addressed the topic (Aslan, Stevenson, and Hendry 2012; Cannas and Gosling 2021; Cheng and Gupta 1989; Gordon, Proth, and Chu 2002; Gosling and Naim 2009; Hendry and Kingsman 1989; Ragatz and Mabert 1984; Slotnick 2011; Stevenson, Hendry, and Kingsman 2005; Zennaro et al. 2019), all of these had different perspectives or contextual focuses. Consequently, previous reviews did not comprehensively map the state of the art of artifacts to support delivery date setting in ETO contexts. Additionally, as the fourth main contribution of the doctoral research, paper #2 also develops a conceptual model of the factors that influence coordination needs for delivery date setting in ETO contexts based on a synthesis of findings from multi-case studies in the extant literature. The identified factors correspond not only to the coordination needs across different functions within an ETO enterprise but also the coordination needs across different enterprises in an ETO supply chain.

As the fifth and perhaps the main contribution of the doctoral research, an S&OP reference framework for delivery date setting in ETO contexts has been developed in paper #3 using the systematic literature review methodology. The value of this contribution is twofold since (1) ETO contexts have been one of the main contextual gaps in the extant S&OP research (Kreuter et al. 2022; Kristensen and Jonsson 2018), and (2) the ETO research and practice have lacked a comprehensive framework to support the design of a cross-functionally coordinated planning process for delivery date setting, as highlighted by the results of paper #2. The S%OP framework opens many new research avenues for S&OP and delivery date setting research in ETO contexts, as discussed in paper #3. The sixth main contribution of this doctoral study, in paper #4, is demonstrating how the proposed S&OP framework can support case studies of the delivery date setting process in ETO contexts and allow for uncovering unique theoretical insights and improvement areas in the studied contexts.

Finally, this doctoral study's seventh and final theoretical contribution is that it provides a wide range of research objectives for future studies within delivery date setting and S&OP in papers #2 and #3. The literature reviews reported in the two papers systematically map the current research, identify gaps in the existing research, and formulate specific research agendas to address the existing gaps and advance the state of the art of these topics. We believe that addressing the research agenda proposed in papers #2 and #3 is essential for better supporting planning practices in ETO industrial contexts.

4.6 Implications for practice

The issue of lacking fit between the needs of ETO manufacturers and existing planning tools, methodologies, and frameworks is not a recent revelation and has been highlighted by various studies over the last three decades (Aslan, Stevenson, and Hendry 2012, 2015; Bertrand and Muntslag 1993; Little et al. 2000; Stevenson, Hendry, and Kingsman 2005; Zennaro et al. 2019). The inadequacy of the extant S&OP frameworks in addressing ETO manufacturers' planning needs is yet another instance of this previously observed phenomenon. Perhaps due to this inadequacy, S&OP and its applications have remained unexplored in ETO contexts. The findings and results of this doctoral research underline the potential of how the S&OP concept can be applied in ETO companies and provide a reference framework to facilitate this application. Managers in ETO companies can utilize the framework for assessing which tactical planning activities are most critical for setting delivery dates in their planning environment and if their existing planning processes address these activities (paper #3). As pointed out in paper

#3 and highlighted by the findings from paper #4, the need for context-specific adjustments to the framework and its elements are inevitable, given the wide variety of characteristics of ETO companies across geographies and industrial sectors. Nevertheless, the framework elements have been defined and described in paper #3 and should be recognizable for practitioners from diverse ETO contexts. Furthermore, the framework's design is highly granular, where individual planning activities and planning inputs are identified. This feature makes the framework adaptable by modifying or excluding the activities and information flows in the framework or introducing additional ones.

The case studies of the two maritime equipment suppliers (paper #4) suggest that the importance of planning while setting delivery dates has diminished in the companies due to the ongoing long period of low demand. Nevertheless, executive-level managers from both companies also emphasized that they recognized how essential it would be to quote planning-based delivery dates in the future when demand increases, such that projects can be delivered timely and profitably. Consequently, both companies have ongoing strategic efforts to improve their planning processes at the tactical and operational levels. The S&OP reference framework developed in this doctoral research (paper #3) and the mapping of existing tools and practices for delivery date setting (paper #2) will have immediate utility in such strategic initiatives. These results can support these companies in restructuring or reconfiguring their tactical planning process behind tendering and delivery date setting and enable them to identify the existing planning and decision-support tools that can be used in the process.

Historically, most commercial enterprise information systems and planning software packages have been developed to address mass production contexts' business processes and planning needs. As a result, these systems do not align with the needs of ETO production contexts, which has led to the widespread development and adoption of ad-hoc systems in ETO companies (Adrodegari et al. 2015; Aslan, Stevenson, and Hendry 2012, 2015; Zennaro et al. 2019). Among the two maritime equipment supplier companies studied in this doctoral research (paper #4) – ProCo uses a stand-alone application for a high-level feasibility assessment of production lead times based on available capacity, where the planner lacks a forward planning functionality; and HanCo, which has outsourced production, has no capacity-based feasibility assessment functionality for engineering. In their findings from the ETO machinery building industry, Adrodegari et al. (2015) report that most of their studied companies do not have an integration between their enterprise information systems and any software tools supporting delivery date setting, suggesting that updated data for planning and decision-making is only sporadically available. Furthermore, the state-of-the-art review in paper #2 highlights various gaps in the existing planning and decision-support methodologies that must be addressed to better address the managerial and planning needs in ETO industrial contexts. Based on these findings and considering the planning complexity of delivery date setting in ETO contexts, the development of methodologies and software tools for planning and decision-support appears as a critical area for improving the state of delivery date setting practice in ETO companies. To this end, the proposed S&OP framework should be used to conceptualize, formally describe, and develop the planning methodologies and software functionalities required in ETO contexts to support planning activities and information flow for delivery date setting. Moreover, the granularity of the framework allows for focusing on individual planning activities while exploring, developing, or selecting relevant decision-support tools.

In the past, ETO companies have lagged behind other production contexts in applying advanced digital technologies such as cyber-physical systems, Internet-of-Things, big data analytics, cloud computing, etc. (Zennaro et al. 2019) that are often encapsulated under the concept of Industry 4.0 (Zheng et al. 2021). In response, recent studies have explored the applications of these technologies for improving planning and operational performance in ETO contexts through, e.g., efficient knowledge sharing and information sharing, closer supplier collaboration, increased information visibility and data availability, etc. (Cannas and Gosling 2021; Strandhagen et al. 2020; Weng et al. 2020). The proposed framework can support ETO companies in identifying specific technology requirements for streamlining information flows in the S&OP process to increase the availability of information for planners and managers while setting delivery dates.

5 Conclusion

This chapter concludes the dissertation with a summary of the results with some concluding remarks (5.1). The chapter also highlights some research limitations (5.2) and proposes how future research can build further on this doctoral study (5.3).

5.1 Summary and concluding remarks

This doctoral study has investigated how ETO manufacturers can design their S&OP process for effectively setting delivery dates. The study uses primarily two research approaches – case research and systematic literature review. Case research allowed for industrial contextualization of the research topic in the initial phases of the study. The systematic review approach was first utilized to identify specific knowledge gaps and research needs and then to develop an S&OP reference framework based on the synthesis of the extant research. Finally, case research was used to illustrate the proposed framework's application in the final phase of the study. The three main RQs of the study have been addressed using these research approaches, and the results are summarized below.

RQ1*: How do the characteristics of an engineer-to-order manufacturer influence the design requirements for sales and operations planning?* The findings from papers #1 and #2 indicate that the influence of ETO environments' contextual characteristics on S&OP design requirements is significant and complex. Long product delivery lead times and order-driven engineering, procurement, and production activities imply that S&OP design requirements in ETO contexts starkly differ from the S&OP process designs traditionally advocated and implemented in mass production contexts, where S&OP primarily addresses forecast-driven production and inventory planning for product families. Low production volumes and long delivery lead times impose that S&OP should be order-driven. Various order-specific activities and parallel or simultaneous execution of order-fulfillment activities for various orders impose that S&OP is performed with a multi-project perspective with material availability constraints and capacity constraints from production and engineering resources. Furthermore, diverse and highly specialized production resources impose higher levels of detail and granularity in planning capacity for production resources. In addition to the factors exemplified here, the findings from the papers suggest that a wide range of factors also influence the required level of coordination across different functions in the S&OP process. Therefore, the characteristics of ETO contexts render designing the S&OP process a complex task. Findings from paper #1 revealed delivery date setting as one of the main S&OP decisions or planning tasks in ETO contexts. Therefore, the remainder of the doctoral study focused on this specific task.

RQ2*: What are the available tools, methods, and frameworks for setting delivery dates within sales and operations planning in engineer-to-order manufacturing?* The findings from paper #2 show that most of the contributions in the extant research have focused on developing planning and decision-support tools, e.g., optimization models, mathematical models, planning heuristics, etc. Planning or decision-making frameworks that can guide planning process design have also been developed, but these have been the subject of very few studies, especially when compared to the number of decision-support tools that have been proposed. Furthermore, most studies have focused on supporting the estimation of production lead times, while the estimation of procurement and engineering lead times have been overlooked. The review of the current state of the art of artifacts for setting delivery dates within S&OP in ETO contexts, as presented in paper #2, revealed the need for developing process reference frameworks for delivery date setting as one of the items on the agenda for future research. Therefore, the final phases of the doctoral research focused on developing an S&OP reference framework for delivery date setting.

RQ3*: What are the main sales and operations planning activities and information flows for delivery date setting in engineer-to-order contexts?* The review in paper #3 identifies 13 main S&OP activities for delivery date setting in ETO contexts clustered under the broad S&OP subprocesses of sales planning, engineering planning, procurement planning, and production planning. The review also identifies various information flows associated with each S&OP activity, such that each information flow provides a set of planning inputs for a particular planning activity. The planning activities and information flows identified in paper #3 have been synthesized into an S&OP framework for delivery date setting in ETO contexts. The proposed framework can support practitioners in mapping, analyzing, and designing or redesigning their delivery date setting process with an emphasis on cross-functional coordination, which previous empirical studies have found to improve the effectiveness of delivery date setting. The framework incorporates planning activities and information flows from a wide range of ETO contexts described in the extant literature. Therefore, as discussed in paper #3 and as illustrated by the findings of paper #4, applying the framework in ETO companies will require contextual adjustments based on the specific characteristics of a company's planning environment. Nevertheless, incorporating elements from a wide range of ETO contexts increases the generalizability of the framework. Furthermore, the granularity of the framework is expected to enable practitioners to easily assess the relevance of specific planning activities and information flows.

While this doctoral study has focused on supporting the design of the planning process for setting delivery dates, it is essential to acknowledge that many ETO companies still commit to delivery dates without much planning, as also observed in the case studies in paper #4. Such planning-less order-promising may be unavoidable for winning orders in low-demand periods. However, we believe that ETO companies must not adopt this as their standard mode of operations to avoid high costs due to overtime, subcontracting, and delay penalties in high-demand periods. The S&OP framework and future research agenda proposed in this doctoral study can support ETO companies in improving the robustness of their delivery date setting process.

5.2 Research limitations

This section highlights some of the main limitations of this doctoral research. Firstly, the doctoral study only partially demonstrates the application of the proposed S&OP reference framework in paper #4. While a more thorough empirical demonstration of applying the framework could have further strengthened the validity of the framework, this has been excluded from the doctoral study due to time constraints. Secondly, the industrial contextualization of the research problem in paper #1 and the demonstration of the framework's application in paper #4 have both been based on the maritime equipment manufacturing industry. While the literature review and synthesis-based contributions in papers #2 and #3 are much more general than a specific sector, maritime equipment suppliers have been the researcher's main industrial context of interest throughout the doctoral study. Any biases introduced because of this could be a limitation for the broader relevance of some of the results. Thirdly, a significant portion of the doctoral study overlapped with the COVID-19 pandemic, which hindered access to the industry. These hindrances included the lack of physical meetings and on-site observations due to travel restrictions and the general unavailability of managers and executives to participate in research activities such as interviews and workshops due to the various pandemic-induced operational and supply chain disruptions and uncertainties. Finally, while this doctoral study develops a framework to support the design of a cross-functional planning process for delivery date setting, designing the process is only a preliminary step in achieving coordination. Practical barriers and challenges in achieving coordination in practice while implementing the process have not been investigated within this doctoral research due to time constraints. The knowledge of such barriers and challenges can strengthen the practical utility of the proposed framework in improving coordination.

5.3 Future research

To the best of the author's knowledge, this doctoral study is the first to investigate the requirements and design of the S&OP process in an ETO production context. As recent literature highlights (Kreuter et al. 2022), the application of the S&OP concept particularly fits ETO production contexts due to their characteristically high planning complexity. However, none of the extant S&OP research considers the unique planning needs of ETO companies (Kreuter et al. 2022; Kristensen and Jonsson 2018; Shurrab, Jonsson, and Johansson 2020b). Therefore, this doctoral study can be considered the initiation of a research stream dedicated to S&OP applications in ETO contexts. This doctoral project has primarily focused on the application of S&OP for improving cross-functional coordination in delivery date setting. However, S&OP can also be a valuable concept for addressing the ongoing coordination needs of multi-project planning and control for confirmed customer orders in ETO contexts, which future studies in this research stream should explore.

As highlighted in paper #3, the proposed S&OP reference framework has been developed based on literature from a wide variety of ETO contexts. Consequently, planning activities and information inputs from diverse industrial contexts have been incorporated into the framework. While this improves the generalizability of the framework, it also implies that adaptations or adjustments to the framework will be necessary while applying the framework in specific ETO contexts due to the non-homogeneity or diversity of ETO industrial contexts found in practice (Zorzini et al. 2008; Zorzini, Stevenson, and Hendry 2012). This suggests testing the relevance of the various framework elements in different ETO companies as a key research need for refining the framework's applicability in different industrial contexts. The generalizability of the proposed S&OP framework also highlights its utility as a research tool for future multi-case studies on similarities and differences in planning needs and practices for tendering and delivery date setting in different ETO contexts.

This doctoral study has contributed to the topic of delivery date setting with the only state-of-the-art review specifically focusing on the needs of ETO contexts. As a result of the exhaustive review of the literature on the topic, the study has identified a wide range of gaps that should be addressed by future research and proposed an agenda for future research to address these gaps (paper #2). The proposed research agenda provides numerous research objectives that future studies should pursue.

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(3) Bhalla, Swapnil, Erlend Alfnes, Hans-Henrik Hvolby, and Olumide Emmanuel Oluyisola. 2022. “Sales and operations planning for delivery date setting in engineer-to-order manufacturing: a research synthesis and framework.” *International Journal of Production Research*:1-31. doi: https://doi.org/10.1080/00207543.2022.2148010.

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Paper 1

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Requirements for Sales and Operations Planning in an Engineer-to-Order Manufacturing Environment

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Abstract. Sales and Operations Planning (S&OP) is the process through which enterprises develop tactical plans for aligning supply and demand management activities, usually with the objective of maximizing profitability. Demand-supply balancing is particularly complex and challenging in Engineer-to-Order (ETO) manufacturing environments, which are characterized by highly customer-driven order-fulfilment processes, creating a dynamic and uncertain planning environment. Recent studies highlight that ETO environments and their contextual influence on S&OP have been overlooked within extant S&OP research. This paper addresses this by investigating how the characteristics of ETO manufacturing influence the design of S&OP. Through a case study of a maritime equipment manufacturer, the paper identifies requirements that are imposed on the S&OP process by the characteristics of an ETO planning environment. These requirements serve as basis for identifying three main research areas that can support the design of S&OP in ETO environments, namely, customer enquiry management, multi-project management and spare parts management. The findings are summarized in a high-level framework for S&OP in ETO production and related research areas.

Keywords: Sales and operations planning · Tactical planning · Engineer-to-order

1 Introduction

Sales and operations planning (S&OP) refers to the process by which enterprises develop tactical supply and demand management plans [1]. The S&OP process usually aims to maximize revenue and/or profitability by minimizing the imbalance between supply and demand, while operating within the constraints set by strategic decisions [2]. Since its conception, knowledge on S&OP has matured and advanced significantly but unevenly across industrial environments [1, 3], as exemplified by the lack of normative guidance for S&OP design in engineer-to-order (ETO) environments [4].

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Trends such as digitalization, globalization and increasing global competition force manufacturers to adapt to stay effective and efficient [5, 6], where S&OP can serve as top-management's lever to steer the business [1]. The importance of effective S&OP is further underlined in ETO environments such as shipbuilding supply chains, where markets have undergone dramatic changes in demand, profit margins and competition during the last decade [7]. The high complexity of ETO operations and structural differences between ETO and mass-production environments limit the extent to which extant knowledge can be applied to guide S&OP design in ETO environments, as most of the previous S&OP research was contextualized in high-volume production environments [1, 4]. Therefore, this paper investigates how the characteristics of ETO manufacturing environments create design requirements for the S&OP process.

The remainder of the paper is structured as follows. Section 2 further elaborates on the gap in literature vis-à-vis S&OP in ETO environments, and provides theoretical background for the case study in Sect. 3, which serves to identify the requirements imposed by the characteristics of an ETO manufacturing environment on the design of the S&OP process. Section 4 relates the identified requirements to relevant research areas and bodies of knowledge that can support S&OP design in ETO environments, organizing the findings in a proposed framework. Finally, Sect. 5 concludes the paper, and lists limitations and further research directions.

2 ETO Manufacturing, S&OP, and Strategic Fit

ETO production environments, i.e. companies and/or supply chains operating with an ETO strategy, are typically characterized by big-sized complex products that are produced in low volumes and high variety, with several customer order-driven engineering and production activities [8, 9]. These order-driven activities create substantial planning complexity in ETO environments, which in turn creates the need for using specialized tools and practices in planning processes [4, 10], e.g., advanced planning and scheduling (APS) systems, collaborative planning, etc. Production planning and control (PPC) literature proposes the application of the strategic fit concept in designing planning processes and in selecting and/or developing tools and practices to be used in the planning processes; arguing that planning processes should be designed according to the requirements of the planning environment [5]. Understanding a planning environment and its requirements is essential for using appropriate planning methods, as lack of fit between the planning environment's characteristics and PPC processes negatively affects manufacturing firms' performance [11]. Consequently, as a PPC process, the strategic fit concept has also been applied to the S&OP process.

Kristensen and Jonsson's [1] application of the strategic fit concept and contingency theory in analyzing S&OP literature reveals the shortcomings of extant S&OP literature vis-à-vis ETO manufacturing environments. Their review suggests that most of the S&OP literature has been contextualized in relatively high-volume industrial environments, e.g., retail, food production, pharmaceuticals, etc. As a result, S&OP literature is contextually weak in describing and guiding the S&OP process in ETO environments and lacks a reference framework for researchers and practitioners [4].

Existing S&OP frameworks, such as the widely used five-step process framework for S&OP [12, 13], are aligned with the characteristics of high-volume manufacturing environments and define S&OP as the process of setting inventory levels and production volumes for product families based on demand forecasts and planned capacity levels. However, in ETO environments, where engineering, procurement and production activities are often planned based on customer orders due to low forecast accuracy [9], the role and structure of the S&OP process is not accurately described by existing S&OP process frameworks. Moreover, existing PPC frameworks for ETO environments, such as those found in references [9, 14], provide some insights into how S&OP might support the fulfilment process of individual orders, but do not clarify the ongoing role, inputs, objectives and outcomes of S&OP as a planning process.

3 S&OP Requirements in ETO Manufacturing

This section identifies the requirements imposed on the S&OP process by the characteristics of an ETO manufacturing environment. As described in the Sect. 2, understanding the planning environment and its characteristics is essential for designing PPC processes, to ensure strategic fit between the planning requirements and the features of a PPC process. To identify the requirements imposed on the S&OP process by the characteristics of an ETO manufacturing environment, a case study of a maritime equipment manufacturer was conducted, where data collection focused on describing the planning environment of the case company. The case selection logic is best described as convenience sampling, since the case company itself is the industrial context that motivated the research problem addressed in this paper, while also being a suitable context for conducting research to address the problem, i.e., a typical ETO production environment, as further described in Subsect. 3.1.

The case company is and has been NTNU's industrial partner in research projects, which facilitated access to historical production data and transcripts from various interviews and workshops conducted over the course of several years by other researchers in the research group, including the second author. Based on factory visits (last in March 2020) curated by the master planner, and the insights gained from the archived data, a preliminary description of the characteristics of the company's planning environment was drafted. To validate the characteristics, semi-structured interviews with the master planner and the head of the planning department were conducted remotely between November 2020 and February 2021. These interviews were recorded and transcribed, and the transcripts were verified with the interviewees.

3.1 Characteristics of the Case Company

The case company, which will be referred to as 'SHIPRO' (short for Ship Propulsion - not the real name), is an original equipment manufacturer (OEM) that supplies propulsion and maneuvering equipment (propellers, gearboxes, thrusters, etc.) for ships through a globally dispersed sales network. SHIPRO's target customer segments include offshore vessels, fishing and research vessels, cruise ships, ferries, and naval vessels, and their product portfolio consists of a wide variety of propeller and thruster systems to fit the needs of different ship-types. Table 1 presents the main characteristics of SHIPRO's product, order-fulfilment process and resources, and market environment.

Table 1. Main characteristics of SHIPRO's planning environment

Product characteristics: • customized and standard propeller and thruster systems for ships, consisting of heavy-duty mechanical, hydraulic, and electronic subsystems • big-sized product with deep and wide bill-of-materials (BOM) with up to 8 levels • long product life (over 25 years) and maintenance regulations make after-sales maintenance, repair, and spare parts sales an important part of SHIPRO's business
Process & resource characteristics: • fulfilment of each customer order for new equipment is managed as a project, and several such projects are managed and executed simultaneously • functionally laid-out job-shop production for fabrication of components and steel-structures; fixed positions for sub-assemblies and final assembly • customer order-based steel-structure fabrication, sub-assembly, and final assembly • fabrication of machined components is partly customer order- or project-based, and partly based on spare part demand forecasts • various specialized single-axis and multi-axis CNC-machines (computer numerical control) for component fabrication – only few components (less than 10%) have alternate routings • production lead time for the same product varies significantly across different projects due to variations in the composition of the order-book or project-portfolio • high variability in customization requirements across projects – less than 100 engineering hours typically used for order-specific configuration for standard equipment orders, whereas customized equipment may require twice-thrice the number of engineering hours and multiple iterations before drawings are finalized
Market characteristics: • high variability in annual demand and production volumes – have varied between 200 and 500 thrusters per year in the last 5 years • high variability in product mix – depends on demand for types of new vessels • delivery dates are contractually committed – necessitates reliable estimation of delivery lead time during project sales phase to ensure high delivery precision • high responsiveness in spare part delivery – promised delivery lead time for spare parts is three weeks with a 95% service level target • stock-keeping-units (SKUs) with wide range of demand and supply characteristics in spare part portfolio, e.g., low vs. high annual demand; sporadic vs. stable demand; replenishment lead time of few days vs. several weeks, etc.

3.2 S&OP Requirements at SHIPRO

This subsection analyzes the characteristics of the case company's planning environment, as presented in the previous subsection, to identify the implications of the characteristics on the design of the S&OP process. We interpret these implications as requirements that these characteristics impose on the design of the S&OP process. The concept of strategic fit is used as the theoretical fundament to analyze the planning environment's characteristics or attributes, such that each attribute results in one or more requirements for the S&OP design.

Figure 1 shows the five main requirements identified based on SHIPRO's planning environment, where each requirement is linked to one or more planning environment

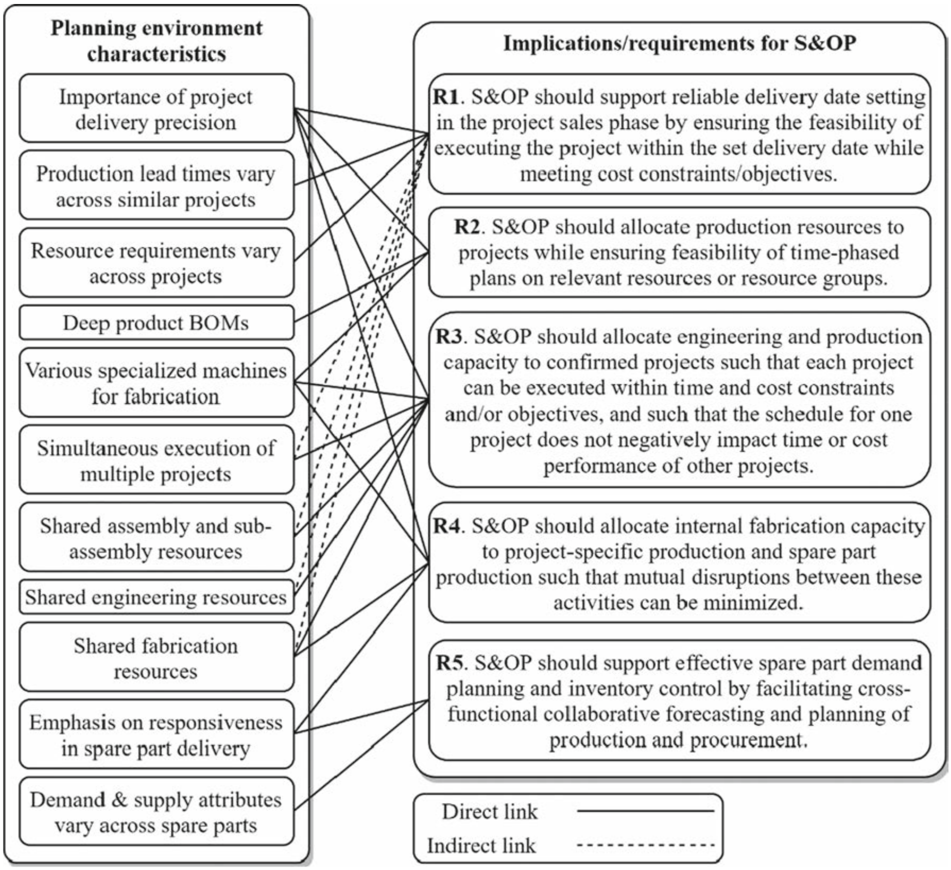

Fig. 1. Requirements for S&OP design based on the case company's planning environment

attributes that generate the requirement. While most of the attribute-requirement links are shown as solid lines, four of the linkages to **R1** (requirement #1) are shown as dashed lines to represent an indirect link. For instance, the fact the SHIPRO executes multiple projects simultaneously on shared resources does not itself generate the requirement that S&OP should support reliable delivery date setting (**R1**). Instead, simultaneous execution of multiple projects on shared resources leads to variability in the production lead time for similar projects, which in-turn necessitates that reliable delivery date setting is supported by S&OP (**R1**).

The S&OP requirements identified in the case study, as shown in Fig. 1, can be associated with the three broad phases of customer-supplier interaction (CSI) associated with each product, i.e., *project-sales* (**R1**), *project-execution* (**R2, R3** and **R4**) and *after-sales service* (**R4** and **R5**). By fulfilling **R1**, S&OP can support effectiveness of the sales process by ensuring that estimated delivery dates are realistic and competitive. By fulfilling **R2, R3** and **R4**, S&OP can support project-execution by increasing the likelihood of achieving delivery and cost targets set and agreed upon with the customer in the sales phase. Finally, by fulfilling **R4** and **R5**, S&OP can maintain customer-satisfaction by supporting responsiveness in spare part delivery while ensuring that the responsiveness is not achieved at the expense of delayed projects and vice-versa. Another insight that can be gained from the attribute-requirement linkages shown in Fig. 1 is that the requirements associated only with the *project-sales* and *project-execution* phases (**R1**–**R3**) are generated by engineering, fabrication and assembly resources; whereas the requirements associated with the *after-sales service* phase (**R4** and **R5**) are only generated by the fabrication resources.

4 Relating ETO S&OP to Existing Research Areas

Having identified the requirements that an ETO planning environment's characteristics impose on the S&OP process design, the question arises as to how the S&OP process should be designed to fulfil these requirements. Furthermore, the analysis in in Subsect. 3.2 provides the insight that the requirements are associable with different phases of CSI. *Can this insight be used while designing the S&OP process in an ETO environment?* This section explores this question through a discussion of concepts from literature that are considered relevant for the three CSI phases. The purpose of this discussion is not to provide conclusive guidelines for individual design elements of the S&OP process, e.g., meeting and collaboration, organization, information technology and tools, planning parameters, etc. [1]. Instead, the discussion aims to propose possible links between S&OP and other research areas that appear relevant based on the requirements identified in the case. These links can serve to identify relevant tools and/or practices to use within the design of the S&OP process.

Three main research areas within operations management (OM) literature emerge as relevant for S&OP process design in an ETO context based on the requirements identified in Subsect. 3.2, and the CSI phases they are associated with. These are:

1. *Customer Enquiry Management* – linked to project-sales (**R1**),
2. *Multi-Project Management* – linked to project-execution (**R2, R3** and **R4**),
3. *Spare Parts Management* – linked to after-sales service (**R4** and **R5**).

The first two research areas emerged from ETO literature that was identified using backward and cited reference searches, starting from a relatively recent systematic literature review on 'big-sized customized product manufacturing systems' [8]. While we found support for the requirements associated with after-sales service (i.e., **R4** and **R5**) in ETO literature [7], a particular research area that could be related to S&OP did not emerge from this literature. Consequently, keyword searches for terms like 'service parts', 'spare parts', 'after-sales', etc. were used on Scopus to identify relevant literature, from which the third research area emerged process.

These research areas and their overlaps with S&OP in an ETO environment, as seen in the case, have been visualized in a proposed framework shown in Fig. 2. The following three subsections briefly describe the link of each research area with S&OP in ETO environments, thus also serving as descriptions of the elements of the framework.

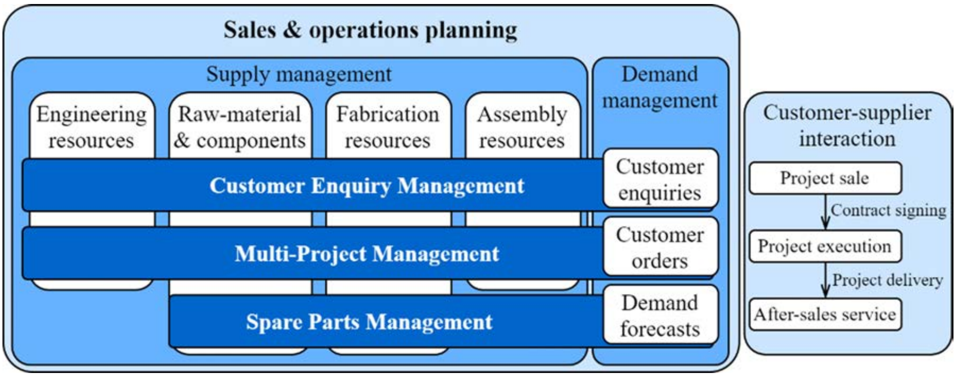

Fig. 2. A framework of S&OP in ETO production and related research areas

4.1 Customer Enquiry Management (CEM)

Customer enquiries and offer-preparation for responding to these enquiries are the first planning triggers for the order-fulfilment process in ETO environments, and serve as precursors to confirmed projects [9, 15]. *Customer enquiry* is used here as an overarching term for enquiries, tender invitations, Requests for Proposal (RFPs), sales leads and any other forms of information through which ETO companies identify potential projects or customer orders. The decision process that takes place in ETO companies between receiving a customer enquiry and the consequent processing of a confirmed order is referred to as CEM [15] or RFP-management [9]. The main decisions and activities within CEM are listed below.

- **Strategic filtering of customer enquiries** (a.k.a. *project selection* or *project portfolio management* [16]): deciding whether management wishes to make an offer for an enquiry, based on factors such as profitability of customer segment, development of core in-house competencies, long-term growth strategy, etc. [4, 15, 16].
- **Preliminary product engineering**: specifying preliminary technical characteristics and features of the product to match customer's requirements [9, 15]. The importance of this process is emphasized by the fact that the features of the technical solution are often the order-winning criteria in many ETO environments [17].
- **Macro process planning (MPP) and rough-cut capacity planning (RCCP)** (a.k.a. *project planning* and *aggregate capacity planning* respectively [9]): identifying main tasks within the order-fulfilment activities, i.e., engineering, procurement, fabrication, etc. and estimating aggregate activity durations and resource requirements for these activities to establish tentative project milestones [9, 16, 18].
- **Specification and negotiation of commercial characteristics of the project**: estimation of project cost and duration based on outputs of MPP and RCCP, e.g., activity durations, type of planned capacity – internal or subcontracted, etc. These estimates are used to quote price and delivery dates for customer enquiries, which may be followed by negotiation and/or replanning [9, 15, 16, 18].

Through CEM, managers and planners can control the selection of projects that are accepted, the delivery dates for accepted projects, and identify the need for any tactical capacity adjustments, e.g., through hiring personnel or subcontracting. Because of the role of CEM in controlling the workload imposed on internal resources on a tactical level, CEM can be considered closely related to S&OP. Moreover, CEM could be integrated as an element of S&OP, and tools and practices from CEM literature [15, 19] can be incorporated into the S&OP process in ETO environments.

4.2 Multi-project Management (MPM)

Hans et al. [16] define a project as a "unique undertaking consisting of a complex set of precedence-related activities that have to be executed using diverse and mostly limited company resources". In ETO environments, projects result in the production of products that are uniquely designed and/or engineered to fit customers' requirements, where each project requires resources for physical processes such as fabrication, assembly, testing, etc., and for non-physical processes such as product design and engineering, process planning, etc. [9]. Furthermore, each project requires material inputs that can be transformed into the finished product by fabrication and assembly processes. The finiteness of available resources and material create the need for MPM in ETO environments that execute multiple projects simultaneously [9, 16].

MPM refers to the ongoing process of creating and managing resource and material plans for multiple projects while ensuring that, firstly, schedules and milestones of individual projects are met, and secondly, mutually conflicting material and resource allocations to projects are avoided [16]. Through this, MPM plays a vital role in ensuring that resources and materials are available in the required quantity at the right time to meet delivery promises made during CEM. Because of this emphasis on ensuring realistic availability and allocation of material and resources, MPM plays a vital role in tactical level demand-supply balancing in ETO environments, emerging as another process that can be integrated with S&OP in ETO environments.

4.3 Spare Parts Management (SPM)

SPM collectively refers to demand management and inventory control for spare parts [20]. Spare parts are independent demand items which pose unique challenges within forecasting and inventory control due to the wide range of part characteristics usually found in OEMs' spare part portfolios [21]. Consequently, specialized tools and practices have been proposed in the SPM literature for SKU-classification, forecasting and inventory control [20], e.g., multi-criteria classification methods, forecasting methods for intermittent demand items, etc. These specialized tools and practices from SPM literature can be used in the S&OP process for tactical planning activities such as spare part demand forecasting, planning raw-material and component inventories, and allocating fabrication resources. Furthermore, integrating tools and practices from SPM, MPM and CEM into S&OP can support planners and managers in avoiding capacity and material conflicts across plans generated by SPM, MPM, and CEM.

5 Conclusions, Limitations, and Further Research

This paper has identified the requirements that are imposed on the design of the S&OP process by the characteristics of an ETO planning environment. The requirements, which were identified from a case study of a maritime equipment manufacturer, have been further linked to three research areas in extant literature, that can serve as relevant bodies of knowledge for guiding the design of the S&OP process in ETO environments. The findings were summarized in a high-level framework (Fig. 2).

The limitations of this study and the abundance of unexplored topics provide several directions for further work. Firstly, the study is based on a single case, which limits the generalizability of the findings across ETO contexts. Therefore, identifying S&OP requirements in other ETO contexts, understanding similarities and differences in S&OP requirements across these contexts and the planning environment attributes that lead to the differences can support development of generalizable and robust frameworks and models for S&OP in ETO environments. Secondly, despite undertaking a detailed single case study, this paper has only addressed S&OP design on a high level, i.e., by identifying design requirements and relevant bodies of knowledge to support the design. Future studies can explore how traditional design elements of S&OP, e.g., meeting and collaboration, organization, information technology and tools, etc. should be designed to fulfil the requirements of ETO contexts. Finally, the study has not exhaustively explored OM literature for concepts and research areas that can support S&OP design in ETO environments. Therefore, applications of other relevant concepts such as customer-order-decoupling-point, capable-to-promise, etc. should also be explored for further development of the proposed framework.

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Paper 2

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Tools and practices for tactical delivery date setting in engineer-to-order environments: a systematic literature review

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ABSTRACT
The research interest in topics related to production and supply chain planning and control in engineer-to-order (ETO) environments has grown significantly over the last three decades. One of the strategically important and challenging decision areas for planning and control in ETO environments is estimating and quoting feasible delivery dates and assessing the feasibility of customer-imposed delivery dates, collectively referred to as delivery date setting (DDS). While DDS has received substantial attention in literature, research supporting the process in ETO companies is fragmented – lacking clear guidelines for industrial practice and gaps to guide future research on the topic. To address these issues, this study systematically reviews literature supporting DDS in ETO environments, identifying tools and practices proposed in the extant literature, and proposing an agenda for future research. Findings suggest that most of the research has focused on developing planning and decision-support tools for tactical capacity planning to support reliable DDS, however, with a noticeable lack of alignment with industrial decision-support needs of ETO environments. Furthermore, despite previous research emphasising the importance of high levels of coordination and formalisation in the DDS process, there is a lack of research to guide practitioners in achieving high levels of coordination and formalisation.

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Engineer-to-order; delivery date setting; lead time estimation; sales and operations planning; tactical planning

1. Introduction

Manufacturing companies producing big-sized electromechanical equipment with complex product structures, such as machine tools, power generation equipment, maritime equipment, etc., are often characterised by an Engineer-To-Order (ETO) strategy, which entails designing and/or re-designing products to customise them based on customer-specific requirements (Alfnes et al. 2021; Hicks, McGovern, and Earl 2000). Order-fulfilment activities, i.e. activities performed to fulfil specific customer orders, in ETO environments include physical activities, such as procurement, fabrication, assembly, testing, etc.; as well as non-physical activities, such as tendering, design, engineering, process planning, etc. (Adrodegari et al. 2015; Amaro, Hendry, and Kingsman 1999; Bertrand and Muntslag 1993; Wikner and Rudberg 2005). Order-specific product customisation and the cumbersome and high-value components used in such products necessitate that these activities are partially or fully order-driven instead of forecast-driven (Adrodegari et al. 2015; Gosling and Naim 2009; Olhager 2003). The order-specificity of these activities creates a complex environment for production and supply chain planning processes in ETO companies (Mello et al. 2017; Stavrulaki and Davis 2010).

One of the production and supply chain planning processes, which is of high strategic importance for ETO companies, is the delivery date setting (DDS) process, which comprises of (1) estimating the delivery dates quoted before order-confirmation, e.g. in tendering, bidding, responding to customer enquiries or requests-for-proposal (RFPs), etc.; and (2) assessing the feasibility of meeting delivery dates requested or imposed by customers, alternatively known as the order acceptance decision (Carvalho, Oliveira, and Scavarda 2015; Hicks, McGovern, and Earl 2000; Zijm 2000; Zorzini, Stevenson, and Hendry 2012). The main challenge within DDS in ETO environments is determining the delivery lead time (i.e. "the time from the receipt of an order to the delivery of the product" (Chapman et al. 2017, 15)) required for executing the order-fulfilment activities while meeting the company's strategic objectives vis-à-vis operating costs, profitability, customer service, etc.

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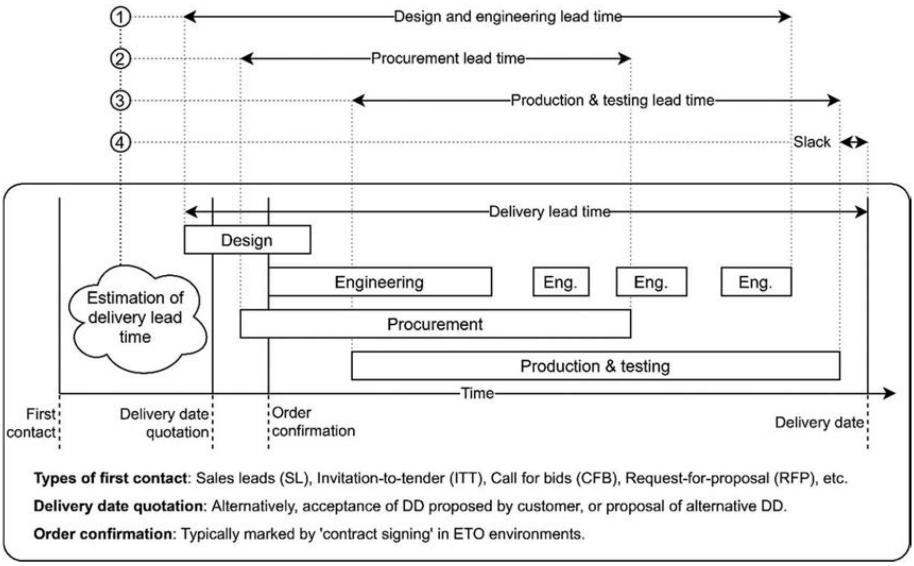

Figure 1. Typical order-fulfilment timeline in ETO manufacturing - adapted from illustrations by Iakymenko et al. (2018) and Semini et al. (2014).

ETO environments are typically characterised by long delivery lead times, owing to many order-driven activities (Zennaro et al. 2019). These long delivery lead times are comprised of design and engineering lead times, procurement or supplier lead times, and lead times for production, including fabrication, assembly, and testing (Alfnes et al. 2021). In some ETO contexts, lead times for commissioning, installation, etc., may also constitute significant parts of the delivery lead time (Adrodegari et al. 2015; Semini et al. 2014). Moreover, the different components of delivery lead times often overlap, e.g. due to parallel execution of engineering, procurement, and production activities (Cannas et al. 2019; Iakymenko et al. 2018). Figure 1 illustrates the delivery lead time components in a generic ETO order-fulfilment timeline.

Due to the characteristically long delivery lead times, delivery precision can be a key performance indicator for customer service levels in ETO environments, and in the long run, be a source of competitive advantage (Amaro, Hendry, and Kingsman 1999; Cannas et al. 2020; Grabenstetter and Usher 2014; Hicks, McGovern, and Earl 2000). Improving the reliability of delivery lead time estimation in the DDS process is one of the critical components of improving delivery performance in ETO environments (Hicks, McGovern, and Earl 2000). While the DDS process and its sub-processes, e.g. delivery lead time estimation, delivery date quotation, and delivery date feasibility assessment or order acceptance, have received a lot of attention in the literature, many extant studies focus on the needs of Make-to-Order (MTO) environments with no order- or customer-specific design and engineering, and do not address the needs of ETO environments.

Customer-specific design and engineering are vital features differentiating the ETO and MTO order-fulfilment strategies. This differentiation is crucial for delivery lead time estimation since customer-specific engineering activities introduce significant uncertainty in the delivery lead time in ETO environments (Alfnes et al. 2021; Shurrab, Jonsson, and Johansson 2020). Specifically, customer-specific engineering adds two main elements of uncertainty to delivery lead times, namely:

- Uncertainty in design and engineering lead times, as it is often difficult to predict the duration and number of iterations required before product drawings are finalised. This varies across customers due to, e.g. variations in customers' technical knowledge of the product, change behaviour, etc. (Shurrab, Jonsson, and Johansson 2020).
- Uncertainty in procurement and production lead times, as planning procurement and production activities is challenging before product specifications, process specifications, material requirements, capacity requirements, etc., are finalised (Alfnes et al. 2021).

Moreover, up to 70-80% of the value of ETO products may be created in the upstream supply chain (Gourdon and Steidl 2019), which further contributes to the uncertainty in delivery lead times in ETO environments.

Another factor differentiating DDS in ETO and MTO environments is the hierarchical decision level for setting delivery dates and executing the associated planning and estimation tasks. Within operations management literature, planning decisions and tasks are often classified hierarchically as strategic, tactical, or operational (Anthony 1965; Pereira, Oliveira, and Carravilla 2020; Stevenson 2015) – where the decisions and tasks on these levels usually differ in terms of their:

- planning horizons, i.e. long, mid-range, and short.
- decision scope, e.g. organisation or enterprise-wide decisions, cross-functional decisions, and function-specific decisions or tasks.
- organisational level, e.g. top-management level, middle-management level, and supervisory, execution or operative level.

The appropriate decision level for DDS in MTO environments has been debated by researchers for several years, with Kingsman, Tatsiopoulos, and Hendry (1989) perhaps marking the initiation of this debate. While some have argued that DDS should be considered a tactical decision in MTO environments (Ebadian et al. 2008; Ebadian et al. 2009), separating it from operational tasks of dispatching and detailed scheduling on the shop floor (Huang 2017), many others have continued to treat it as an operational level decision, integrating it with detailed scheduling in the shop-floor (Li and Ventura 2020; Oğuz, Sibel Salman, and Bilgintürk Yalçın 2010). However, for ETO environments, the classification of DDS as a tactical decision is almost unequivocal in literature, as described below.

In the hierarchical classification framework of strategic, tactical, and operational decisions, DDS in ETO environments best fits as a tactical decision that is characterised by high planning complexity and uncertainty, and should be addressed as part of the organisation's sales and operations planning (S&OP) process (Carvalho, Oliveira, and Scavarda 2015; Shurrab, Jonsson, and Johansson 2020). The high complexity of DDS emerges from that ETO environments are often multi-project manufacturing environments where a large number of factors must be considered for reliable DDS, e.g. engineering requirements and capacity, production capacity, material availability, suppliers' lead times, overtime and subcontracting costs, the strategic importance of individual customers, etc. (Adrodegari et al. 2015; Carvalho, Oliveira, and Scavarda 2015; Grabenstetter and Usher 2014; Shurrab, Jonsson, and Johansson 2020; Zorzini, Corti, and Pozzetti 2008; Zorzini, Stevenson, and Hendry 2012). Trends such as globalisation and global competition (Cannas et al. 2019, 2020) and outsourcing and offshoring (Stavrulaki and Davis 2010; Zorzini, Stevenson, and Hendry 2012) have further added to this complexity. The high uncertainty characterising DDS emerges from (1) other 'floating' quotations or unconfirmed orders (also known as contingent demand) when delivery dates for an order are quoted, and (2) partially undefined product and process specifications when delivery dates are quoted (Carvalho, Oliveira, and Scavarda 2015; Hicks, McGovern, and Earl 2000; Wullink et al. 2004). Due to typically long delivery lead times, DDS in ETO environments requires mid-range to long planning horizons (Zennaro et al. 2019), and significant uncertainty dictates that estimation of delivery lead times is usually based on rough-cut or aggregate planning (Adrodegari et al. 2015; Carvalho, Oliveira, and Scavarda 2015; Hans et al. 2007), which aim to balance supply and demand (Shurrab, Jonsson, and Johansson 2020). Collectively, these characteristics justify the classification of DDS in ETO environments as a tactical S&OP decision.

Previous literature suggests four main practices to manage the high complexity and uncertainty of DDS in ETO environments, namely,

(1) cross-functional coordination, i.e. information-sharing between different functions or departments, and joint decision-making to mitigate risks emerging from misaligned or conflicting objectives of different functions, and scatteredness of information such as customers' requirements, suppliers' lead times, engineering workloads, production workloads, etc. among different functions (Hendry and Kingsman 1989, 1993; Kingsman et al. 1993; Konijnendijk 1994; Zorzini, Corti, and Pozzetti 2008; Zorzini et al. 2008).
(2) supply chain coordination, i.e. information-exchange with key downstream actors, e.g. customers and sales agents, and upstream actors such as suppliers and subcontractors; and collaborative decision-making to mitigate risks emerging from unrealistic assumptions regarding suppliers' capacity availability, lead times, etc. (Alfnes et al. 2021; Hicks, McGovern, and Earl 2000; Zorzini, Stevenson, and Hendry 2012).
(3) formalisation of the DDS process, i.e. establishing clear and systematic process flows for activities that are performed for quoting delivery dates, and formalising the underlying decision-making procedures and decision-rules (Adrodegari et al. 2015; Zorzini, Corti, and Pozzetti 2008; Zorzini et al. 2008; Zorzini, Stevenson, and Hendry 2012).

(4) the use of software tools for planning and decision-support for effectively and systematically considering relevant factors for estimating lead times and determining delivery dates to be quoted (Adrodegari et al. 2015; Carvalho, Oliveira, and Scavarda 2015; Corti, Pozzetti, and Zorzini 2006; Grabenstetter and Usher 2014).

The main practices for DDS in ETO environments highlighted above point to four corresponding industrial application areas that research should support, i.e. mechanisms for *cross-functional coordination*, mechanisms for *supply chain coordination*, process frameworks and methodologies for *formalising the DDS process*, and development of *planning and decision-support tools* to support DDS. The identified application areas lead us to pose the research questions (RQs) that motivate this study.

RQ1: What tools, methods and frameworks are proposed in the literature to support delivery date quotation and order acceptance decisions in ETO manufacturing?

RQ2: What gaps and challenges should future research address to better support DDS in ETO manufacturing?

While several published studies address different issues within DDS in ETO and MTO environments, research on the topic is fragmented, lacking clear guidelines for industrial practice in ETO environments and a set of gaps to guide future research on the topic. To address this shortcoming of DDS literature vis-à-vis ETO environments, it is essential to (1) assess the extent to which DDS literature supports the application areas within DDS in ETO environments and (2) outline an agenda for future research on the topic. The current study aims to accomplish this through a systematic review of literature. The characteristics of extant DDS literature, as described below, necessitate a systematic review to address these research questions.

Firstly, as highlighted earlier, the type of industrial contexts that previous DDS studies have aimed to support varies from ETO (Ghiyasinasab et al. 2021; Micale et al. 2021) to MTO (Li and Ventura 2020; Oğuz, Sibel Salman, and Bilgintürk Yalçın 2010) and hybrid MTO/Make-to-Stock (MTS) (Rafiei and Rabbani 2012; Wang et al. 2019) environments. Therefore, while there are vast volumes of literature on the topics of DDS, lead time estimation, and order acceptance, not all of this literature offers relevant insights for the application areas within DDS in ETO environments. Secondly, while MTO and ETO environments may have different requirements vis-à-vis DDS, tools and frameworks proposed for MTO environments can sometimes be adapted to address the needs of ETO environments (Adrodegari et al. 2015). Therefore, it is also essential to assess which studies contextualised in MTO environments provide relevant tools, methods or frameworks that can be utilised or adapted for ETO environments. Finally, the ETO strategy has been adopted in a wide variety of industrial contexts that differ in (1) the complexity and level of customisation of products, (2) production processes and systems, (3) level of vertical integration, (4) planning methodologies and planning systems used, etc. (Adrodegari et al. 2015; Alfnes et al. 2021; Aslan, Stevenson, and Hendry 2015; Hicks, McGovern, and Earl 2000; Zennaro et al. 2019; Zorzini, Corti, and Pozzetti 2008; Zorzini et al. 2008; Zorzini, Stevenson, and Hendry 2012). As a result, different ETO environments also have unique requirements for tools and practices to support DDS that strategically fit the characteristics of their planning environment (Buer et al. 2016; Zorzini et al. 2008). This further necessitates analysis of tools and practices proposed in literature to assess their generalisability to different ETO contexts.

There are reviews in extant literature that address some DDS issues in ETO environments, however, only partly since they focus on other topics. For instance, Aslan, Stevenson, and Hendry (2012) focus in their literature review on assessing the applicability of enterprise resource planning (ERP) systems in MTO and ETO environments, identifying a need to develop tools for DDS that can be embedded within ERP systems. The authors corroborate this finding in a later mixed-method study (Aslan, Stevenson, and Hendry 2015). Hendry and Kingsman (1989) and Stevenson, Hendry, and Kingsman (2005) are older reviews with a similar perspective. Zennaro et al. (2019) review literature on MTO and ETO production environments, focusing on production systems that manufacture big-sized products. They identify models for defining price and delivery times, and models for capacity planning as two of the main research areas in these environments and identify some key contributions in these areas that are relevant for DDS, e.g. Grabenstetter and Usher (2014); Carvalho, Oliveira, and Scavarda (2015); etc. However, due to the exploratory nature and broader scope of their literature review, their coverage of the DDS-related research areas is limited to planning and decision-support tools. Other related literature reviews include Cannas and Gosling (2021) and Gosling and Naim (2009), where also, the authors adopt a broader perspective of supply chain management in ETO environments. In addition to identifying relevant planning and estimation tools (similar to Zennaro et al. (2019)), these papers also identify literature relevant for coordination between functions and with suppliers in ETO environments, e.g. Mello et al. (2017); Zorzini, Corti, and Pozzetti (2008); etc. However, these reviews also have a broader conceptual scope and do not focus on DDS-related research areas. Other reviews, such as Cheng and Gupta (1989); Gordon, Proth, and Chu (2002); Ragatz and Mabert (1984a); and Slotnick (2011), focus on operational level DDS, where DDS is often integrated with detailed scheduling and sequencing on the shop floor, which is not common practice in ETO contexts. Therefore, to the best of our knowledge, our study is the first to take the perspective of ETO manufacturing environments in systematically reviewing the literature on DDS, delivery lead time estimation, and order acceptance.

The remainder of the paper is organised as follows. Section 2 describes the methodology adopted for identifying, selecting, and analysing relevant literature. Section 3 presents descriptive statistics about the reviewed literature and summarises the main contributions from extant research in the four application areas identified earlier, addressing RQ1. Section 4 discusses the main gaps observed in the extant literature and proposes an agenda for future DDS research to better support ETO companies, addressing RQ2. Section 5 summarises the findings and contributions of this paper.

2. Methodology

This study adopts a systematic literature review (SLR) approach for answering the RQs presented in Section 1. The SLR approach is suitable for answering this study's main RQs as the underlying aim of the RQs is to (1) establish the state of the art on the topic (DDS) within a context of interest (ETO manufacturing), and (2) identify research gaps to serve as research agenda for future knowledge development on the topic to support industrial practice. The SLR approach focuses on transparency of the steps adopted in reviewing literature and has therefore been argued as an effective tool for laying the foundation for future research by uncovering areas where more research is required through analysis and synthesis of past research (Watson and Webster 2020; Webster and Watson 2002). Furthermore, in their seminal paper on systematic reviews in management studies, Tranfield, Denyer, and Smart (2003) highlight that SLRs not only contribute to theory development, but also support practitioners by developing "a reliable knowledge base by accumulating knowledge from a range of studies".

Our SLR follows the typical steps suggested by methodological references on SLRs within operations and supply chain management (Thomé, Scavarda, and Scavarda 2016; Tranfield, Denyer, and Smart 2003), similar to other recent SLRs (Cannas and Gosling 2021; Kristensen and Jonsson 2018; Pereira, Oliveira, and Carravilla 2020), namely: (1) formulating the problem; (2) searching and selecting literature; (3) analysing the data, and synthesising and interpreting the results. The following subsections provide an overview of these steps.

2.1. Problem formulation

The main factors motivating this SLR are described in Section 1. They can be summarised as (1) the strategic importance of DDS in ETO environments, (2) the complexity and uncertainty characterising DDS that make it a challenging task in practice, and (3) the lack of guidelines for practitioners and a future research agenda based on the state of the art of the topic in extant literature. These factors are further reinforced by industrial trends observed over the last decades, namely, increased globalisation and advancements in information and communication technologies. Globalisation has led to fiercer competition among globally dispersed ETO manufacturers and supply chains on performance dimensions such as price and delivery reliability (Alfnes et al. 2021; Cannas et al. 2020). Meanwhile, the growing emergence and viability of advanced communication and computation technologies, which are often encapsulated within the Industry 4.0 concept, create opportunities to address industrial problems through applications of technology that have not been feasible before (Zheng et al. 2021). However, establishing the state of the art and its gaps are prerequisites for exploring whether and how technological solutions could further the state of the art within DDS in ETO environments.

2.2. Literature identification and selection

The relevant literature for this SLR was identified using two databases - Scopus and WebOfScience. The search string used to identify literature was organised into three blocks of keywords – one *concept-related keyword block* and two *context-related keyword blocks*. Figure 2 shows the search string, visualising the three keyword blocks as components of a 'scoping funnel'.

The concept-related keyword block was initialised with terms such as 'lead time estimation' and 'delivery date setting', and gradually expanded as other relevant terms, e.g. 'customer enquiry management', 'tendering', etc., were identified using references from Zennaro et al. (2019). Initially, the search string was only comprised of the first two keyword blocks. The third keyword block was later added to focus the search results on manufacturing contexts since the ETO strategy has also been adopted in non-manufacturing contexts, such as the construction industry (Shurrab, Jonsson, and Johansson 2020). The keywords within each search block were connected with the *or* Boolean operator, and the three search blocks were connected with the *and* operator as shown in Figure 2.

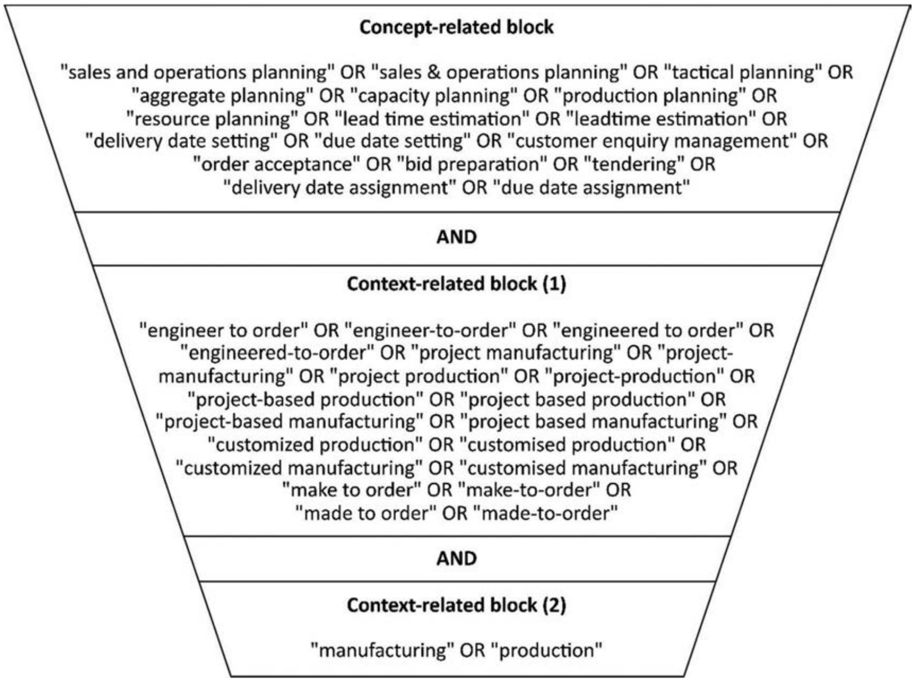

Figure 2. Keyword-search string visualised.

The search was constrained only to identify papers that contained the specified keywords in their abstracts, titles, or the paper's list of keywords.

Using the specified keywords and searching for literature up to and including October 2021, 582 results were retrieved from Scopus, and 398 from WebofScience, including journal articles, conference proceedings, and book sections. These results were exported into an EndNote library, where, after automated removal of duplicates, 627 results remained. Data for these 627 results, e.g. title, authors, year of publication, source name, etc., were exported to an Excel spreadsheet for record-keeping and analysis. After a manual screening for duplicates, nine other duplicate papers were identified and excluded, leaving 618 unique results.

The titles and abstracts of the 618 papers were screened for identifying and excluding irrelevant papers. During this screening step, we excluded papers (1) that were not in English; (2) focusing on topics unrelated or vaguely related to delivery date quotation, delivery lead time estimation, and order acceptance; and (3) concerning products or production environments producing products that cannot be characterised as structurally complex, e.g. food, apparel, etc. Consequently, 362 papers were excluded, leaving 256 papers for further consideration.

The full texts of the 256 papers were assessed to identify papers that should be included in the review. In this step, besides the three exclusion criteria stated above, we also excluded papers that (4) were literature reviews, conceptual or discussion papers that did not propose a specific tool, method, or framework for the decision-area of DDS; (5) did not have a full text published and available online; and (6) were not from a peer-reviewed source. Consequently, 182 of the papers were excluded, leaving 74 papers for the next steps in the review. Based on these 74 papers, 33 additional papers were identified through backwards and forward citation searches, resulting in 107 papers. The reader is referred to methodological papers on SLRs, e.g. Thomé, Scavarda, and Scavarda (2016), for a description of the backward and forward citation search technique.

The 107 identified papers focus on issues relevant to DDS, delivery lead time estimation or order acceptance, albeit in different production environments, namely, ETO, MTO, hybrid MTO/ATO, and hybrid MTO/MTS contexts. We performed a preliminary content analysis of these 107 papers to select papers that offered relevant insights, tools, methods, or frameworks for tactical DDS in ETO environments, leaving 54 papers for the final review and detailed content analysis. For the transparency of this preliminary content analysis, Table 5

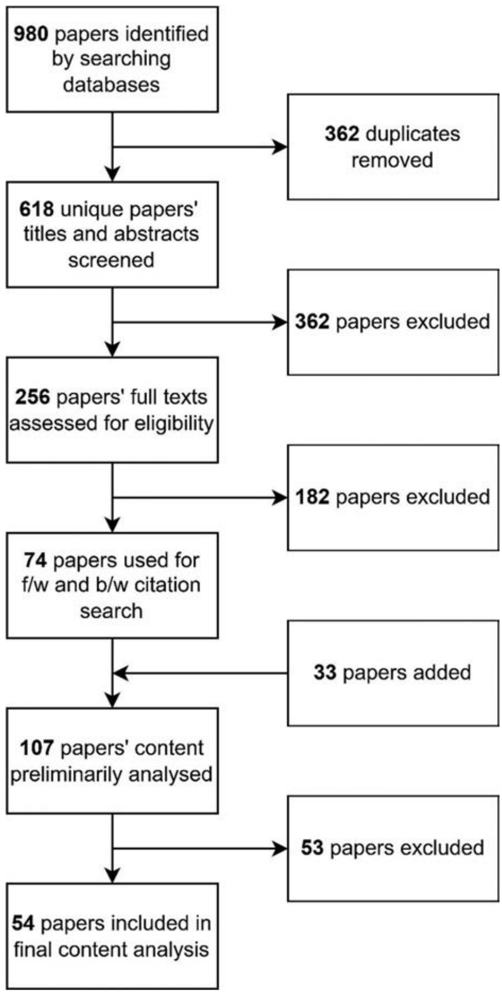

Figure 3. PRISMA flowchart illustrating the literature identification and selection process (adapted from Buer, Strandhagen, and Chan (2018) and Moher et al. (2009)).

in the Appendix summarises the 53 papers that were excluded in this step. Figure 3 summarises the literature identification and selection process in a PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flowchart, adapted from Buer, Strandhagen, and Chan (2018) and Moher et al. (2009).

2.3. *Data analysis and results' synthesis*

The content of papers included in the review was analysed using the four application areas within DDS (introduced in Section 1) as a guiding framework. The papers were classified according to each paper's application area(s). Different strategies were adopted for analysing the contributions within each application area.

For contributions within *cross-functional coordination* and *supply chain coordination*, the content analysis focused on (1) identifying relevant coordination mechanisms (tools and practices that facilitate coordination) proposed or described in the papers; and (2) identifying insights on the effect of contextual factors on coordination needs or requirements. For contributions within *DDS formalisation*, the content analysis focused on identifying frameworks or methodologies that can serve as a reference for designing and developing formal DDS processes in ETO companies. Finally, for contributions within *planning and decision-support tools for DDS*, the content analysis focused on (1) identifying the main problems within DDS addressed by the proposed tools; (2) identifying the different types of tools and techniques proposed for addressing the problems; and (3) identifying relevant dimensions to describe the proposed tools and logically cluster them. Table 1 shows how the results and research agenda for the four application areas are organised to address RQ1 and RQ2.

3. Results

This section presents the results of the content analysis of the reviewed literature. First, we present the distribution of the identified literature across different journals and years. These distributions are presented for DDS literature relevant for ETO environments, i.e. papers concerning tactical DDS; and the overall DDS literature, which includes papers from Table 5 in the Appendix. Next, subsection 3.1 categorises relevant papers based on the DDS application areas within which their contributions are positioned. Subsection 3.1 also describes the additional categorical dimensions for classifying the relevant literature identified inductively during the content analysis. Subsections 3.2, 3.3, and 3.4 summarise contributions from literature in the different application areas.

Table 1. Structure of results and research agenda for the four main application areas.

Application area	Subsections for relevant results (Section 3) and research agenda (Section 4)		
Cross-functional coordination	3.1 (classification of all reviewed papers)	3.2 (RQ1)	4.1 (RQ2)
Supply chain coordination			
Formalisation		3.3 (RQ1)	
Planning & decision-support tools		3.4 (RQ1)	4.2 (RQ2)

Table 2. Distribution of papers in different sources (journals and conference proceedings).

Source	Number of papers (tactical)	Number of papers (overall)
International Journal of Production Research	14	27
International Journal of Production Economics	12	15
European Journal of Operational Research	3	9
Computers and Industrial Engineering	2	3
Applied Mathematical Modelling	2	2
Production Planning and Control	2	2
Journal of the Operational Research Society	1	3
OR Spectrum	1	2
International Journal of Advanced Manufacturing Technology	1	2
Others – I (16)	16	16
Others – II (16)	0	26
Total	54	107

Table 2 shows the distribution of papers across journals and conference proceedings for papers relevant for tactical DDS and papers on DDS in general. As evident, the *International Journal of Production Research* and the *International Journal of Production Economics* have been the two leading outlets for research on the topic of DDS, irrespective of the decision level (i.e. tactical or operational). Moreover, almost 50% of the reviewed papers are from these two journals.

Figure 4 shows the distribution of published papers across the years. As noticeable, the early years until 1988 show no papers within tactical DDS, while the overall trend of the number of papers has been upward since 1989. This is consistent with the fact that Tatsiopoulos and Kingsman (1983) perhaps pioneered tactical DDS, being the first to argue that DDS is not necessarily an operational decision and should be considered on higher levels of decision hierarchy, following up on this in their later paper in 1989 (Kingsman, Tatsiopoulos, and Hendry 1989). A surprising observation is that despite the growing interest in literature on ETO manufacturing (Cannas and Gosling 2021; Zennaro et al. 2019), there have been no publications addressing DDS in ETO environments during recent years 2018–20.

3.1. Classification of literature supporting DDS in ETO manufacturing

The relevant literature has been selected such that each paper contributes towards one or more of the four main application areas within DDS in ETO environments, as identified in Section 1. Table 3 classifies the reviewed papers into one or more application areas based on the papers' contributions. In addition, the content analysis of papers revealed other dimensions that can be used to classify the papers, as described below.

- *Type of production system or configuration of production resources*, which identifies the type of manufacturing system considered, e.g. single-resource, job shop, assembly job shop (i.e. a job shop with an assembly stage), flow shop or line, etc. If the type of manufacturing system is considered an independent variable in the study, this dimension is labelled 'varied', implying that different resource configurations are considered.
- *Industrial context and order-fulfilment strategy*, which identify the industrial environment that the research is contextualised in or is motivated by, i.e. the industry sector or main products produced; and the order-fulfilment strategy of the industrial context, i.e. ETO, MTO, MTO/ATO or MTO/MTS.
- *Empirical nature*, which identifies the methodological positioning of a paper, following the classification adapted from Carvalho, Oliveira, and Scavarda (2015) and Jahangirian et al. (2010), into one of the following categories – practical problem-solving paper (class A), hypothetical problem-solving paper (class B), and methodological paper (class C). A paper is classified under class A if (1) the paper proposes a method or tool that has been applied in an industrial case, and (2) the paper provides implementation details and/or describes post-implementation improvements. A paper is classified under class B if (1) the paper addresses a problem that is motivated analytically, or (2) the paper briefly mentions a motivating practical context but does not explicitly present a specific industrial case or describe how data from the case has been used. A paper is classified under class C if (1) the paper addresses an analytically or practically motivated problem, testing the proposed method or technique on case data, but does not include practical implementation details or a post-implementation performance assessment, or (2) the paper addresses an analytically motivated problem without a specific industrial case and does not quantitatively assess the performance of the proposed method or technique. N.B. Exceptions from this classification scheme are

Table 3. Summary of reviewed papers.

Reference	Application area: CFC	SCC	Form.	Tools	Tool type	Production system	Technique (formulation / solution)	Opt. obj. / Perf. ind.	Emp. nature	Ind. context	OFS
Kingsman, Tatsiopoulos, and Hendry (1989)				✓	D	Job shop			C	Subcontracting company	MTO
Adam et al. (1993)				✓	M, H	Assembly job shop		Lead time, lateness, tardiness and %age of tardy jobs	B		
Hendry and Kingsman (1993)				✓	D	Job shop			C		
Kingsman et al. (1993)	✓			✓	D				C	High-tech. manufacturer	MTO
Kingsman et al. (1996)			✓	✓	D					Capital goods manufacturers and subcontracting companies	ETO and MTO
Roman and del Vallei (1996)				✓	H	Assembly job shop		Mean [earliness, tardiness, and flowtime], %age of tardy jobs, maximum tardiness, standard deviation of tardiness	B		
De Boer, Schutten, and Zijm (1997)				✓	D	Job shop, fixed pos.			C	Ship repair/maintenance yard	ETO
Kingsman and Mercer (1997)	✓			✓	D				C	Military equipment supplier	MTO
Özdamar and Yazgaç (1997)				✓	O	Flow shop / line(s)	Linear programming	Minimising total backorder and overtime costs	A	Kitchen cupboard manufacturer	MTO
Wang, Fang, and Hodgson (1998)				✓	O		Fuzzy optimisation	Minimising difference b/w delivery dates desired by the customer and feasible for the manufacturer	C	Furniture manufacturer	MTO
Easton and Moodie (1999)				✓	O	Single resource	Numerical optimisation	Maximising expected contribution from bid	B		MTO
Park et al. (1999)				✓	H, D	Assembly job shop		Rate of meeting promised delivery dates, processing time of enquiry, manufacturing costs	A	Rotating machinery manufacturer	MTO
Azevedo and Sousa (2000)		✓		✓	D				C	Semiconductor manufacturing	MTO
Kingsman (2000)			✓	✓	D				C	Subcontracting manufacturer	MTO
Ruben and Mahmoodi (2000)				✓	M	Varied		Average flow time and tardiness, and standard deviation of lateness	B		MTO
Hegedus and Hopp (2001)				✓	O		Analytical optimisation	Minimising sum of finished goods inventory holding cost, delay cost, and tardiness cost	C	Electronics assembly	MTO / ATO

(*continued*).

Table 3. Continued.

Reference	Application area				Tool type	Production system	Technique (formulation / solution)	Opt. obj. / Perf. ind.	Emp. nature	Ind. context	OFS
	CFC	SCC	Form.	Tools							
Calosso et al. (2003)		✓	✓	✓	O		Mixed-integer linear programming	Maximising profit and minimising (1) relative fluctuation in resource usage and (2) resource utilisation rate for customer request evaluation; Minimising (1) total cost, (2) relative fluctuation in resource usage and (3) resource utilisation rate for supplier bid evaluation	C	Business-to-business e-commerce	MTO
Moses et al. (2004)				✓	H	Job shop		Absolute flow-time estimation error and absolute lateness	B		MTO
Wullink et al. (2004)				✓	O	Job shop		Minimising expected costs over various scenarios	B		ETO
Ebben, Hans, and Olde Weghuis (2005)				✓	H	Job shop		Utilisation and service level	B		MTO
Corti, Pozzetti, and Zorzini (2006)				✓	H	Job shop			C		MTO
Robinson and Moses (2006)				✓	H	Job shop		Mean absolute lateness	B		MTO
Stevenson (2006)				✓	D	Job shop			C	Subcontracting and precision engineering	MTO
Hing, van Harten, and Schuur (2007)				✓	D	Single resource		Total average reward	B		
Kapuscinski and Tayur (2007)				✓	O	Single resource	Dynamic programming	Minimising total expected cost	B		MTO
Ebadian et al. (2008)		✓	✓	✓	O	Job shop	Mixed-integer programming	Minimising operating costs (sum of regular time, overtime, subcontracting and lateness penalty costs)	C		MTO
Wu and Liu (2008)				✓	H	Flow shop / line(s)			C	Manufacturer of integrated circuit packaging	MTO
Zorzini, Corti, and Pozzetti (2008)	✓		✓	✓	H	Assembly job shop			MCS	Capital goods manufacturers (electromechanical components, tool machinery, woodworking machinery, and textile machinery)	ETO and MTO

(*continued*).

Table 3. Continued.

Reference	Application area				Tool type	Production system	Technique (formulation / solution)	Opt. obj. / Perf. ind.	Emp. nature	Ind. context	OFS
	CFC	SCC	Form.	Tools							
Zorzini et al. (2008)	✓	✓	✓	✓	H				MCS	Capital goods manufacturers (tool machinery, plastic and rubber machinery, textile machinery, and packaging machinery)	ETO
Ebadian et al. (2009)				✓	D	Job shop			C		MTO
Arredondo and Martinez (2010)				✓	O	Single resource	Reinforcement learning (Average-reward Reinforcement Learning for Order Acceptance)	Maximising average revenue	B		
Alfieri, Tolio, and Urgo (2011)				✓	O	Assembly job shop	Mixed-integer linear programming	Minimising order-makespan	C	Machining centre manufacturer	ETO
Kalantari, Rabbani, and Ebadian (2011)				✓	O, D	Flow shop / line(s)	Mixed-integer linear programming	Minimising operating costs (sum of regular time, overtime, subcontracting and lateness/earliness penalty costs)	C		MTO / MTS
Alfieri, Tolio, and Urgo (2012)				✓	O	Assembly job shop	Stochastic programming	Minimising order-makespan	C	Machining centre manufacturer	ETO
Hemmati, Ebadian, and Nahvi (2012)			✓	✓	D	Assembly job shop			C	Domestic appliance manufacturer	MTO
Ioannou and Dimitriou (2012)				✓	M	Varied			C	Manufacturer of office furniture components	MTO
Parsaei et al. (2012)				✓	D				C	Manufacturer of vehicle belts	MTO
Rafiei and Rabbani (2012)				✓	D	Job shop			C	Manufacturer of wood products	MTO / MTS
Thürer et al. (2012)				✓	M, H	Assembly job shop		Shortness of lead time (measured as 95% reliable lead time) and mean lateness	B		MTO
Zorzini, Stevenson, and Hendry (2012)	✓	✓	✓	✓	H				MCS	Capital goods manufacturers (sorting machinery, vacuum forming and thermoforming machinery, textile machinery, laser cutting and waterjet cutting systems, injection moulding machines, industrial refrigeration and thermoregulation systems)	ETO and MTO

(*continued*).

Table 3. Continued.

Reference	Application area				Tool type	Production system	Technique (formulation / solution)	Opt. obj. / Perf. ind.	Emp. nature	Ind. context	OFS
	CFC	SCC	Form.	Tools							
Manavizadeh et al. (2013)				✓	O	Flow shop / line(s)	Metaheuristic (Simulated Annealing)	Minimising the operational costs (sum of regular time, overtime, outsourcing, lateness/earliness penalties and raw-material costs for all orders)	B		MTO
Wattanapornprom and Li (2013)				✓	D			Production cost, ending inventory cost, overtime cost	C	Parasol manufacturer	MTO / ATO
Grabenstetter and Usher (2014)				✓	M			Mean absolute lateness (MAL), standard deviation of MAL, proportion of tardy jobs	C	Manufacturers of motor control centre, switchboards, process instrumentation, switchgear, busway	ETO
Mourtzis et al. (2014)				✓	D	Assembly job shop			C	Injection mould manufacturer	ETO
Thürer et al. (2014)				✓	H	Varied		Percentage tardy, mean throughput, mean lead time	B		MTO
Yang and Fung (2014)				✓	O	Multi-site network	Mixed-integer non-linear programming, Branch-and-price	Maximising profit	B	Telecommunication equipment manufacturing	MTO
Adrodegari et al. (2015)			✓						MCS	Machinery building companies (different industrial machinery)	ETO
Carvalho, Oliveira, and Scavarda (2015)				✓	O	Assembly job shop	Mixed-integer linear programming	Minimising sum of production and overtime costs of processing incoming orders and accepted orders, capacity change cost, personnel payroll, and subcontracting costs	A	Manufacturer of high-pressure boilers and reactors	ETO
Carvalho, Oliveira, and Scavarda (2016)				✓	O	Assembly job shop	Mixed-integer linear programming, Monte Carlo simulation	Minimising sum of production and overtime costs of processing incoming orders and accepted orders, capacity change cost, personnel payroll, and subcontracting costs	A	Manufacturer of high-pressure boilers and reactors	ETO

(*continued*).

Table 3. Continued.

	Application area										
Reference	CFC	SCC	Form.	Tools	Tool type	Production system	Technique (formulation / solution)	Opt. obj. / Perf. ind.	Emp. nature	Ind. context	OFS
Mourtzis, Doukas, and Vlachou (2016)				✓	D	Assembly job shop			C	Injection mould manufacturer	ETO
Piya, Khadem, and Shamsuzzoha (2016)				✓	O	Flow shop / line(s)	Numerical optimisation	Maximising acceptance probability and profit	B		MTO
Brachmann and Kolisch (2021)	✓			✓	O		Mixed-integer programming	Minimising the total weighted lateness (earliness or tardiness), and minimising the cumulated negative (undertime) and positive (overtime) deviations from the regular capacity	C	Company engineering and manufacturing packaging machines for pharmaceutical industry	ETO
Ghiyasinasab et al. (2021)	✓			✓	O		Multi-objective optimisation	Minimising cost of work for regular time, overtime and outsourcing; project duration; and number of setups	A	Wood production for construction industry	ETO
Micale et al. (2021)				✓	O		Mixed-integer linear programming	Maximising the difference between the unit margin contribution of the new order and the sum of penalty costs due to delays in deliveries	C	Hydraulic marine and offshore crane-manufacturer	ETO
Total	7	5	9	53							

CFC: cross-functional coordination; **SCC**: supply chain coordination; **Form.**: formalisation; **Opt. obj.**: optimisation objective; **Perf. ind.**: performance indicator; **Emp. nature**: empirical nature; **Ind. context**: industrial context; **OFS**: order fulfilment strategy; **D**: decision-making procedure or decision-support system; **M**: mathematical model; **H**: heuristic for tactical planning or insights for tactical capacity planning heuristics; **O**: optimisation model; **A**: practical problem-solving paper; **B**: hypothetical problem-solving paper; **C**: methodological paper; **MCS**: multiple case study.

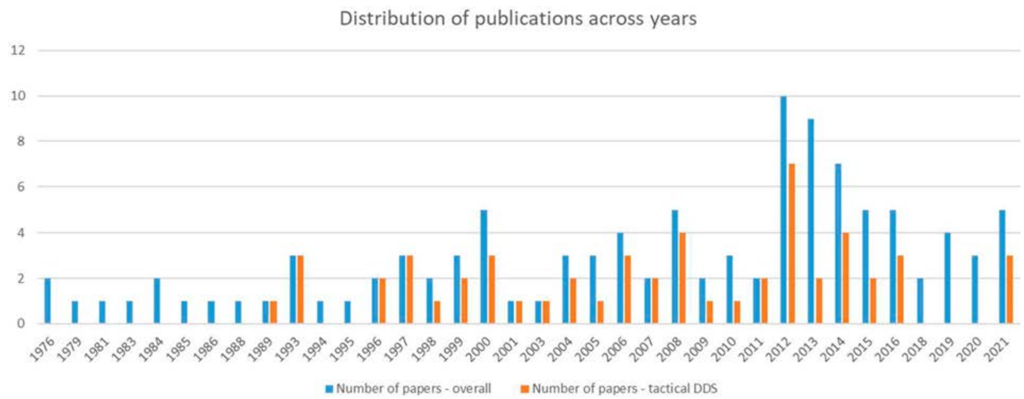

Figure 4. Distribution of publications across years - the overall number of papers and the number of papers concerning tactical DDS.

papers studying industrial practice in multiple companies, that are classified as 'multiple case study'.

Besides the dimensions described above, we identified additional dimensions that apply to papers in the application area of *planning and decision-support tools*, as described below and used in Table 3.

- *Type of tool*, which identifies whether a paper proposes or describes (1) an optimisation model (and the problem that the model addresses), or (2) mathematical models for representing lead times or delivery dates as functions of other variables and parameters, or (3) heuristics for tactical capacity planning or resource-loading, or (4) other decision-making methodologies and decision-support systems (and the decision addressed).
- *Technique(s) for optimisation modelling* identifies the approaches adopted for formulating and/or solving optimisation problems in the papers proposing optimisation models.
- *Optimisation objective or performance indicators used*, which identifies (1) the main objective pursued in optimisation in papers proposing optimisation models, or (2) the performance indicators used, if any, to evaluate the performance of proposed heuristics, mathematical models, or other decision-making methodologies.

As evident from Table 3, most of the papers are positioned within the application area of *planning and decision-support tools*, with some of these papers also addressing other application areas. Expectedly, most relevant papers are from MTO and ETO environments, and some others are from hybrid MTO/ATO or MTO/MTS environments.

3.2. Cross-functional and supply chain coordination

The positive influence of cross-functional coordination and supply chain coordination on the effectiveness of DDS has been extensively highlighted in literature, not only by studies focusing on DDS, e.g. Kingsman et al. (1993); Zorzini et al. (2008); and Zorzini, Stevenson, and Hendry (2012); but also studies focusing on other issues in ETO environments. For instance, in a mixed-methods study on the interface between marketing and manufacturing functions in ETO environments, Konijnendijk (1994) identify the uncertainty during lead time estimation and DDS for customer orders as the most significant challenge necessitating coordination between the marketing and manufacturing functions. Hicks, McGovern, and Earl (2000) highlight the importance of coordination during the quotation phase between different functions within the enterprise, e.g. sales/marketing, engineering, design, and procurement, and coordination with key suppliers. Highlighting the importance of aggregate capacity planning in the DDS phase, Zijm (2000) points out that this aggregate capacity planning in ETO companies should be cross-functional, considering not only manufacturing but also the design and engineering department(s).

Despite the criticality of cross-functional coordination and supply chain coordination for effective DDS, we found few studies with contributions that aim to enable or improve coordination in the DDS process in ETO environments. The few papers identified in this area can be grouped into two main clusters based on their contribution type. The first cluster consists of three studies that contribute insights into contextual factors that influence the need for cross-functional coordination and supply chain coordination in the DDS process in ETO environments. The second cluster consists of seven studies that propose methods, models, or frameworks for decision-support in cross-functional planning or collaborative planning and negotiation across tiers in the supply chain.

3.2.1. Contextual factors influencing coordination needs

In a multiple case study of DDS practices in 15 ETO and MTO capital goods manufacturers, Zorzini, Corti, and Pozzetti (2008) identify the main contextual factors affecting the cross-functional coordination requirements for effective DDS and order acceptance. These factors should be considered in the strategic selection of relevant coordination mechanisms based on the required level of coordination. The main factors affecting the level of cross-functional coordination needed are identified by Zorzini, Corti, and Pozzetti (2008) as (1) *level of product complexity*; (2) *degree of product customisation*; (3) *flexibility of production capacity*; and (4) *relevance of delivery time as an order winning criterion*; while two other secondary factors, namely, (5) *company size* and (6) *the number of tenders and orders managed annually* are also found to be relevant in some cases. They also propose four different levels of cross-functional coordination, namely, *no coordination*, *occasional coordination*, *ongoing coordination,* and *advanced coordination*, linking each coordination-level to a set of coordination mechanisms with increasing degree of sophistication, namely, e-mails and phone, on-demand meetings, standard documentation, periodic follow-up meetings, integrated information systems, and dedicated organisational roles for coordination.

Building on findings from Zorzini, Corti, and Pozzetti (2008), Zorzini et al. (2008) develop a contingency framework for the customer enquiry management or DDS process to study the effect of the design of DDS practices on delivery performance in 18 ETO capital goods manufacturing companies. Zorzini et al. (2008) identify *contextual uncertainty* as another important factor affecting the level of cross-functional coordination and upstream supply chain coordination (i.e. coordination with suppliers and subcontractors) required in the DDS process. Furthermore, Zorzini et al. (2008) find a high level of cross-functional coordination in the DDS process a best practice.

Zorzini, Stevenson, and Hendry (2012) expand the contingency framework proposed by Zorzini et al. (2008) through a study of the DDS process in seven ETO and MTO capital goods manufacturing companies, taking a supply chain perspective rather than scoping in on individual manufacturing enterprises. They identify factors affecting the required level of supply chain coordination in the DDS process as (1) *the level of vertical integration*; (2) *the number of tiers in the supply chain*; (3) *the number of actors in each tier*; (4) *the level of the geographical dispersion of suppliers and subcontractors*; and (5) *downstream actors' (customers/sales agents) level technical knowledge of the product*. They also find the *level of technical knowledge of the product and production system* in different departments within the company as a factor influencing the required level of cross-functional coordination in the DDS process. Furthermore, they identify the *proportion of customised orders* as a moderating factor between DDS process design and delivery performance, which has been overlooked in their previous studies (Zorzini, Stevenson, and Hendry 2012).

Figure 5 synthesises the findings from the papers summarised above into a conceptual framework of contextual factors affecting cross-functional and supply chain coordination needs in the DDS process. The proposed framework can serve as a decision-support tool for identifying the appropriate level of coordination and selecting relevant coordination mechanisms while designing or redesigning the DDS process in ETO companies.

3.2.2. Decision-support for planning across functions and supply chains

Kingsman et al. (1993) focus on the coordination between sales/marketing and production functions, proposing the use of *strike rate matrices* to facilitate this coordination. Their proposed methodology entails combining information from the production function, namely, pairs of production lead times and production costs for different scenarios, and information from the marketing function, i.e. order-winning probabilities (strike rates) for different pairs of lead times and prices (calculated from production costs) into a matrix that can serve as decision-support for the marketing function while quoting delivery dates. Kingsman and Mercer (1997) further elaborate the description of the methodology, describing the procedure for initialising and updating the matrices, and illustrate its application with an example of a military equipment supplier.

Azevedo and Sousa (2000) propose a component-based architectural design of a decentralised information system to address the decision-support requirements for order-promising in distributed MTO manufacturing enterprises. Calosso et al. (2003) model the process of interfirm negotiations with suppliers and customers in the DDS process in an MTO business-to-business electronic-commerce environment and propose mixed-integer linear programming models to address the decision-support needs of the focal MTO manufacturing firm as well as the customer and suppliers. Ebadian et al. (2008) focus on the decision-support requirements of

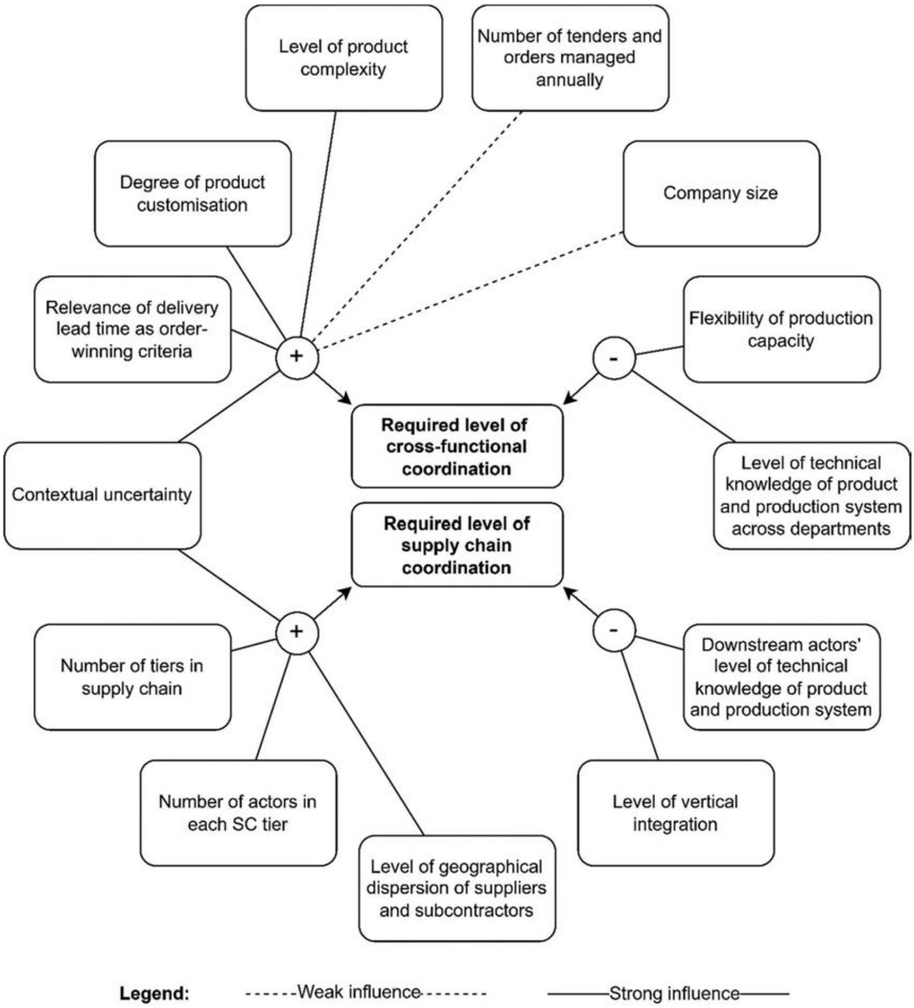

Figure 5. Conceptual framework of contextual factors affecting coordination needs based on findings from Zorzini, Corti, and Pozzetti (2008); Zorzini et al. (2008); and Zorzini, Stevenson, and Hendry (2012).

the focal MTO firm and propose two mixed-integer programming models to (1) determine the delivery time and price to be quoted for new orders by minimising production costs, and (2) determine the best set of suppliers and subcontractors for an order by minimising raw-material purchasing costs, subcontracting costs, and procurement lead times.

In recent contributions, Brachmann and Kolisch (2021) and Ghiyasinasab et al. (2021) propose decision-support models for tactical or aggregate planning in ETO environments taking a cross-functional perspective. Brachmann and Kolisch (2021) model a flexible resource-constrained multi-project scheduling problem (FRCMPSP) using mixed-integer programming and considering engineering and production resources in the model; and illustrate the utility of the model through the example of an ETO manufacturer of packaging machines for the pharmaceutical industry. Ghiyasinasab et al. (2021) propose a multi-objective optimisation approach for multi-project scheduling to support order acceptance in an ETO SME (small/medium-sized enterprise) supplying engineered wood to the construction industry, where engineering and production activities are incorporated into the proposed set of models.

Table 4. Contributions in the area of DDS formalisation.

Reference(s)	Contribution
Kingsman et al. (1996)	The high-level design of a decision-support system to address DDS problems observed in ETO capital goods manufacturers and MTO subcontracting companies. The proposed design visualises the information and process flows between the modules of the system, which correspond to different activities within the DDS process.
Kingsman (2000)	A high-level process model for the DDS process of an MTO subcontractor, where the proposed process model focuses on differentiating between manual decisions/activities and the activities performed within the proposed planning system.
Calosso et al. (2003)	A UML-based (Unified Modelling Language) process model of negotiations with suppliers and customers in the DDS process in an MTO business-to-business electronic-commerce environment.
Ebadian et al. (2008); Hemmati, Ebadian, and Nahvi (2012)	A decision-making structure for DDS in MTO environments, using simple flowcharts to model the process.
Zorzini, Corti, and Pozzetti (2008)	A process model for DDS in 15 ETO and MTO capital goods manufacturers, using a flowchart for process modelling.
Adrodegari et al. (2015)	A high-level process reference framework for production planning and control in ETO environments based on case studies of 21 ETO machinery building companies. The framework covers the main activities within the DDS process on a high level of activity-aggregation.

3.3. Formalisation

Formalising the DDS process entails establishing predefined procedures, decision rules, roles and responsibilities of the actors involved, information flows and workflows among the different actors, etc. Such formalisation can systematise decision-making in the DDS process, ensuring that any relevant factors and constraints are considered. Furthermore, predefined procedures and actors' roles and responsibilities may lower cross-functional barriers for information flow. However, achieving high levels of formalisation of the DDS process in practice can be challenging in ETO environments, and the level to which the DDS process can be formalised depends on a particular context's characteristics (Kingsman 2000; Kingsman et al. 1993; Konijnendijk 1994; Zorzini et al. 2008).

Due to the diversity or lack of homogeneity across different ETO contexts, designing and developing widely applicable planning systems and generally valid process models and frameworks has been difficult (Hicks and Braiden 2000; Zorzini et al. 2008). Nevertheless, process models and frameworks have been suggested as valuable tools for supporting the formalisation of business processes by externalising and making explicit the information flows and decision mechanisms that might otherwise remain tacit and hinder continuous improvement (Kalpic and Bernus 2002). Therefore, the contributions of the majority of the studies relevant for the application area of DDS process-formalisation are context-specific frameworks, which are summarised in Table 4. These frameworks can serve as initial references for developing process models or frameworks for DDS process-formalisation in other contexts. Exceptions to this type of contribution are the studies by Zorzini et al. (2008) and Zorzini, Stevenson, and Hendry (2012), which establish the DDS process's formalisation as a best practice through multiple case studies.

3.4. Planning and decision-support tools

As highlighted earlier, planning and decision-support tools represent the application area that most research within DDS has focused on. Contributions in this area include (1) optimisation models for planning and decision-support with explicitly stated objective function(s) and constraints, e.g. linear programming models (Özdamar and Yazgaç 1997), mixed-integer programming models (Calosso et al. 2003), dynamic programming models (Kapuscinski and Tayur 2007), stochastic programming models (Alfieri, Tolio, and Urgo 2012), etc., solved either with exact solution methods (Carvalho, Oliveira, and Scavarda 2015), or heuristics (Wullink et al. 2004; Yang and Fung 2014) and metaheuristics (Manavizadeh et al. 2013); (2) mathematical models or polynomial models representing lead times and/or delivery dates as functions of other variables and parameters, derived analytically or using regression-analysis (Grabenstetter and Usher 2014; Ioannou and Dimitriou 2012; Thürer et al. 2012); (3) heuristics for capacity planning or resource-loading (Corti, Pozzetti, and Zorzini 2006; Thürer et al. 2012) and insights for developing resource-loading heuristics in different contexts (Ebben, Hans, and Olde Weghuis 2005; Robinson and Moses 2006; Zorzini, Corti, and Pozzetti 2008); and (4) other procedures and methods for decision-making and decision-support systems (Kingsman, Tatsiopoulos, and Hendry 1989; Kingsman et al. 1996; Mourtzis et al. 2014; Parsaei et al. 2012). Using the criteria introduced in subsection 3.1, Table 3 summarises relevant papers' contributions. The main insights and observable trends, similarities, and differences from this body of literature are outlined below.

3.4.1. Optimisation models

The content analysis of papers proposing optimisation models to support DDS suggests the possibility to

Table 5. Summary of papers focusing on operational DDS (excluded from final content analysis).

Reference	Focus	Production system	Method/technique for DDA or OAS	Empirical nature	Industrial context
Eilon and Chowdhury (1976)	DDA	Job shop	Mathematical model	B	
Heard (1976)	DDA	Single resource	Dynamic programming	B	
Weeks (1979)	DDA	Job shop	Mathematical model	B	
Seidmann and Smith (1981)	DDA	Job shop	Analytical optimisation	B	
Bertrand (1983)	DDA	Job shop	Heuristic	B	
Baker (1984)	DDA	Job shop	Mathematical model	B	
Ragatz and Mabert (1984b)	DDA	Job shop	Mathematical model	B	
Bookbinder and Noor (1985)	DDA	Single resource	Mathematical model	B	
Cheng (1986)	DDA	Job shop	Mathematical model	B	
Bector, Gupta, and Gupta (1988)	DDA	Single resource	Linear goal programming	B	
Philipoom, Rees, and Wiegmann (1994)	DDA	Job shop	Neural network	B	
Smith, Minor, and Wen (1995)	DDA	Assembly job shop	Mathematical model	B	
Liao and Lin (1998)	DDA	Job shop	Mathematical model	A	MTO manufacturer of sewing machine parts
Moses (1999)	DDA	Assembly job shop	Reinforcement learning	B	
ElHafsi (2000)	DDA	Cellular	Analytical optimisation, Dynamic programming, Heuristic	B	Manufacturer of aluminium parts for automotive and home-appliance industries
Hopp and Roof Sturgis (2000)	DDA	Flow shop / line(s)	Mathematical model	B	
Hsu and Sha (2004)	DDA	Job shop	Artificial neural networks	B	Semiconductor wafer fabrication
Watanapa and Techanitisawad (2005a)	DDA	Single resource	Metaheuristic (Genetic algorithm)	B	
Watanapa and Techanitisawad (2005b)	DDA	Single resource	Heuristic (Pattern search)	B	
Öztürk, Kayaligil, and Özdemirel (2006)	DDA	Varied	Regression trees	B	
Alenezi, Moses, and Trafalis (2008)	DDA	Job shop	Support vector regression	B	
Sawik (2009)	DDA	Flow shop / line(s)	Integer programming	C	
Oğuz, Sibel Salman, and Bilgintürk Yalçın (2010)	OAS	Single resource	Mixed-integer linear programming	B	
Van Foreest, Wijngaard, and Van Der Vaart (2010)	OAS	Single resource	Heuristic	B	
Cesaret, Oğuz, and Sibel Salman (2012)	OAS	Single resource	Metaheuristic (Tabu search algorithm)	B	
Xiao et al. (2012)	OAS	Flow shop / line(s)	Integer programming, Metaheuristic (simulated annealing based on partial optimisation)	B	
Zhang and Wu (2012)	DDA	Job shop	Metaheuristic (probabilistic model-building genetic algorithm)	B	
Germs and Van Foreest (2013)	OAS	Single resource	Markov Decision Process	B	
Hao et al. (2013)	OAS	–	Reinforcement learning	B	
Lin and Ying (2013)	OAS	Single resource	Metaheuristic (Artificial Bee Colony)	B	
Nguyen et al. (2013)	OAS	Single resource	Metaheuristic (Genetic algorithm - NSGA-II) and Hyperheuristic (Genetic programming based hyperheuristic)	B	

(*continued*).

Table 5. Continued.

Reference	Focus	Production system	Method/technique for DDA or OAS	Empirical nature	Industrial context
Rasti-Barzoki and Hejazi (2013)	DDA	Single resource	Integer programming	B	
Thürer et al. (2013)	DDA	Job shop	Mathematical model, Heuristic	B	
Wang, Xie, and Cheng (2013)	OAS	Flow shop / line(s)	Metaheuristic (Artificial Bee Colony)	B	
Nguyen, Zhang, and Johnston (2014)	OAS	Single resource	Heuristic (Genetic programming-enhanced branch and bound)	B	
Park et al. (2014)	OAS	Single resource	Metaheuristic (Genetic programming-enhanced Tabu Search and Particle Swarm Optimisation)	B	
Zhong, Ou, and Wang (2014)	OAS	Single resource	Heuristic	B	
Lin and Ying (2015)	OAS	Flow shop / line(s)	Integer programming, Metaheuristic (multi-initiator simulated annealing)	B	
Rahman, Sarker, and Essam (2015)	OAS	Flow shop / line(s)	Metaheuristic (Memetic algorithm)	C	MTO manufacturer of sanitaryware
Thevenin, Zufferey, and Widmer (2015)	OAS	Single resource	Metaheuristic (Adaptive Memory algorithm)	B	
Nguyen (2016)	OAS	Single resource	Metaheuristic (Genetic algorithm - NSGA-II) and Hyperheuristic (Genetic programming based hyperheuristic)	B	
Thürer and Stevenson (2016)	DDA	Flow shop / line(s)	Mathematical model	B	
Silva, Subramanian, and Pessoa (2018)	OAS	Single resource	Heuristic (Iterated Local Search)	B	
Wu et al. (2018)	OAS	Job shop	Metaheuristic (Water flow-like algorithm)	B	
Bıçakcı and Kara (2019)	OAS	Single resource	Mixed-integer linear programming	B	
Rahman, Janardhanan, and Nielsen (2019)	OAS	Flow shop / line(s)	Metaheuristic (Hybrid Genetic Algorithm and Particle Swarm Optimisation)	B	
Wang, Zhang, and Yin (2019)	OAS	Flow shop / line(s)	Metaheuristic (Genetic Algorithm)	B	
Wang et al. (2019)	OAS	Job shop	Metaheuristic (Genetic Algorithm)	B	
Li and Ventura (2020)	OAS	Single resource	Dynamic programming	B	
Mundt and Lödding (2020)	OAS	–	Heuristic	C	
Schneckenreither, Haeussler, and Gerhold (2020)	DDA	Flow shop / line(s)	Artificial neural networks	B	
Bender and Ovtcharova (2021)	DDA	–	Mixed-integer linear programming	C	
Bıçakcı, Kara, and Sağır (2021)	OAS	Single resource	Machine learning (AutoML)	B	

differentiate the proposed papers based on four main criteria, namely, (1) the decisions or problems that the proposed model addresses within the DDS process, (2) their main underlying objective in the decision-making process, (3) the paper's empirical nature, and (4) the context guiding the formulation and assumptions of the proposed model. The main objective(s), the empirical nature, and the context of the papers in terms of the type of production system or configuration of resources, the industrial context, and the order-fulfilment strategy are summarised in Table 3. The main decisions addressed by the proposed models are summarised below, along with a discussion of their corresponding objectives.

Most of the optimisation models proposed for supporting DDS focus on the tactical capacity planning- or resource-loading problem, which entails planning production and/or engineering by allocating capacity to tenders/customer enquiries and confirmed customer orders over a time horizon of several weeks/months and quoting delivery dates (or assessing the feasibility of customer-requested delivery dates) based on such a finite capacity plan (Alfieri, Tolio, and Urgo 2011), where subcontracting and overtime can be used for adding capacity flexibility (Carvalho, Oliveira, and Scavarda 2015). The two exceptions are Hegedus and Hopp (2001), who focus on determining the optimal policy for quoting delivery dates under customer-requested delivery dates and uncertain procurement lead times; and Piya, Khadem, and Shamsuzzoha (2016), who focus on simultaneous negotiation of multiple orders. Two of the papers integrate tactical capacity planning with other decisions, namely, Easton and Moodie (1999), who integrate tactical capacity planning with pricing; and Calosso et al. (2003), who integrate tactical capacity planning with pricing and supplier selection.

Carvalho, Oliveira, and Scavarda (2015, 2016); Ebadian et al. (2008); Ghiyasinasab et al. (2021); Kalantari, Rabbani, and Ebadian (2011); Kapuscinski and Tayur (2007); Manavizadeh et al. (2013); Wullink et al. (2004); and Özdamar and Yazgaç (1997) propose models for tactical capacity planning with cost minimisation objectives. Besides a cost-minimisation model, Ghiyasinasab et al. (2021) propose additional models with project/order makespan minimisation and setup time minimisation objectives to facilitate comparative analysis of plans with different objectives. Alfieri, Tolio, and Urgo (2011, 2012) also propose models with makespan minimisation objectives. Other objectives for tactical capacity planning models include maximising profit or revenue (Arredondo and Martinez 2010; Calosso et al. 2003; Easton and Moodie 1999; Micale et al. 2021; Yang and Fung 2014), minimising the difference between promised- and customer-requested delivery dates (Wang, Fang, and Hodgson 1998), minimising lateness and overtime (Brachmann and Kolisch 2021), and minimising fluctuations in usage and utilisation rate of resources (Calosso et al. 2003).

While some of the papers consider delivery dates as endogenous or internally set, treating them as a model output (Easton and Moodie 1999; Kapuscinski and Tayur 2007; Özdamar and Yazgaç 1997), most others assume exogenous or customer-requested delivery dates as model constraints, e.g. Alfieri, Tolio, and Urgo (2011); and Carvalho, Oliveira, and Scavarda (2015). Ebadian et al. (2008) differentiate between negotiable and non-negotiable exogenous delivery dates, which suggests that delivery dates can be a 'hard' constraint in some problem instances while being a 'soft' constraint in other cases (Hvolby and Steger-Jensen 2010; Zorzini, Corti, and Pozzetti 2008).

Some of the above papers also incorporate uncertainty in optimisation, considering primarily two sources of uncertainty, namely, (1) uncertainty in resource requirements due to unpredictability of order-confirmation or acceptance of tender/bid by customer(s), i.e. contingent orders; and (2) uncertain activity duration or resource-requirements due to incomplete product- and process specifications, i.e. bill-of-materials (BOM) and routing. Uncertainty in resource requirements due to contingent orders is considered by Easton and Moodie (1999) in their capacity planning and pricing model and by Piya, Khadem, and Shamsuzzoha (2016) in their negotiation model. Uncertainty of activity duration and/or resource requirements due to incomplete BOM and routing has been addressed in literature through different scenario-based models for planning. Alfieri, Tolio, and Urgo (2012) propose a two-stage stochastic programming model, Carvalho, Oliveira, and Scavarda (2016) propose a robust optimisation model supported by Monte Carlo simulation, and Wullink et al. (2004) propose a single-stage stochastic programming model for tactical capacity planning under uncertain activity duration and/or resource requirements. Other papers use deterministic models to support scenario-based planning with a 'what-if' analysis of alternative plans (Carvalho, Oliveira, and Scavarda 2015; Ghiyasinasab et al. 2021).

3.4.2. Mathematical models

The second stream of literature within the application area of tools for planning and decision-support consists of papers that develop and/or test mathematical models to represent lead times as a function of other factors that are known or can be estimated. This stream consists of five papers whose contributions and findings are summarised and discussed below.

Adam et al. (1993) and Thürer et al. (2012) compare different mathematical models and heuristic procedures for lead time estimation in assembly job shops using simulation. Factors used in these papers for estimating production lead times include total work content or sum of processing times for a new order, work content on the critical path of a new order, and different measures of unprocessed work in the shopfloor, e.g. estimated waiting time and workload in queues at relevant work centres. Ruben and Mahmoodi (2000) also compare different mathematical models and heuristic procedures for lead time estimation, but in a shop with a single bottleneck work centre whose position varies. The considered mathematical models estimate lead times: (1) using workload in queues at all relevant work centres; or (2) only using workload in the queue at the bottleneck work centre; or (3) using workload in queues at the bottleneck and non-bottleneck work centres while differentiating between the two. Ioannou and Dimitriou (2012) derive analytical expressions for estimating lead times for dynamically updating manufacturing lead times in MRP (Material Requirements Planning)/ERP systems in MTO manufacturing environments with different resource configurations, where they model lead times as a function of the sum of processing times at the machines included in an order's production routing and the time spent waiting in queues in front of these machines. Grabenstetter and Usher (2014) develop the 'regression-driven complexity-based flow time prediction' (RegComp) method for estimating engineering lead times in ETO environments and illustrate the utility of the proposed method through the example of an ETO motor control centre manufacturer. They model engineering lead times as a function of (1) number of functional requirements, (2) number of basic components, (3) number of design interdependencies, (4) number of technologies, (5) number of regulations and standards, (6) number of sub-systems, and (7) presence of a reference job. Grabenstetter and Usher (2014) and the authors' earlier paper (Grabenstetter and Usher 2013) are valuable contributions to engineering lead time estimation within the DDS literature, which predominantly comprises papers focusing on production lead times.

While the papers from Adam et al. (1993); Ruben and Mahmoodi (2000); and Thürer et al. (2012) are originally positioned within operational DDS, these studies also offer valuable insights for production lead time estimation within tactical DDS in ETO environments because of (1) being contextualised in a production system with a moving bottleneck (Ruben and Mahmoodi 2000), and (2) being contextualised in assembly job shops (Adam et al. 1993; Thürer et al. 2012). Estimating production lead times based on bottleneck work centres can help simplify the task of estimation (Zorzini, Corti, and Pozzetti 2008). However, in practice, bottlenecks in the production process are often not stationary but shifting based on the production orders in the backlog (Mestry, Damodaran, and Chen 2011). The findings from Ruben and Mahmoodi (2000) provide insights into the conditions under which bottleneck-based production lead time estimation for tactical DDS may be effective in ETO environments. They find that bottleneck-based lead time estimation is most effective when the bottleneck is located early in the production process. Not surprisingly, they also conclude that the effectiveness of bottleneck-based lead time estimation decreases with increasing 'shiftiness' of the bottleneck.

Assembly job shops often characterise production environments producing complex products with multi-level product structures (Thürer et al. 2012), as is often the case for complex ETO products. Therefore, the studies of Adam et al. (1993) and Thürer et al. (2012) provide valuable insights into (1) the behaviour of assembly job shops, and consequently, (2) the type of methods that can be used in these shops to estimate production lead times. Findings from both of these studies suggest that simple heuristic procedures (i.e. critical path flow time procedure (Adam et al. 1993) and forward-finite-loading (Thürer et al. 2012)) outperform regression-analysis based mathematical models in lead time estimation accuracy. Furthermore, the findings of Thürer et al. (2012) demonstrate the utility of carefully developed resource-loading heuristics for production lead time estimation and DDS in complex production systems that characterise ETO environments.

The above discussion highlights (1) the inadequacy of using simple mathematical models or closed-form analytic expressions for estimating production lead times in tactical DDS in ETO environments and (2) the utility of heuristic procedures for the same. The discussion also underlines the trade-off between the simplicity of estimation methods and their corresponding estimation accuracy. Simple analytical expressions may be better received by practitioners as the basis for decision-support and estimation tools as compared to black-box optimisation tools (de Man and Strandhagen 2018), which may also be computationally burdensome for large problem instances (Alfieri, Tolio, and Urgo 2011, 2012). However, findings from Thürer et al. (2012) suggest that such simple mathematical models may not provide sufficient estimation accuracy. Therefore, carefully designed heuristics for resource-loading or tactical capacity planning can provide the practically essential balance between the simplicity of mathematical models and the accuracy of optimisation models for tactical capacity planning in ETO environments.

3.4.3. Heuristics for tactical capacity planning

This sub-subsection summarises the stream of literature that concerns the development of tactical capacity planning heuristics for DDS without formulating optimisation problems with formally stated objectives and constraints. Such heuristics can be effective planning and decision-support tools in industrial practice in ETO environments. They allow for the utilisation of domain- and context-specific knowledge of researchers and practitioners for circumventing the complexity of formulating and solving large-scale optimisation problems for tactical capacity planning, which often grow drastically in their computational complexity (Alfieri, Tolio, and Urgo 2012; Brachmann and Kolisch 2021; Micale et al. 2021) and may be under-preferred by practitioners in comparison to simpler, well-understood heuristic methods (de Man and Strandhagen 2018). This stream of literature includes (1) papers proposing heuristics that can be utilised as-is or adapted for tactical capacity planning and (2) papers providing insights that can be utilised for developing heuristics for tactical capacity planning.

Adam et al. (1993) propose the *critical path flow time* (CPFT) heuristic procedure for lead time estimation in assembly job shops and find its application advantageous for (1) single-level assembly jobs in terms of tardiness and percentage of tardy jobs, (2) two-level assembly jobs in terms of percentage of tardy jobs, and (3) three-level assembly jobs in terms of tardiness. Thürer et al. (2012) suggest further improvements to the CPFT procedure and find it outperformed by the *forward-finite-loading* (FFL) heuristic, suggesting FFL as the heuristic that should be preferred in practice due to its consideration of time-phased workload. Thürer et al. (2012) attribute the original development of the FFL heuristic to Bertrand (1983), referring to it as the *Bertrand approach*. In their comparative studies of different DDS methods, both, Thürer et al. (2012) and Moses et al. (2004) consider simulation-based heuristics called *simulation-based due date setting* (SIM) and *incremental forward simulation* (IFS) respectively for estimating delivery dates, which are both based on the simulation-based heuristic called *total work based on simulation* (TWSIM) proposed by Roman and del Vallei (1996). Results from the study of Thürer et al. (2012) suggest that the FFL heuristic also outperforms these simulation-based heuristics.

Park et al. (1999) develop a heuristic entitled *heuristic delivery date decision algorithm* (HDDDA) for DDS in an MTO electric motor manufacturing context, where the focus is on the bottleneck process, i.e. the final assembly. Corti, Pozzetti, and Zorzini (2006) propose a methodology for the feasibility assessment of customer-requested delivery dates based on capacity requirements, arguing that the 'what if' analysis feature distinguishes their approach from previous work. The proposed approach classifies potential orders under three classes: *feasible*, *feasible with capacity adjustments*, or *infeasible*. Wu and Liu (2008) propose procedures for determining delivery dates and assessing the feasibility of customer-requested delivery dates based on the bottleneck resource in a drum-buffer-rope system, illustrating the application of the proposed Capable-to-Promise (CTP) approach in MTO manufacturing of integrated circuit packaging. Their proposed approach provides a time-phased view of capacity-constrained resources' unused capacity and allows sales personnel to sell idle capacity more effectively.

Ebben, Hans, and Olde Weghuis (2005) and Robinson and Moses (2006) study the effect of granularity in resource-loading heuristics, where Ebben, Hans, and Olde Weghuis (2005) focus on the effect of considering aggregated capacity from multiple resources (*Aggregate Resource Loading* or *ARL* heuristic) versus considering the capacity for each resource individually (*Resource Loading per Resource* or *RLR* heuristic); and Robinson and Moses (2006) focus on the size of the time-buckets considered in resource-loading. Findings from these studies suggest that (1) heuristics considering individual resources should be preferred over those considering aggregated resources (Ebben, Hans, and Olde Weghuis 2005); and (2) the size of time-buckets used for resource-loading heuristics should be carefully selected based on context-specific considerations such as target utilisation and mean processing time (Robinson and Moses 2006). Other important factors to be considered in this decision are identified by Zorzini, Corti, and Pozzetti (2008) and Zorzini et al. (2008) in their multiple-case studies, e.g. level of product complexity, degree of product customisation, flexibility of production capacity, relevance of delivery time as an order winning criterion, contextual uncertainty, etc., with further supporting evidence provided by Zorzini, Stevenson, and Hendry (2012).

One of the essential inputs for developing tactical capacity planning heuristics is the capacity allocation strategy, i.e. forward loading or backward loading (Thürer et al. 2012), alternatively referred to as forward and backward planning (Zorzini, Corti, and Pozzetti 2008). Thürer et al. (2014) and numerous other papers (Corti, Pozzetti, and Zorzini 2006; Ebadian et al. 2008; Thürer et al. 2012; Zorzini, Corti, and Pozzetti 2008) highlight the link between the type of delivery dates (i.e. endogenous or internally set or negotiable versus exogenous or customer-imposed) and the type of capacity allocation strategy used in tactical capacity planning. The forward planning strategy is more suitable when delivery dates are set internally and then quoted to a customer or when delivery dates are requested by customers but are negotiable. On the other hand, the backward planning strategy is more suitable for order acceptance decisions for orders with fixed customer-imposed delivery dates. In practice, managers and planners may encounter both types of orders, which necessitates that heuristics proposed for tactical capacity planning can utilise both forward and backward planning strategies, as required.

3.4.4. Decision-making methodologies and decision-support systems

Besides the three categories of tools supporting DDS summarised in the previous three subsections, namely, (1) optimisation models, primarily for tactical capacity planning; (2) mathematical models for estimating lead times and delivery dates; and (3) tactical capacity planning heuristics; there are few other methodologies, frameworks, and decision-support systems proposed in the literature to support different decisions and tasks within DDS. The methodologies, high-level frameworks, and decision-support systems proposed in this stream of literature are summarised below.

In one of the earliest papers considering DDS as a tactical decision, Kingsman, Tatsiopoulos, and Hendry (1989) propose a methodology for managing customer enquiries in MTO environments that comprises three elements: aggregate production planning, strike rate analysis, and delivery date and price quotation. The production planning component of the methodology is further described by Hendry and Kingsman (1993) and Kingsman (2000), and the strike rate analysis component by Kingsman et al. (1993) and Kingsman and Mercer (1997). Kingsman et al. (1996) combine the methodological elements to conceptualise a decision-support system to address the needs of ETO capital goods manufacturers and MTO subcontracting companies. Later, Stevenson (2006) utilise methodological elements from Hendry and Kingsman (1993); Kingsman et al. (1993); and Kingsman (2000) to develop a decision-support system and study issues related to the implementation of the system in an MTO subcontracting company.

De Boer, Schutten, and Zijm (1997) discuss the elements of a decision-support system developed for capacity planning in an ETO ship maintenance facility, outlining a forward planning heuristic for tactical capacity planning for DDS (similar to the FFL heuristic from Thürer et al. (2012)), and discussing the resource-constrained project scheduling problem formulation for detailed project scheduling. Park et al. (1999) describe a decision-support system and underlying heuristics for bottleneck-based planning developed for capacity planning and DDS in MTO production of electric motors. Azevedo and Sousa (2000) describe the 'component-based' architecture of a decentralised information system developed for addressing DDS in an MTO production network in the semiconductor industry. Hing, van Harten, and Schuur (2007) explore the application of Reinforcement Learning (RL) for order acceptance in job shops using a Q-learning RL algorithm.

Ebadian et al. (2009) propose a methodology for prioritising customer orders based on a *customer attractiveness analysis* of different customers in MTO contexts, extending their previous work on decision-making within DDS (Ebadian et al. 2008). Kalantari, Rabbani, and Ebadian (2011) focus on the decision-support requirements for DDS in hybrid MTS/MTO production, proposing the use of fuzzy TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) to prioritise customer orders. Later, Hemmati, Ebadian, and Nahvi (2012) propose the application of TOPSIS for prioritising customer orders in the case of an MTO domestic appliance manufacturer. Parsaei et al. (2012) combine fuzzy AHP (Analytical Hierarchy Process) and TOPSIS for prioritising customer orders in the case of an MTO manufacturer of vehicle safety belts. In the case of a hybrid MTS/MTO producer of wood products, Rafiei and Rabbani (2012) propose a heuristic for determining the lot sizes for MTS and MTS/MTO product families.

Wattanapornprom and Li (2013) propose a framework for integrating Available-to-Promise (ATP) and CTP functions with Master Production Scheduling (MPS) in the case of an MTO/ATO parasol manufacturer. Mourtzis et al. (2014) propose a methodology for estimating lead times for orders based on their similarity to previous orders using Case-Based Reasoning (CBR), and Mourtzis, Doukas, and Vlachou (2016) implement the methodology as a mobile application that aims to address the needs of an ETO manufacturer of injection moulds.

4. Research gaps and future research agenda

Based on the content analysis of the papers summarised in the previous section, this section (1) outlines the main research gaps within DDS in ETO environments and (2) proposes an agenda for future research activities to address the outlined research gaps. Based on an overview of the reviewed literature and the distribution of contributions in different application areas, we consider it appropriate to organise the discussion of research gaps and proposed research agenda under two subsections, namely, (1) *formalisation and coordination*, which discusses the gaps and research agenda for three application areas within DDS – formalisation, cross-functional coordination, and supply chain coordination; and (2) *planning and decision-support tools*, which discusses the gaps and research agenda for the application area of the same name.

4.1. Formalisation and coordination

Within research relevant for DDS in ETO environments, we observe a general dearth of contributions to support (1) the formalisation of the DDS process; and (2) coordination among different functions or departments and across the supply chain. Only 14 of the 54 reviewed papers contribute towards formalisation or coordination in the DDS process. Despite findings from previous empirical research suggesting high levels of formalisation of the DDS process and coordination in the DDS process as best practices (Zorzini et al. 2008; Zorzini, Stevenson, and Hendry 2012), there is little research to support practitioners in achieving these high levels of formalisation and coordination.

There is a need to develop process models and reference frameworks for the DDS process that explicate the information flow between different actors involved to support practitioners in ETO environments in formalising the DDS process. Most of the previously proposed process models and frameworks (summarised in subsection 3.3) are contextualised in MTO environments. Furthermore, the modelling or mapping methodologies vary across extant models and frameworks, suggesting the need to explore which methodologies are suitable for mapping and modelling the DDS process in ETO environments. As previous literature has highlighted, ETO environments can differ significantly in their characteristics, and consequently, in their requirements for the DDS process (Hicks, McGovern, and Earl 2000; Zorzini et al. 2008; Zorzini, Stevenson, and Hendry 2012). Therefore, case studies in different ETO environments are expected to be vital for understanding these differences, and subsequently, for developing process models and reference frameworks for the DDS process. The three multiple case studies on DDS in the extant literature, i.e. Zorzini, Corti, and Pozzetti (2008); Zorzini et al. (2008); Zorzini, Stevenson, and Hendry (2012), are indispensable contributions for the general understanding of the DDS process in ETO environments. However, the diversity of manufacturing companies operating with an ETO strategy necessitates further case studies for improving our understanding of similarities and differences in DDS practices and norms across different industry sectors and geographical regions. Evidence from multiple case studies can also serve as a basis for developing typologies or taxonomies of ETO companies (Hicks, McGovern, and Earl 2001; Willner et al. 2016) based on their DDS requirements. Such typologies can facilitate clarification of generalisability and contextual limitations of DDS tools and practices across different ETO environments.

Extant operations management literature suggests maturity models as valuable tools for (1) documenting and diagnosing the current state of business processes and strategy implementation (Grimson and Pyke 2007; Wagire et al. 2021); and (2) planning process improvements and designing evolutionary paths to increase the effectiveness of business processes (Danese, Molinaro, and Romano 2018). Due to the lack of maturity models in the extant literature on DDS in ETO environments, developing maturity models for the DDS process is another important area for future research. There is also a need for empirical research to identify coordination mechanisms that ETO companies can use to address different coordination problems in the DDS process. While broader research on cross-functional coordination (Konijnendijk 1994; Nam et al. 2018) and supply chain coordination (Mello et al. 2017) in ETO environments can provide some insights for this, further research focusing on coordination problems within DDS is required to support coordination improvements in practice.

Exploring the applications of Industry 4.0 technologies for improving cross-functional and supply chain coordination in the DDS process in ETO environments represents another promising area for future research. Industry 4.0 technologies such as cyber-physical systems (CPS), Internet-of-Things (IoT), big data analytics (BDA), cloud computing, etc., have significantly expanded the solution space for solving many industrial problems in manufacturing companies over the last decade (Zheng et al. 2021). However, opportunities for utilising these technologies to address problems in ETO environments have not been sufficiently explored (Strandhagen et al. 2020; Zennaro et al. 2019), and the DDS process is no exception from this trend. Therefore, future studies should investigate whether and how Industry 4.0 technologies can be utilised for coordination improvements in ETO companies and supply chains in the DDS process.

Summarising the discussion above, the following points are proposed as agenda for future research on coordination and formalisation in the DDS process in ETO environments:

(1) Developing process models and reference frameworks to support DDS process design.
(2) Exploring suitable mapping or process modelling methodologies for DDS.
(3) Case research contextualised in different ETO industrial contexts and geographical locations.
(4) Developing typologies or taxonomies of ETO companies based on DDS requirements.
(5) Developing maturity models for the DDS process.
(6) Exploring applications of Industry 4.0 technologies for improving coordination in the DDS process.

4.2. Planning and decision-support tools

While the body of literature on planning and decision-support tools for DDS in ETO environments is larger than the literature on formalisation and coordination, there are crucial gaps that necessitate further research and development in this area. Firstly, we observe that most of the literature in this area has focused on supporting the estimation of production lead times and production resource-loading or capacity planning. While these are valuable contributions, they only partially address planning and decision-support requirements for delivery lead time estimation and DDS in ETO environments, where engineering and procurement lead times are essential elements of the delivery lead time. Very few papers propose tools or systems for planning and decision-support across functions, e.g. sales and production (Kingsman and Mercer 1997; Kingsman et al. 1993), or engineering and production (Brachmann and Kolisch 2021; Ghiyasinasab et al. 2021); and across supply chains (Azevedo and Sousa 2000; Calosso et al. 2003). Therefore, we consider a comprehensive view of delivery lead times in developing planning and decision-support tools in future research an important aspect of enriching DDS literature vis-à-vis ETO environments. The regression-based approach for estimating engineering lead times proposed by Grabenstetter and Usher (2013, 2014) is perhaps the only method of its kind in the literature. However, since the approach has been developed based on data from a single case company, it is essential to assess the broader validity of this approach in ETO environments. Therefore, future studies should undertake similar studies in other ETO environments to test and further develop the RegComp approach proposed by Grabenstetter and Usher (2014).

One of the main challenges in developing and implementing planning and decision-support tools for DDS in ETO environments is the lack of formalised knowledge and information; and reliance on managerial experience, expertise, and tacit knowledge (Adrodegari et al. 2015; Zennaro et al. 2019). Commercial enterprise information systems have been found inadequate in supporting business processes and decisions in ETO environments, partly because of the lack of alignment between business processes in ETO environments and the traditional manufacturing enterprise structures underlying commercial enterprise information systems (Aslan, Stevenson, and Hendry 2012, 2015). While managerial experience and expertise may continue to be essential for effective DDS in ETO environments, advances in data storage, processing, and computation technologies provide new opportunities for supporting managerial intuition with data-driven insights. Design and development of effective enterprise information systems focusing on business processes and decision-support needs of ETO companies is an important step in this, which computational or formal ontologies can support. Formal ontologies have been suggested in the extant literature as tools for "formal, explicit specification of a shared conceptualisation of a domain of interest" (Scheuermann and Leukel 2014; Studer, Richard Benjamins, and Fensel 1998), that can be utilised in the development of industrial information systems (Ameri et al. 2021; Křemen and Kouba 2011; Usman et al. 2013). Therefore, developing high-level and application-specific ontologies to support the development of planning and decision-support systems for DDS in ETO environments can be valuable contributions in future research.

As evident from the reviewed literature, almost half of all reviewed papers have focused on the tactical capacity planning or resource-loading problem, either proposing optimisation models for the problem with different objectives or proposing and/or testing different heuristics for tactical capacity planning without formulating it as a formal optimisation problem. Findings from papers proposing optimisation models for tactical capacity planning suggest that while these models provide useful insights into the behaviour of the modelled ETO systems, the computation times for solving these models with exact algorithms can grow drastically with an increase in the size and complexity of the modelled problem, e.g. number of activities in a project, degree of parallel execution of activities in a project, number of projects planned or replanned, etc. (Alfieri, Tolio, and Urgo 2011, 2012; Carvalho, Oliveira, and Scavarda 2015; Micale et al. 2021). For instance, Alfieri, Tolio, and Urgo (2011, 2012) call for future research to develop more efficient ad-hoc or heuristic algorithms for their proposed models due to the long computation times for larger problem instances. Furthermore, complex optimisation models that are not well-understood by users (planners and managers) and require long computational times have been found to negatively influence users' willingness to use such models in practice (de Man and Strandhagen 2018; Ivert and Jonsson 2011). Instead, simple, well-understood heuristics developed using tacit domain knowledge of managers and the understanding of system behaviour gained from optimisation models can be helpful decision aids for practitioners. Furthermore, we observe that most of the models proposed in the reviewed literature have been theoretically motivated without explicitly linking model development to the industrial need in a specific context, with few exceptions (Carvalho, Oliveira, and

Scavarda 2015, 2016; Ghiyasinasab et al. 2021). To narrow the gap between theory and practice in the area of planning and decision-support for DDS, we call for more class A (i.e. practical problem-solving) research in this area and emphasise that future development of tactical capacity planning tools should be motivated by practitioners' decision-support needs within DDS in specific ETO contexts, regardless of whether the proposed tools are exact optimisation-based or heuristics. Moreover, focusing on users' or stakeholders' needs and decision-support requirements may also provide better insights into whether users prefer sophisticated models that provide optimal solutions or near-optimal solutions derived from simple heuristics.

Finally, based on literature proposing heuristics for tactical capacity planning, forward- and backward-finite-loading are the most straightforward approaches for determining delivery dates and for assessing the feasibility of customer-imposed delivery dates, respectively. However, for using these loading methods for DDS in ETO environments, additional methods are required for developing comprehensive capacity planning heuristics. For instance, ETO products are often characterised by wide BOMs with numerous diverging branches for different sub-assemblies. As a result, it may be possible to produce components for various sub-assemblies in parallel. However, if the same resources are used for fabricating components for different sub-assemblies, this introduces new precedence constraints in tactical capacity planning, adding to the planning complexity. Therefore, if forward- or backward loading approaches are to be used, it is also essential to define the appropriate method for BOM-traversal for specifying which components and sub-assemblies should be prioritised in resource-loading, at least on the bottleneck resources. The problem is further complicated by the 'bottleneck shiftiness' in such contexts, which means that each resource-loading scenario may have a different set of bottlenecks. Therefore, while extant literature provides preliminary inputs and insights, there is a need for further research to develop effective resource-loading heuristics for ETO environments, which should also be motivated by practical needs in specific industrial contexts.

Summarising the discussion above, the following points are proposed as agenda for future research on planning and decision-support tools in the DDS process in ETO environments:

(1) Developing tools for cross-functional planning and decision-support in DDS.
(2) Further testing of engineering lead time estimation tools proposed in the literature.
(3) Developing ontologies to support the development of effective planning and decision-support systems for DDS.
(4) Developing heuristic algorithms for optimisation formulations proposed in extant literature that are computationally inefficient to solve with exact solution algorithms.
(5) Documenting managerial decision-support needs for effective DDS in ETO environments and developing planning and decision-support tools based on industrial requirements.
(6) Further developing tactical capacity planning heuri stics such that practical aspects such as complex product structures, parallel execution of activities, bottleneck shiftiness, etc., are accounted for.

5. Conclusion

This paper investigates the state of the art within DDS and delivery lead time estimation focusing on the needs of ETO manufacturing environments. A systematic literature review approach is adopted to (1) identify the tools, methods and frameworks proposed in the literature for supporting DDS in ETO environments; and (2) identify the gaps in extant research and formulate an agenda for future research. We differentiate between tactical DDS and operational DDS from the outset, considering only the former to be relevant for ETO environments. This differentiation also serves as the basis for one of the literature exclusion criteria in our methodology. The content analysis and summary of contributions from the reviewed literature are structured using a framework of four industrial application areas for research within DDS, namely, cross-functional coordination, supply chain coordination, process formalisation, and tools for planning and decision-support. These application areas also serve as the basis for discussing gaps in extant research and formulating an agenda for future research.

We find that despite previous research emphasising the importance of high levels of cross-functional coordination, supply chain coordination and formalisation in the DDS process in ETO environments, there is little research focusing on how these high levels of coordination and formalisation should be achieved in practice. Various initiatives that can be undertaken in future research to address this gap are discussed, e.g. empirical and inductive development of process models and frameworks for DDS, development of maturity models for the DDS process, cross-industry and cross-geography studies to elucidate differences and similarities in DDS practices, etc.

While many papers propose tools for planning and decision-support, most of these tools only address lead time estimation for the production process. To address the needs of ETO environments, where procurement and engineering lead times form significant portions of the delivery lead times, we call for a more comprehensive perspective of delivery lead times in future research on DDS in ETO environments. Furthermore, we find the majority of the papers proposing tools for planning and decision-support to be theoretically motivated, where industrial cases are used, if at all, to illustrate the application of the proposed tool. Instead, we call for future research to adopt more inductive methodologies, similar to Carvalho, Oliveira, and Scavarda (2015, 2016); Ghiyasinasab et al. (2021), and use industrial cases and practitioners' decision-support needs as the fundament for developing planning and decision-support tools. As a prerequisite for this, future studies should also focus on describing and documenting industrial problems and the decision-support needs of practitioners.

To the best of our knowledge, this paper is the first systematic literature review on DDS in ETO environments where the existing knowledge on the topic has been analysed, and the agenda for future knowledge development has been presented. Furthermore, the paper compiles and summarises contributions from extant literature, which is expected to be helpful for the interested researchers and practitioners. Moreover, a secondary contribution of this paper is the identification of papers within operational DDS, which were excluded in the last stage of the literature identification process and are summarised in the Appendix in Table 5. A limitation of this study is that only two scholarly databases were used for identifying literature, which may have limited the coverage of literature. We expect that the forward and backward citation searches have contributed to minimising the negative impact of this limitation.

Data availability statement (DAS)

The data related to the final list of papers included in the systematic literature review is included in the manuscript, and any additional data about the papers can be made available by the authors upon request.

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Appendix

Table 5 summarises papers excluded from the review because of their focus on operational DDS. The items of reporting for these papers are:

- Focus, which identifies whether the paper focuses on assigning delivery dates (delivery date assignment/due date assignment/DDA) or assessing the feasibility of customer-specified delivery dates based on detailed scheduling (order acceptance and scheduling/OAS).
- Production system (described in subsection 3.1).
- Method/technique used in the paper for DDA or OAS.
- Empirical nature (described in subsection 3.1).
- Industrial context (described in subsection 3.1).

Paper 3

Bhalla, Swapnil, Erlend Alfnes, Hans-Henrik Hvolby, and Olumide Emmanuel Oluyisola. 2022. “Sales and operations planning for delivery date setting in engineer-to-order manufacturing: a research synthesis and framework.” *International Journal of Production Research*:1-31. doi: https://doi.org/10.1080/00207543.2022.2148010.

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

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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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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)

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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

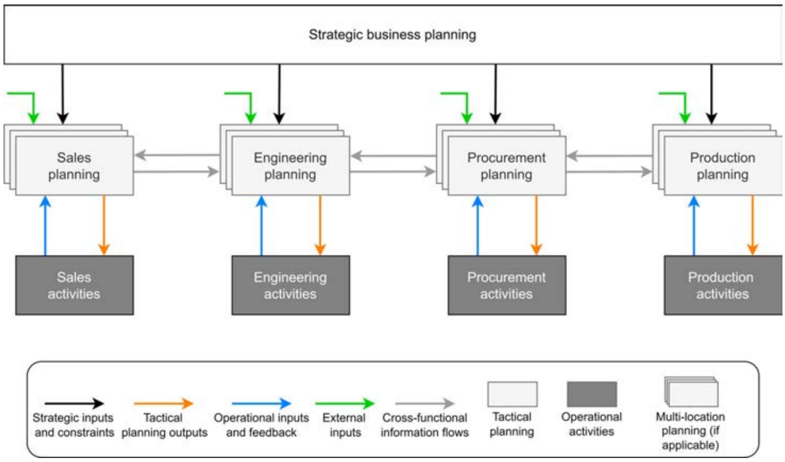

Figure 1. Overall framework for S&OP in ETO contexts (adapted from Pereira, Oliveira, and Carravilla (2020) and Nam et al. (2018)).

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'

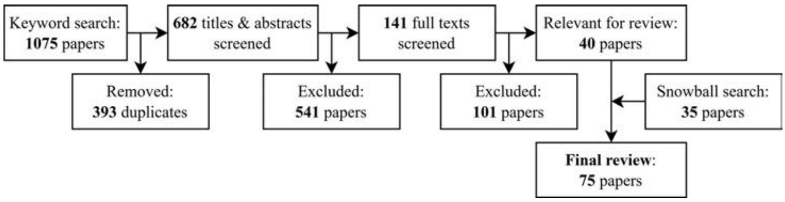

Figure 2. PRISMA flowchart for the process of identifying and selecting literature.

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.

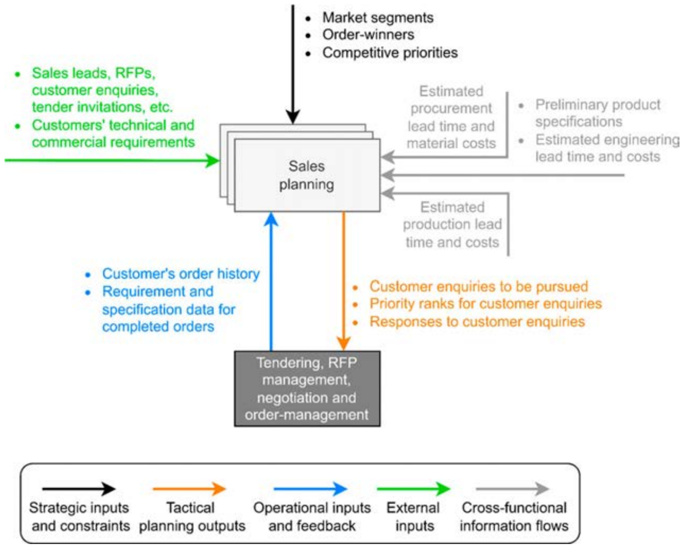

Figure 3. Tactical sales planning – information inputs and planning outputs.

- 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

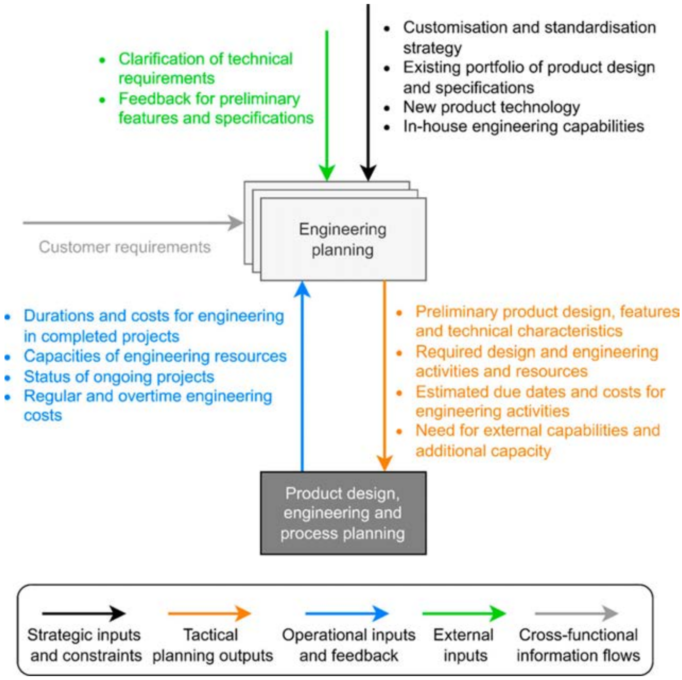

Figure 4. Tactical engineering planning – information inputs and planning outputs.

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.

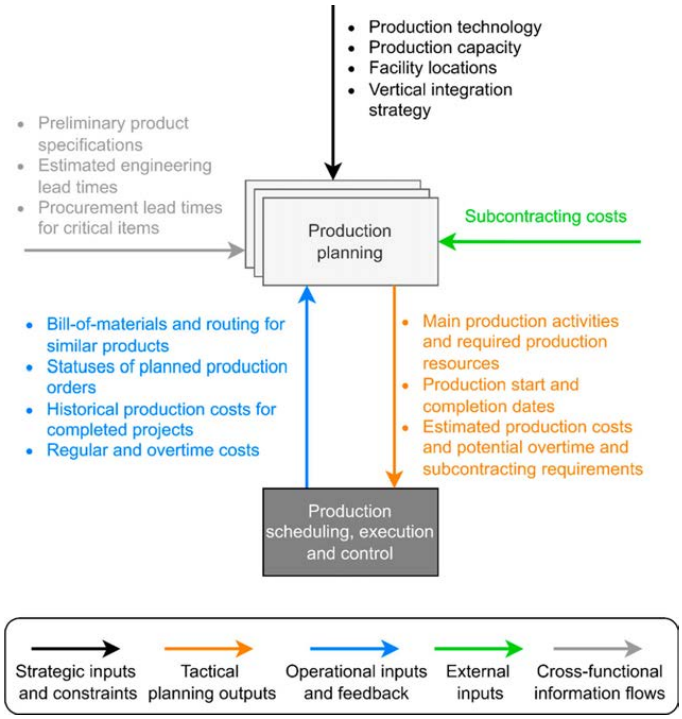

Figure 6. Tactical production planning – information inputs and planning outputs.

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

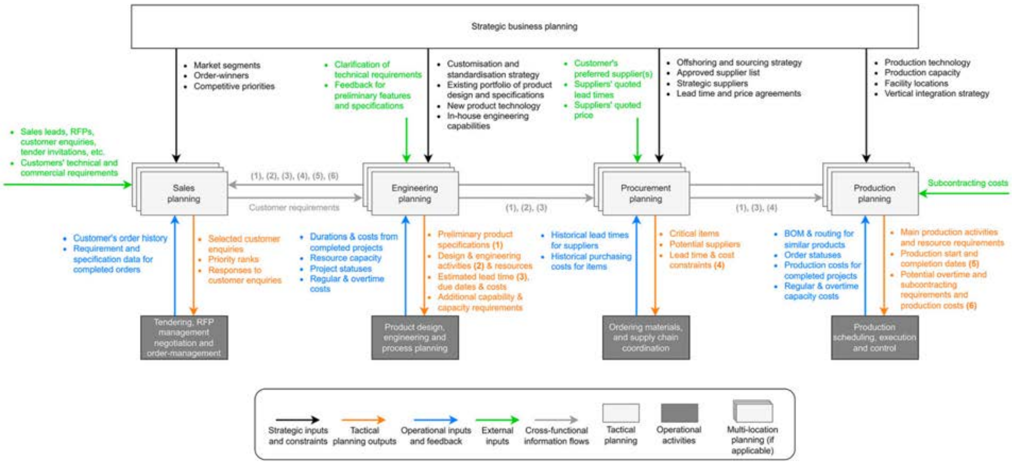

Figure 7. Proposed S&OP reference framework for setting delivery dates in ETO contexts.

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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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.

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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

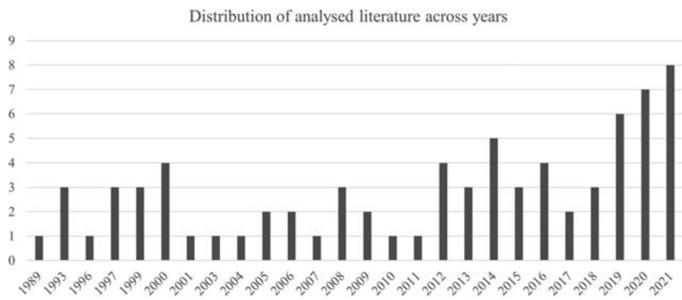

Figure A1. Distribution of papers across years.

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

	Planning activities				Information flow or input				
Reference	Sales	Engineering	Procurement	Production	Strategic	External	Operational	C/F	Type of contribution
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.

	Planning activities				Information flow or input				
Reference	Sales	Engineering	Procurement	Production	Strategic	External	Operational	C/F	Type of contribution
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.

Paper 4

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Sales and Operations Planning for Delivery Date Setting in Engineer-to-Order Maritime Equipment Manufacturing: Insights from Two Case Studies

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Abstract. Delivery date setting (DDS) is a challenging and competitively critical tactical decision in engineer-to-order (ETO) environments, which requires integrated planning for effective decision-making. Despite the variety of industrial contexts in DDS literature, the maritime equipment industry has been an unexplored context vis-à-vis planning needs for effective DDS. This study uses a sales and operations planning (S&OP) framework to investigate the current state of the DDS process of two maritime equipment suppliers. Findings indicate that the low market demand over the last few years has influenced the DDS process design in the companies, suggesting that the process should be reconfigured to remain effective under periods of high demand. More cases from the maritime equipment industry are needed to assess if the findings are valid across the industry.

Keywords: Tactical sales and operations planning · Delivery date setting · Engineer-to-order

1 Introduction

Maritime equipment such as engines, propellers, thrusters, cranes, winches, etc., for ships are complex, high-value, electromechanical products that are often customized according to the requirements of ship owners, designers, and engineers. Adopting such an engineer-to-order (ETO) strategy for delivering customized equipment allows maritime equipment suppliers to deliver technologically competitive and innovative solutions to their customers [1]. However, operating with an ETO strategy also creates substantial uncertainty in product specifications, process specifications, and delivery lead times, making delivery date setting (DDS) a complex and challenging task [1, 2]. The DDS process and effectiveness can be competitively critical for winning orders in ETO contexts [3, 4]. The planning needs for effective DDS vary across ETO companies and industry sectors [2, 5], and case studies from various ETO contexts can be found in the extant DDS literature, e.g., industrial machinery production [2, 6, 7], boiler and reactor

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manufacturing [8], engineered wood production [9], industrial electrical and electronic equipment [10], etc. However, there are no case studies on the DDS practices of maritime equipment suppliers in the extant literature, and studying these practices in unexplored industrial contexts is one of the main research needs for establishing a common reference framework for tactical planning activities across ETO contexts [5]. This paper aims to contribute to this research need by investigating the DDS practices in the maritime equipment industry using the case research approach. The paper studies these practices based on a modest case sample of two case companies to ensure greater detail for the studied cases and the contextual factors affecting DDS practices in the cases. The paper investigates the two equipment suppliers' DDS practices using a tactical sales and operations planning (S&OP) theoretical framework presented in Sect. 2. Section 3 presents findings from the case studies. Section 4 concludes the paper by summarizing the implications of the main findings.

2 Theoretical Framework

The ETO strategy has been widely adopted by companies producing complex, big-sized, industrial products that are often too high-value and customer-specific to be mass-produced [11]. The order-winning process in ETO environments usually entails a tendering or customer enquiry stage, where a customer's technical and commercial requirements are translated to preliminary specifications of the product and estimated commercial characteristics of order-fulfillment such as price and delivery dates [1, 12]. Setting these delivery dates is usually a tactical planning decision in ETO environments, which entails creating preliminary aggregate plans and roughly estimating quantities, flow times, and resource requirements [8, 9, 13].

DDS is a complex decision since there are various order-fulfillment activities, e.g., design, engineering, procurement, fabrication, assembly, testing, etc., whose lead times should be considered while setting delivery dates in ETO environments [9, 14, 15]. Furthermore, due to varying levels of customer-specificity of these order-fulfillment activities, variables affecting the activity lead times, i.e., product specifications, material requirements, resource requirements, etc., are often uncertain [1, 2, 4]. These characteristics of DDS in ETO companies create a uniquely complex and uncertain context for tactical planning. Extant research on DDS in ETO environments suggests formalization of the tactical planning process and integrated planning across functions as best practices for managing the complexity and uncertainty of DDS [2, 7, 9, 14, 16]. Integrated planning across functions enables cross-functional information sharing and coordination and ensures that relevant factors are considered in the planning process. Formalizing the planning process standardizes or systematizes planning and decision-making with predefined rules and procedures that ensure the involvement of relevant actors in planning and decision-making based on explicitly stated objectives or priorities.

While previous DDS research emphasizes the importance of formalizing and integrating the tactical planning process for effective DDS, the extant literature has lacked frameworks that can support companies in adopting these practices [5]. Meanwhile, sales and operations planning (S&OP) has emerged as an approach for integrated tactical planning, whose applications in ETO environments have been essentially overlooked in the extant research, despite its potential to address the complexity and uncertainty characterizing tactical planning and DDS in ETO environments [17]. S&OP integrates tactical planning across functions and supply chains, effectively balancing demand and supply while aligning plans for operational activities with strategic objectives and constraints [18]. Linking S&OP with DDS in ETO environments, **Table 1** shows a framework of the main S&OP activities for DDS, clustered under four main planning functions for sales, engineering, procurement, and production, which also correspond to the four main supply chain functions in ETO environments [19].

Table 1. The theoretical framework of S&OP activities for DDS in ETO environments

Planning function	Planning activities	Ref
Sales planning	Selecting customer enquiries	[2]
	Prioritizing customer enquiries	[12]
	Determining delivery lead time, date, and price	[20]
Engineering planning	Defining preliminary product specifications	[1, 12]
	Determining detailed engineering activities and resources	[1, 12]
	Estimating lead times and costs and setting due dates	[9, 10]
	Identifying external capability and additional capacity needs	[1, 9]
Procurement planning	Identifying critical items	[7, 14]
	Selecting potential suppliers	[7, 14]
	Determining procurement lead times and prices	[14, 21]
Production planning	Identifying main production activities & resource requirements	[8, 12]
	Identifying feasible production start and end dates	[8, 9]
	Estimating production costs & non-regular capacity requirements	[8]

3 Case Studies

The Norwegian shipbuilding and maritime equipment industries are known for their high-quality, highly customized, and innovative products [22–24], with the widespread adoption of the ETO strategy [1, 21, 25]. Maritime equipment suppliers base the fundamental designs of their products on the targeted customer segments (i.e., ship types) and the requirements imposed by the codes, standards, and rules specified by ship classification societies such as DNV (Det Norske Veritas) and Lloyd's Register. Relevant systems and sub-systems can be selected from these basic designs, and their specifications may be modified and combined in different configurations to address specific customers' requirements. The level of customization offered by equipment suppliers may vary across market segments and companies [1].

The operating profits of Norwegian maritime equipment suppliers have dropped historically over the last decade [24], following the dramatic effects of the decline of oil prices in 2014–15 on the global shipbuilding industry [23, 24, 26, 27]. Demand from the higher-margin oil and gas segment has decreased, while sales and delivery of equipment to other segments, e.g., cruise ships, ferries, fisheries, aquaculture, etc., have increased significantly [24].

Maritime equipment suppliers are essential parts of shipbuilding supply chains [21, 27], whose contextual characteristics and planning needs have not received much attention in extant ETO planning and control literature, especially within DDS and tactical planning. To address this gap, this section presents the case studies of the DDS process of two Norwegian ETO maritime equipment suppliers operating in the global shipbuilding market. The first case company is a supplier of propulsion and maneuvering systems for various types of ships and is referred to as ProCo (fictitious name – short for propulsion equipment company). The second case company is a supplier of handling equipment and structures such as cranes, winches, gangways, etc., and is referred to as HanCo (fictitious name – short for handling equipment company).

3.1 Description of Cases

The first case company, ProCo, supplies propulsion and maneuvering systems for various types of ships, e.g., fishing vessels, aquaculture or fish farming vessels, shuttle tankers, ferries, cruise ships, offshore vessels, etc. Their product portfolio includes various standard propellers, thrusters, gearboxes, control systems, etc., that can be configured and customized according to customer requirements. ProCo has a strong strategic focus on localized manufacturing in Norway and is characterized by a high degree of vertical integration with primarily in-house engineering and production, supported by a few strategic suppliers. The second case company, HanCo, supplies specialized handling equipment such as cranes, winches, gangways, etc., for ships used in fishing, aquaculture, offshore oil and gas, offshore wind, etc. The company focuses on the engineering and development of hardware and software technology, and most of the production is outsourced to suppliers, mainly in Europe and some in Asia. HanCo's portfolio of existing product designs has continually expanded since the company was founded ten years ago, with customer requirements often driving the expansion.

In both case companies, tenders and customer enquiries are primarily managed by the sales department without much involvement from the other functions. After identifying potential customers' requirements from tender invitations, sales leads, customer enquiries, etc., engineers in the sales department prepare technical proposals with preliminary product specifications describing how the company's product technology can address the customer's requirements. In most instances, the engineering, procurement, and production departments are first involved in a customer order after contract signing or order confirmation, when the delivery date and price have already been committed using estimates based on historical data on lead times and costs from completed orders. In ProCo's case, the company's planning department, which is responsible for production and inventory planning, may be contacted by sales personnel before contract signing in some cases if the customer-imposed delivery dates are considered 'too tight'. In such cases, the master planner assesses the availability of relevant production resources and critical suppliers to meet the delivery date. For HanCo's case, many customer orders entail prototyping of newly designed modules. The sales department at HanCo estimates the workload for in-house engineering disciplines (mechanical, hydraulics, electrical and electronics, and software) as part of the DDS or S&OP process, and the need for hiring personnel with new competencies is also identified at this stage. However, these estimates are primarily used for estimating the quoted product price. Any capacity-oriented feasibility assessment of meeting the committed delivery dates is not undertaken until after order confirmation. Table 2 characterizes the DDS process of the two case companies using the S&OP framework of planning activities.

Table 2. Evidence of DDS/S&OP activities in the cases

	S1	S2	S3	E1	E2	E3	E4	Pc1	Pc2	Pc3	Pd1	Pd2	Pd3
ProCo	--	--	✓	✓*	--	--	--	✓#	✓#	✓#	✓#	✓#	--
HanCo	--	--	✓	✓*	✓*	--	✓*	--	--	--	--	--	--

Legend:

✓: evidence of activity found in the case
--: evidence of activity not found

*: activities performed by the sales department
#: activities performed for some orders only

S1: select enquiries; **S2**: prioritize enquiries; **S3**: determine delivery lead time/date & price; **E1**: define preliminary specs; **E2**: determine engineering activities & resources; **E3**: estimate engineering lead times & costs; **E4**: identify external capability & capacity needs; **Pc1**: identify critical items; **Pc2**: select potential suppliers; **Pc3**: determine procurement lead times & prices; **Pd1**: identify main production activities & resource requirements; **Pd2**: identify feasible production start & end dates; **Pd3**: estimate production costs & non-regular capacity req.

3.2 Analysis and Discussion

The analysis of the two case companies provides insights into the similarities and differences among their DDS processes, and the main contextual factors influencing their process designs. As Table 2 indicates, many of the S&OP activities in our theoretical framework (Table 1) are not performed in most instances for DDS in the companies. Neither case provides evidence for the sales planning activities of selecting and prioritizing customer enquiries (S1, S2). The estimation of overall lead time and prices (S3) is primarily based on historical data in both cases, usually without any planning inputs from the other functions. Specification of the preliminary product characteristics (E1) is also handled by engineers in the sales departments in both companies. Engineering activities, workload, and capability requirements (E2, E4) are estimated in HanCo's case but only used for cost and price estimation purposes, not for capacity planning before order confirmation. In ProCo's case, procurement- and production planning activities (Pc1–3, Pd1–2) are only performed for enquiries with short delivery times.

We find the characteristically low demand for the shipbuilding and maritime equipment industry as the main contextual factor explaining the lack of evidence for many of the planning activities – S1, S2, E3, Pc1, Pc2, Pc3, Pd1, Pd2, and Pd3, in most cases for both companies. Given the low demand, the companies have focused on maximizing sales, thus overlooking the selection and prioritization of enquiries. The perceived importance of supply planning issues before order confirmation, i.e., capacity planning for engineering and production functions and supplier lead times, has also diminished in recent years due to low demand, long durations of shipbuilding projects, and surplus capacity in the upstream supply chains. As a result, the case companies have focused on winning orders, and usually postpone planning for supply-related issues until after order confirmation in most instances.

The main observed differences between the companies' DDS processes can be explained based on the companies' vertical integration and sourcing strategies. ProCo's highly integrated production and diverse specialized in-house production equipment necessitate closer monitoring of workloads and capacity. Furthermore, their strategic focus on localized manufacturing constrains which suppliers can be used for sourcing components, necessitating closer monitoring of their availability under tight delivery schedules. In contrast, with low vertical integration and outsourced production, engineering is HanCo's core capability, and early identification of the need for new engineering capabilities and additional engineering personnel is essential for maintaining their competitive advantage. Furthermore, flexibility vis-à-vis supplier locations for outsourced production provide HanCo with higher flexibility in acquiring production capacity after order confirmation. This flexibility has possibly been amplified in recent years due to the low demand and surplus capacity in this industry, explaining the lack of HanCo's focus on procurement planning in DDS despite low vertical integration.

Experts within the maritime industry expect demand to increase in the coming years [28], which suggests that the effectiveness of the companies' DDS process could be vulnerable to these changes. With increased demand, engineering capacity planning could be challenging for HanCo, as the managers and planners report difficulties in engineering capacity planning and activity monitoring even in the current market environment. Production capacity planning is expected to be one of the main planning challenges for ProCo under increased demand since the existing backward loading-based planning functionality is inefficient for DDS, requiring multiple manual iterations. Procurement planning is expected to have higher importance for both cases in a high-demand market scenario due to increased competition for obtaining suppliers' capacities.

4 Conclusion

This study has provided some insights into the DDS processes of two ETO maritime equipment suppliers and the contextual factors influencing their process design. The overall market demand in the maritime industry, and the companies' vertical integration and sourcing strategies are found to be the most influential contextual factors for explaining the similarities and differences in DDS practices across the cases. While we consider the influence of the vertical integration and sourcing strategies on the DDS process design to be strategic choices, we believe that elements of the process design that the market demand has influenced should be reconsidered in the case companies for minimizing the vulnerability of their DDS processes to future demand growth expected in the maritime industry [28]. Such a reassessment of the process design can increase its robustness toward market changes. Since the paper investigates the current state of the DDS process of only two maritime equipment suppliers, it is premature to generalize the findings to other companies in this industry. However, previous findings from other industry sectors [2, 7] support the contextual factors identified in this paper, highlighting the potential for their broader relevance. The cases presented in this paper also provide empirical support for the research need to develop effective engineering and production capacity planning tools for addressing the industrial needs of ETO companies, as highlighted in the authors' recent state-of-the-art review on DDS [5].

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