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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].

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 Section 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, Section 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] and [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 section 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 subsection 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

<p>Product characteristics:</p> <ul style="list-style-type: none"> • 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
<hr/> <p>Process & resource characteristics:</p> <ul style="list-style-type: none"> • 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
<hr/> <p>Market characteristics:</p> <ul style="list-style-type: none"> • 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. <hr/>

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.

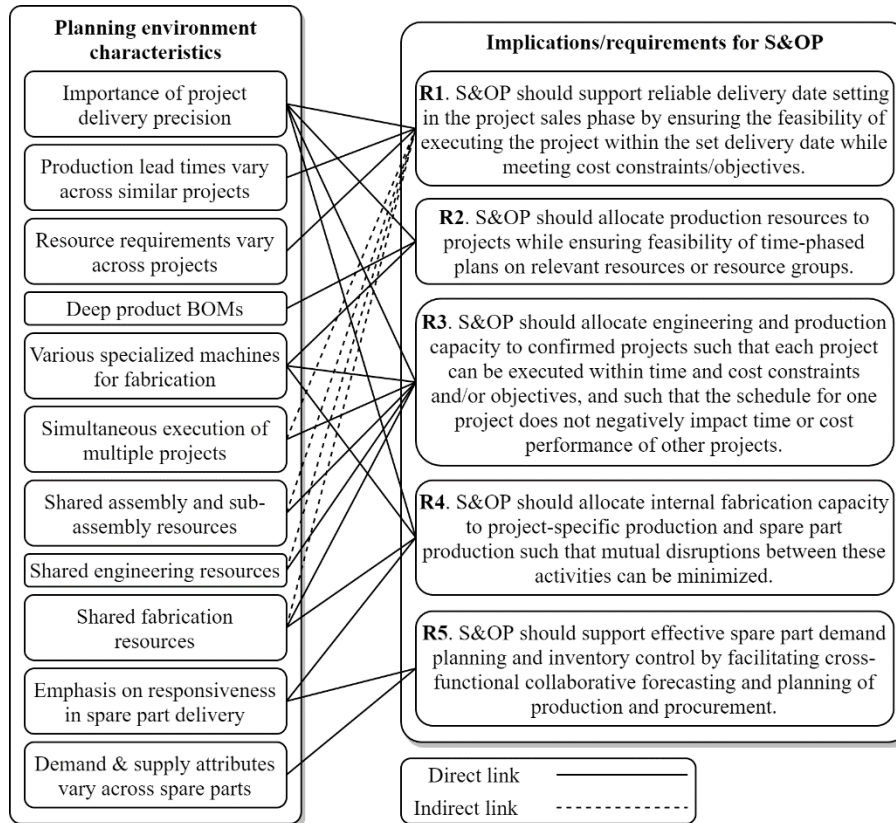


Fig. 1. Requirements for S&OP design based on the case company's planning environment

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

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.

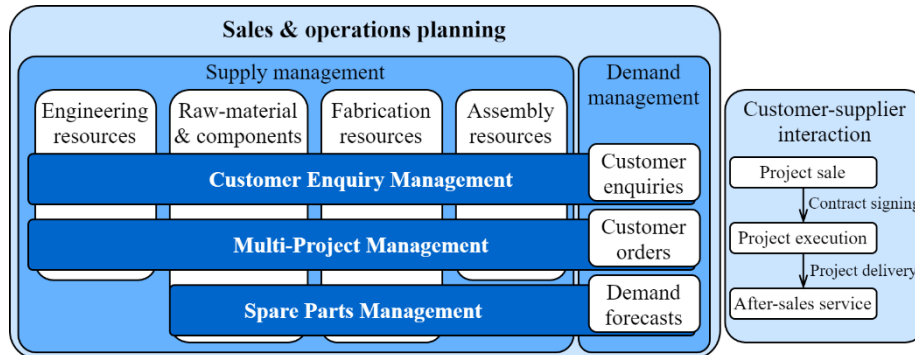


Fig. 2. A framework of S&OP in ETO production and related research areas

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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