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Case analysis of sales and operations planning (S&OP) systems in uncertain engineer-to-order (ETO) equipment production

Erlend Alfnes*, Heidi Dreyer*, Jonathan Gosling, Mohamed Naim** Randi Bakken*, Sarmika Kumaralingam*,**

**Norwegian University of Science and Technology, Trondheim, 7491 Trondheim, Norway (corresponding author Erlend.Alfnes@ntnu.no)*

***Cardiff University, Cardiff, CF10 3EU, UK*

Abstract: In engineer-to-order (ETO) projects, due to the customer-specific design of high-value, complex products and multiple ongoing ETO projects, sales and order planning (S&OP) is complex and involves high uncertainty in order fulfilment caused by customers and sales, engineering, sourcing and supplier and production operations. This study applies a case study research design to extend and test the functional framework established by Bhalla et al. (2023) to better understand how information systems can enable companies to deal with uncertainties in the S&OP process. Two case studies have been conducted, one within the maritime equipment sector and one in the process equipment industry. The study highlights novel key prerequisites to the S&OP systems not previously identified.

Keywords: Engineer-to-order (ETO), Supply chain, Sales and operations planning (S&OP), multi-project planning, order fulfilment, case study

1. INTRODUCTION

Much of the existing research on the sales and operations planning (S&OP) process has been based on high volume, repetitive production environments and less on engineer-to-order (ETO) organizations. There are notable exceptions including the establishment of reference framework for setting delivery dates in ETO contexts (Bhalla et al., 2023). Even so, the ability to deal with ongoing multiple projects is not well understood (Bhalla et al., 2023), especially given the complexities due to the extensive uncertainties faced (Alfnes et al., 2021). In ETO settings, information systems capable of seamless, inter-departmental storing, retrieving, collecting, organizing, and transmission of data enable the S&OP process to absorb more uncertainty (Shurrab et.al. 2022a). Therefore, the aim of this paper is to extend and test the functional framework established by Bhalla et al. (2023) to better understand how companies deal with uncertainties in the S&OP process.

In fulfilling our aim we answer the following research questions:

RQ1: How is S&OP conducted in uncertain ETO environments?

RQ2: What are the S&OP information system prerequisites in uncertain ETO environments?

2. THEORETICAL BACKGROUND

S&OP is a tactical planning approach that aims to balance demand and supply, aligning a company's day-to-day operations with its long-term strategic plans (Olivia and Watson, 2011). Due to the complexity and uncertainty involved, several planning frameworks have been proposed for ETO settings. Adrodegari et al. (2015) have a process perspective and propose a broadly scoped framework with information system requirements for the ETO machine building industry. Shurrab et al. (2022b) present a framework derived from a construction company that represent SOP planning as five sub-processes with activities and decisions (order screening, order customization, order workload analysis, order review, order contracting). This framework highlights the iterative nature and complexity of S&OP processes management in ETO, but its primary focus on customer orders and its derivation from a single case limit its broader applicability.

In our study we apply the more general framework by Bhalla et. al. (2023) to identify S&OP information system prerequisites that supports cross-functionally coordinated and integrated tactical activities in an ETO setting. Bhalla et al. (2023) present a framework of S&OP in ETO environments that divides the function areas of the ETO environment and includes the relevant Planning Activities of each function.

- Sales Planning: Selecting and prioritizing customer orders, and defining delivery lead time, price and delivery date.
- Engineering Planning: Defining preliminary product specifications and detailed engineering activities, setting due dates, estimating lead times and price, and determining the need for external capacity.
- Procurement Planning: Identifying critical items, selecting suppliers, and determining price and lead time.

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• Production Planning: Identifying main activities and resources, identifying feasible start and end dates, estimating costs, and estimating non-regular capacity needs.

One of the primary customer orders is after-sales projects (Adrodegari et al., 2015; Bhalla, 2023; De Boer et al., 1997; Masmoudi et al., 2016). While the above studies establish a good platform for planning in ETO environments, the specific information pre-requisites, especially with respect to aftersales integration, are not fully understood. These activities are of an unpredictable nature (Rauch et al., 2018) and therefore, the S&OP process of after-sales production activities is extracted as a separate planning function in our framework: After-sales Planning. This planning function includes planning activities regarding after-sales activities and resources in addition to estimating due dates and cost.

3. METHODOLOGY

3.1 Research design

The literature about S&OP in uncertain ETO projects is limited, particularly for the tendering phase when deciding on order fulfilment. Therefore, a case study approach is suited for the explorative feature of this study since there is a need to get rich and in-depth data about S&OP in such environments. Two in-depth case studies were conducted by collecting data from multiple sources in two companies. While operating in different industries, the companies were comparable in size and shared a similar focus of their S&OP. The cases were selected based on the following criteria. Companies should be applying a form of ETO production linked to customised equipment suppliers. Cases should have a similar number of employees/company size, but different levels of vertical integration.

3.2 Data collection and cases involved

Data was collected in the two companies at different organisational levels and functions. Semi-structured interviews, questionaries, and workshops were used to explore and validate S&OP in the ETO projects (Table 1).

Workshops were utilised to fulfil participants' expectations, gain an in-depth understanding, and provide the space to explore the participant's opinions related to a specific domain in question (Ørngreen & Levinsen, 2017), and can contribute to the validation and processing of data acquired from the semi-structured interviews and questionnaires (Croom, 2010). Through the workshops, participants shared experiences and ideas, giving the authors a more in-depth understanding and wider perspectives than possible through digital semi-structured interviews, and questionnaires. The workshops allowed open communication with immediate feedback and discussion, helping with clarifying and elaborating on the findings from the other methods. The authors held a workshop physically at each of the case companies. The workshop consisted of a brief presentation of the results from the semi-structured interviews and questionnaires, allowing the participants to reflect, evaluate and validate the results. Excel sheets with the respective results were set up in addition to room for new input data and comments. The workshops facilitated discussions to refine and validate the framework of S&OP prerequisites, ensuring a comprehensive understanding of each company´s activities.

The interviews captured in-depth insight from key stakeholders in sales, engineering procurement, production, and after-sales roles. Questionaries were distributed to validate the interview findings and rank the relevance of identified S&OP prerequisites according to the Likert's scale in the range from 1 to 5.

Table 1. Case interviews

Companies	Interviewees	Role
ProTech	PTa	Dept. head of sales
	PTb	Head of warehouse, procurement and internal production
	PTc	Project coordination
	PTd	Project manager, controller
	PTe	Department manager after-sales and service operations
	PTf	Dept. head engineering
	PTg	Dept. head projects
MarTech	MTa	Production manager
	MTb	Planning manager
	MTc	Chief technical officer
	MTd	Procurement manager
	MTe	Sales manager
	MTf	Electrical engineer
	MTg	Project coordinator and after sales manager

Table 1 shows the central functions of the S&OP and the different roles of the interviewees in the ETO projects. All interviewees in both companies have between 10 and 40 years of experience, demonstrating considerable competence and insight into the subject matter. The interviews were recorded and transcribed by two of the researchers. The companies represent different industries and levels of vertical integration. Table 2 is an overview of the companies' size and main activity.

Table 2. Company overview

Companies	ProTech	MarTech
Employees	60-80	60-80
New build/retrofit projects	10-14	20-25
After sale projects	100	40
Inhouse processes	Sales Engineering Procurement Production competence/skills Testing Installation and commissioning support After sale support	Sales Engineering Procurement Production Testing Installation and commissioning support After sales support
Outsourced processes	Mechanical engineering Installation and commissioning Production	Mechanical engineering

Case Protech produces machinery and equipment for the process industry, and the customised thermal processing equipment is sold globally, either as new developments or retrofit/repeat. The after-sales services provided are organised as individual projects. ProTech outsources most of its production and mechanical engineering but keeps production of key components internal. Case MarTech produces customised winches and subsea handling equipment and services for the maritime industry. The projects are either new build or retrofit equipment and after-sale projects. The majority of the activities are conducted inhouse by MarTech, but some operations, such as part of detailed engineering and painting, are outsourced.

3.3 Data analysis

The analysis used a thematic approach to identify key patterns and insights related to S&OP in the ETO projects. The interview data were coded and grouped into themes corresponding to the S&OP functions. Data from questionnaires was used to validate and rank the identified S&OP prerequisites, providing quantitative support to the qualitative findings. Insights were refined through workshops, where company representatives reviewed and contextualised the results, ensuring they accurately reflected real-world practice. A comparative analysis of the two cases was conducted to highlight similarities and differences, particularly concerning vertical integration, industry-specific challenges and aftersales planning. The combination of these methods ensured a rigorous and triangulated research process, providing both theoretical validation and practical insights into S&OP in uncertain ETO environments.

4. FINDINGS

Our findings are summarized in Tables 3 to 7, which highlight the prerequisites for each stage of the S&OP process.

Table 3. SOP system prerequisites for sales planning

Planning activity	**S&OP Prerequisite**	**Relevance**
Selecting customer enquiries	Documentation of enquiry	**3,5**
	Strategic criteria for enquiries	**4,1**
Prioritising customer enquiries	Historical data on customer and product	**3,9**
	Strategic criteria for enquiries	**4,0**
	Available capacity (engineering, relevant competence, and production)	**4,1**
Determining delivery lead time, date and price	Historical data on suppliers (components, materials, external resources)	**4,1**
	Technical evaluation of product specification	**4,1**
	Planned activities and capacity load (engineering, procurement, production)	**4,5**
	Updated prices and lead times from suppliers	**4,3**

Table 4. SOP system prerequisites for engineering planning

Planning Activity	**S&OP Prerequisite**	**Relevance**
Defining preliminary product specifications	Historical data on product specifications	**4,0**
	Overview of standard components	**4,4**
	Technical evaluation of product specifications	**4,2**
	Monitor changes in product specifications	**4,2**
Determining detailed engineering activities and resources	Historical resource requirements	**4,1**
	Technical evaluation of product specifications	**4,2**
	Monitor changes in detailed engineering	**4,2**
Estimating lead times and costs and setting due dates	Historical data on subcontractors (engineering)	**3,2**
	Monitor completed activities toward planned activities	**4,4**
	Monitor actual hours towards planned hours	**4,3**
Identifying needs for external capacity and additional capacity	Capacity in-house (engineering)	**4,7**
	Resource requirements	**4,8**

Table 5. SOP system prerequisites for procurement planning

Planning activity	S&OP Prerequisite	Relevance
Identifying critical items	BOM structure	**4,1**
	Historical lead times on components	**4,4**
	Updated lead times on components	**4,7**
Selecting potential suppliers	Historical Product information (quality, lead time, price)	**3,9**
	Updated Product information (quality, lead time, price)	**4,7**
Determining procurement lead times and prices	Historical Product information (quality, lead time, price)	**4,1**
	Updated Product information (quality, lead time, price)	**4,2**

Table 6. SOP system prerequisites for production planning

Planning activity	S&OP Prerequisite	Relevance
Identify main production activities and resources	Technical evaluation of BOM and product specifications	**3,8**
	Historical data on resource requirements	**4,0**
	Monitor changes in design and production, testing and installation	**3,8**
Identifying feasible production start and end dates	Main production activities	**4,3**
	Resource requirements	**4,3**
	Available production capacity	**4,1**
	Due date on finished (installed) product	**4,5**
	Monitor critical components	**4,1**
	Monitor completed activities toward plan	**4,1**
	Monitor actual hours toward planned hours	**3,8**
Estimating production costs & non-regular capacity requirements	Resource requirements	**4,1**
	Monitor actual hours toward planned hours	**4,1**
	Monitor completed activities toward plan	**4,1**
	Material requirements including critical and non-critical components	**3,9**
	Monitor material usage (critical and non-critical)	**3,3**
	Monitor non-regular capacity	**4,0**

Table 7. SOP system prerequisites for aftersales planning

Planning activity	S&OP Prerequisite	Relevance
Identify main After-sales activities and resources	Technical evaluation of project description/ site inspection	**4,0**
	Historical data resource requirements	**3,5**
	Historical data on product information	**3,4**
	Monitor changes in design and After-sales activities	**4,2**
Identifying feasible start and end dates	Main After-sales activities	**4,2**
	Resource requirements	**4,2**
	Available capacity	**4,2**
	Due date of finished product	**4,0**
	Monitor critical components	**3,8**
	Monitor completed activities toward plan	**4,2**
	Monitor actual hours toward planned hours	**4,0**
Estimating after-sales costs	Resource requirements	**3,2**
	Monitor actual hours toward planned hours	**4,2**
	Monitor completed activities toward plan	**4,0**
	Material requirements including critical and non-critical components	**4,0**
	Monitor material usage (critical and non-critical)	**3,6**

Table 8 gives a synthesis of our findings highlighting the key prerequisites not previously identified in the literature.

Table 8: Research Synthesis – Key S&OP system Prerequisites

Key S&OP System Prerequisites
Sales – Planned activities and capacity load (engineering, procurement, production) Prerequisite for determining lead time, date and price when responding to a customer enquiry. The ability to deliver is directly influenced by planned activities and capacity load, and should be considered when taking on new projects that contractually bind the company.
Sales – Updated prices and lead times from suppliers Prerequisite for determining lead time, date and price when responding to the customer enquiry. Updated prices and lead times from suppliers are considered to minimise the uncertainty of cost and lead time estimations.
Engineering – Monitor changes in detailed engineering Prerequisite for determining detailed engineering activities and resources. Monitor changes in detailed engineering is done to handle the uncertainty of product

specifications and the changes that can occur from the customer's or design perspective.
Engineering – Resource requirements Prerequisite for identifying needs for external capacity and additional capacity regarding Engineering planning. Resource requirements are the estimated resources that is needed to complete the engineering activities.
Procurement – Historical Product information Prerequisite for determining procurement lead times and prices in Procurement planning. Historical product information including quality, lead time and price, is used to do estimates and forecasts.
Procurement – Updated Product information Prerequisite for determining procurement lead times and prices in Procurement planning. Updated product information including quality, lead time and price, are used to monitor and to set the lead times and prices.
Production – Available production capacity Prerequisite for identifying feasible production start and end dates. Available production capacity refers to the total volume the company can produce in a given timeframe.
Production – Resource requirements Prerequisite for estimating production costs & non-regular capacity requirements. Resource requirements are used to calculate the cost of production and estimate the need for non-regular capacity.
Aftersales – Historical data on product information Prerequisite for identifying main after-sales activities and resources. Historical data on product information gives insight to the design and potential previous work on the product to be considered for the after-sales project to be done.
After sales – Resource requirements Prerequisite for estimating after-sales costs. Resource requirements are used to calculate the cost of the after-sales project.

5. DISCUSSION

5.1 RQ1: How is S&OP conducted in uncertain ETO environments?

The findings suggest that there is close alignment with existing S&OP literature despite there being different production characteristics. However, our study reveals the need for even tighter vertical cross-functional integration due to the higher risk of misaligned plans and unexpected changes. This is particularly true in association with determining delivery lead times and supplier communication, and scenario planning and "what-if" analysis are critical for managing uncertainty. Flexibility in resource allocation (e.g., outsourcing or overtime) is a strategy for dampening uncertainty. Engineering and production planning also align well with existing frameworks (Shurrab et al. 2022b; Bhalla et al., 2023), although there is significant variance in specific aspects such as availability of updated data from ERP systems, information sharing and capacity assessment. This study introduces Aftersales Planning as a separate planning function, displaying the highest diversity, underscoring the limited research in the field. Overall, the findings emphasise the importance of the documentation processes of enquiries, capacity assessment methods, integrating historical data and monitoring practices and focus on vertical integration and cross functional collaboration.

*5.2 R*Q2: What are the S&OP prerequisites in uncertain ETO environments?

The 10 key S&OP Prerequisites across the Planning functions give insights into the practices of the selected case companies. In **sales planning**, the companies emphasize the need for accurate assessment of available capacity and updated supplier data to ensure feasibility and minimise uncertainties of cost and lead times. In **engineering planning**, continuous monitoring changes in specifications and accurate resource estimation are crucial due to the uncertainty and high customisation of ETO environments. **Procurement planning** shows a divided focus, with MarTech emphasising historical data due to customer relations, and ProTech prioritising realtime updates to manage procurement in dynamic markets. The identification of critical items and timelines, as well as supplier selection, are important. The focus of **production planning** is influenced by the level of vertical integration, with ProTech emphasising available capacity and MarTech focusing on resource requirements. **After-sales planning** highlights the importance of historical information, resource requirements for effective planning and planning of maintenance and upgrades. **Across the planning functions**, scenario-based planning and using "what-if" simulations, accurate and updated information, continuous monitoring, resource estimation, cross-functional integration and flexible resource allocation are key. Differences between the case companies suggest that organisational structure and market uncertainty significantly influence the S&OP process.

6. CONCLUSIONS

This research has aimed to determine key S&OP system prerequisites in the uncertain ETO environment. Contributing to the research of S&OP in ETO environments, project planning considerations are included within the proposed S&OP prerequisite framework. Both case companies have project-based production, including commercial and after-sales projects. The need for project planning and cross-functional resource management is emphasized in the case companies.

The proposed framework applies the same functional perspective of Bhalla et al. (2023), contributing to validate and widen the understanding of the cross-functional perspective. Additionally, the level of vertical integration in the case companies was addressed regarding the differences in the S&OP process of the two case companies.

The large number of after-sales projects in the case companies led to the focus of S&OP within the after-

sales planning function. Bhalla et al. (2023) consider after-sales activities as a part of procurement and production planning. This research has however found the differences in after-sales operations in comparison to production activities, to be planned and executed separately. The proposed framework of S&OP prerequisites does therefore contribute to an extended understanding of S&OP within the after-sales function.

The main contribution of the thesis is the 10 key S&OP prerequisites, that emphasize the areas the ETO environment should consider. These are found to be the most significant S&OP prerequisites in the case companies.

A major limitation of the research is the limited number of cases, thereby reducing the generalisability of the findings. There is some limited cross-case comparison but within case analysis is more extensive. Also, the case studies were limited to equipment suppliers in the ETO environment, which may not fully represent the diversity of industries where the ETO strategy is applied. The findings of the semi-structured interviews were dependent on the impression of the researchers. To facilitate in-depth conversations, only one researcher attended each interview, which introduced the potential for methodological differences and variations that might arise when multiple researchers are involved.

Future research will extend the case study base in terms of numbers and types of companies. There is also a need to undertake a deep-dive of the uncertainties and complexities faced by the ETO companies and how they impact on the S&OP process.

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