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# Managing the dynamic needs of engineering resources through sales and operations planning

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## Abstract

This paper explores the uncertainty related to medium-term engineering needs considering sales and operations planning (S&OP). The areas of uncertainty and how they are addressed by S&OP are investigated in an engineer-to-order setting. Uncertainties stem from customer orders and critical competences and are minimized through integrating engineering resource planning into S&OP sub-processes and organization, and through explicating methodologies using IT tools that also support scenario planning. To improve the effect of S&OP, measuring short- and long-term performance is recommended, and aligning S&OP with the bidding and organization development processes is important. Future research may replicate this study using multiple cases.

**Keywords:** S&OP, Case study, Engineer-to-Order

**Introduction**

This paper focuses on the requirements put by engineer-to-order (ETO) environments on the sales and operations planning (S&OP) process. The ETO planning environment has several challenges. The competition in ETO markets is based on providing substantial customization beyond standard product options to embrace very heterogenous customer needs. Allowing product customization in conjunction with incoming customer orders, contracts or inquiries requires intensive and frequent engineering work whereby new or existing products and manufacturing systems are either developed or adapted.

Providing the required engineering competences to conduct the engineering work is crucial to compete on contracts and to successfully deliver orders. Competence requirements change overtime as the heterogeneous ETO market needs evolve. Also, availability of engineering resources and expertise vary. Moreover, obtaining critical engineers is often expensive and takes relatively long time. Therefore, in ETO environments, the criticality of engineers needs to be identified and managed at the tactical planning horizons, i.e. within the scope of S&OP.

Several studies related to the resource-based view (RBV) depart from a strategic perspective to address critical resources as sources of sustainable competitive advantage (e.g. Kraaijenbrink et al., 2010). How to plan critical resources within tactical terms in ETO environments is however still lacking. Therefore, we explore how ETO business characteristics put requirements on and can be handled by an S&OP process.

S&OP is an aggregate planning process that – through cross-functional integration – seeks to balance demand and supply within tactical timeframes (Jonsson and Holmström, 2016). However, limited number of S&OP studies deal with ETO environments (Kristensen and Jonsson, 2018). To the best of our knowledge, no study addresses how S&OP manages the uncertainties associated with the dynamic medium-term needs of engineering resources in an ETO environment. Therefore, to fulfil the purpose of this study, two research questions are formulated as follows:

- RQ1: Which areas of uncertainty can be related to engineering resources within the S&OP process in an ETO environment?
- RQ2: How does S&OP manage the dynamic medium-term needs of critical engineering resources in an ETO environment?

**Conceptual framework**

Sales and operations planning (S&OP) integrates the plans for sales, supply, and production into an overall aggregate plan (Noroozi and Wikner, 2017) and aims at balancing the targeted customer demand, shaped by marketing and sales functions, and the supply capacity, shaped by procurement and operation functions (Jonsson and Holmström, 2016). Therefore, S&OP is defined as: "*a business process that links the corporate strategic plan to daily operations plans and enables companies to balance demand and supply for their products*" (Grimson and Pyke, 2007, p. 33).

Although S&OP is simple in theory, companies vary in how S&OP is implemented. According to Danese et al. (2017), literature mainly addresses implementation that characterize four main S&OP maturity dimensions, including *people and organization*, *process and methodologies*, *information technology (IT)*, and *performance measurement*.

In this paper, the definition of ETO production adopted by several researchers (e.g. Willner et al., 2016, Gosling and Naim, 2009) is applied as to be distinguished from make-to-order (MTO) production, which allows for limited configuration within a pre-defined solution space. Accordingly, ETO production is perceived as directly linked to a customer order with the decoupling point in the design stage dedicated to adapting products. This implies uncertainties affecting the S&OP process. However, ETO literature does not explicitly address the areas of uncertainty that influence critical capacity planning. Therefore, this paper addresses such areas of uncertainties drawing on their generic sources: *customer demand* and *supply capacity*.

The main source of uncertainty stems from demand. Depending on the depth of the product structure and the amount of jobbing needed to process such requests, ETO environments range from basic to complex settings (Hicks et al., 2001). In complex settings individual customer orders typically require large investments in plants, machines, equipment, and engineering resources. Each customer order, inquiry or contract calls for careful considerations that may result in substantial consequences in terms of engineering resources. Therefore, ETO companies need to deal with several areas of uncertainty stemming from *customer orders*.

It is not unusual that the resource preparation process does not conform to the lead time requirements that ETO customers are willing to accept (Olhager et al., 2001), which is crucial in winning customer orders in addition to cost and quality. The competition enforces ETO companies to embrace more uncertainties related to resource requirements through – for instance – rushing up the acceptance to process inquiries without being carefully studied as customers need quick response. This explains the tendency of ETO companies to build and maintain excessive capacities in a capacity lead strategy. Accordingly, ETO companies arguably need to deal with uncertainty areas stemming from *critical competences*.

Figure 1 summarizes the theoretical framework of the paper, which focuses on the interfaces between the generic process of S&OP and the specific areas of uncertainty embedded in ETO settings, which are empirically identified under the main categories of customer order and critical competence to answer RQ1. The arrows in the figure highlight the bidirectional focus of RQ2, where the influence of S&OP on the areas of uncertainty identified to answer RQ1 as well as the influence of these uncertainties on the S&OP maturity dimensions are addressed.

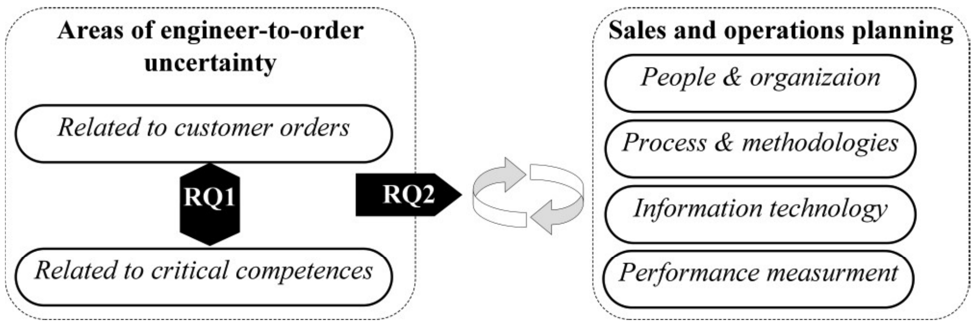



*Figure 1 – S&OP and ETO uncertainties*

**Methodology**

To answer the research questions, an exploratory single case study was conducted at a leading multi-technology first-tier aerospace supplier. According to Yin (2017), a single case study can be used to represent a unique or extreme case. The uniqueness of the selected case stems from being an ETO-oriented firm that possesses a structured S&OP process that includes engineering resource planning.

Drawing on the conceptual framework presented in Figure 1, an interview protocol was developed to collect empirical data. The data was gathered through semi-structured interviews and process-related documents. In total six interviews were held with an average length of 100 minutes. Three interviews were audio recorded and conducted with one participant, while the other three interviews involved a relevant group of participants. The three group interviews were held with management representatives from the logistics and operations planning function. Then, an interview was conducted with the marketing manager, the S&OP coordinator, and a representative from the management team of the engineering function who is part of the S&OP development team.

The unit of analysis was the five main stages of S&OP including data gathering, demand planning, supply planning, pre-S&OP meeting, and executive S&OP meeting (see Wallace and Stahl, 2008). The data was elicited to explicate the uncertainties associated with engineering competences and how they were addressed throughout the process, i.e., identified, communicated and minimized.

Through content analysis, the collected data was analysed, and relevant constructs were identified after iterations of inductive coding (Glaser and Strauss, 2017). Through empirical evidences, areas of uncertainty associated with engineering competences were suggested as constructs under the main categories of customer orders and critical competences. The empirical data on how such areas of uncertainty were addressed throughout S&OP allowed for identifying several requirements for the process design.

Research quality was considered through neutralizing biases and ensuring transparency. Detailed documents describing the S&OP process at the company were studied before interviews. The documents contained the latest update of the standardized process; the inputs, objectives, decisions, and outcomes of each activity; the methods, process and systems used to perform and support the activities; and the representatives from each function and the coordinators involved in each activity. This helped in mapping out the S&OP process at the case company to more effectively gather relevant data.

Interviews were conducted in a sequence that ensured logical data gathering through which the questions about specific areas were posed to the right respondents. S&OP is started by the marketing function to plan demand. This part was well defined and documented, and thus easy to start with to identify the uncertainties. Having done this from the demand planning perspective, the interview with the S&OP coordinator then helped to further explore and describe the issues from the supply planning perspective. Consequently, more holistic knowledge about the uncertainties related to the critical resources within the implemented S&OP was captured, which then helped to identify specific root causes through the interview with the engineering function. Finally, to avoid the single researcher bias, the interviews were transcribed by one researcher and analysed collectively based on the transcripts and the company documents.

**Case description**

The case company provides customized components to three aircraft engine manufacturers. The components are grouped into six main product groups, which are continuously adapted to new components originating from new contracts typically awarded after tendering. The designs of new components are iteratively specified and agreed upon with respective customers. The production processes need to be upgraded to deliver the agreed quantities and specifications according to the new contracts and life cycle plans. Usually, three main production development phases are followed for each life cycle plan. Small quantities are first produced in the production start-up phase, before the ramp-up, and finally, the termination phases. In the aerospace industry, even though the product lifecycle is relatively long, phasing in and out components is complex and requires unique engineering competences that may take up to two years to be fully prepared for proper utilization. Therefore, the case company incorporates activities in S&OP that specifically address the medium-term need of engineering resources.

The S&OP process is conducted with monthly planning buckets and planning frequencies, and with a planning horizon of 36 months. The main logic is that each product group puts forward the future demand and supply needs that are then reviewed and met by the related functions. Forecasts and demand plans are reviewed by marketing, engineering resource requests are reviewed by engineering, while internal and external capacity requests are reviewed by operations and supply chain. When the functions are unable to fulfil the requests within the present budget, escalations are made to the top management that respond through decisions during the S&OP meetings.

**Analysis**

Investigating where the need for engineering resources emerges within S&OP activities lead to identifying 11 areas of uncertainty (see figure 2), 5 of which are related to *customer orders*, while 6 of which are related to *critical competences.* The analysis of each area of uncertainty includes insights into the planning consequences. Then, the ways for how the S&OP process maturity helps to deal with such challenges are presented.

Five areas of uncertainty stem from customer orders including *the source and timing of customer orders*, *customer order specifications*, *the probability of winning customer orders*, and *customer reliability*. The S&OP process starts with each product group developing or updating the demand plan. Inputs from the bidding process (process for screening and reviewing tender requests and preparing competitive bids) provide insights into the future potential customer orders. The *sources of customer orders* are three aircraft engine manufacturers. According to the marketing manager, the source of customer order can be an area of uncertainty for other ETO environments where more potential customers exist. However, since this does not apply in this case, it is difficult to foresee the consequences of having such uncertainty and how S&OP mitigates for it.

The marketing manager also emphasizes that the *timing of customer orders* is uncertain leading considerable consequences on engineering resource plans. Supposedly, learning about the accurate timing of customer inquiries as early as possible allows for higher resource utilization, and timely recruitment and preparation of engineering competences to fulfil the needs from bidding processes and subsequent engineering work.

The S&OP coordinator states that customers are typically uncertain about the *detailed component specifications and quantities*, which increases the uncertainty concerning the future amount and type of engineering work. Underdefined customer specifications also imply increasing the uncertainty concerning the coordination workload needed to compile inputs for engineering resource planning. In the first place, product groups are usually uncertain about if they will *win future customer orders*, which is why they tend to delay crucial decisions concerned with extending and upgrading the engineering resource base. The consequence is that top managers in the S&OP executive meeting approve the recruitment of critical engineers when the work for customer orders needs to start within less than 6 months, whereas the corresponding recruitment and preparation process may take more than a year until these engineers live up to the working standards.

According to the interviewees, *customers* sometimes transmit overestimates (approximately 10% more than the actual demand) as to mitigate the risk of scenarios where the case company runs into production disturbances. That is, customers enforce the case company to build excess capacity, but without sharing such costs.

To mitigate for the areas of uncertainty related to customer orders, the monthly S&OP cycle starts with gathering relevant assumptions from the product groups. The assumptions serve as a foundation for predicting the timing of future customer orders, customer order specifications, win-rate and customer reliability, not only based on figures (forecasts), but most importantly based on events. The assumptions are tracked, reviewed and updated throughout the consecutive S&OP events. The bases of the assumptions originate from the collaboration with customers, which is evident from the marketing team activities associated with the bidding process and the component life cycle reviews. The assumptions are also based on internal business intelligence that has been developed and accumulated over years. The marketing team – which is represented in each product group – then compiles the updates of the forecasts and assumptions prior the demand review that is conducted by the marketing manager who, in turn, validates the updates through questioning the reasons on which they were based. Consequently, the medium-term demand – in terms of the customer orders over 36 months – is updated and approved.

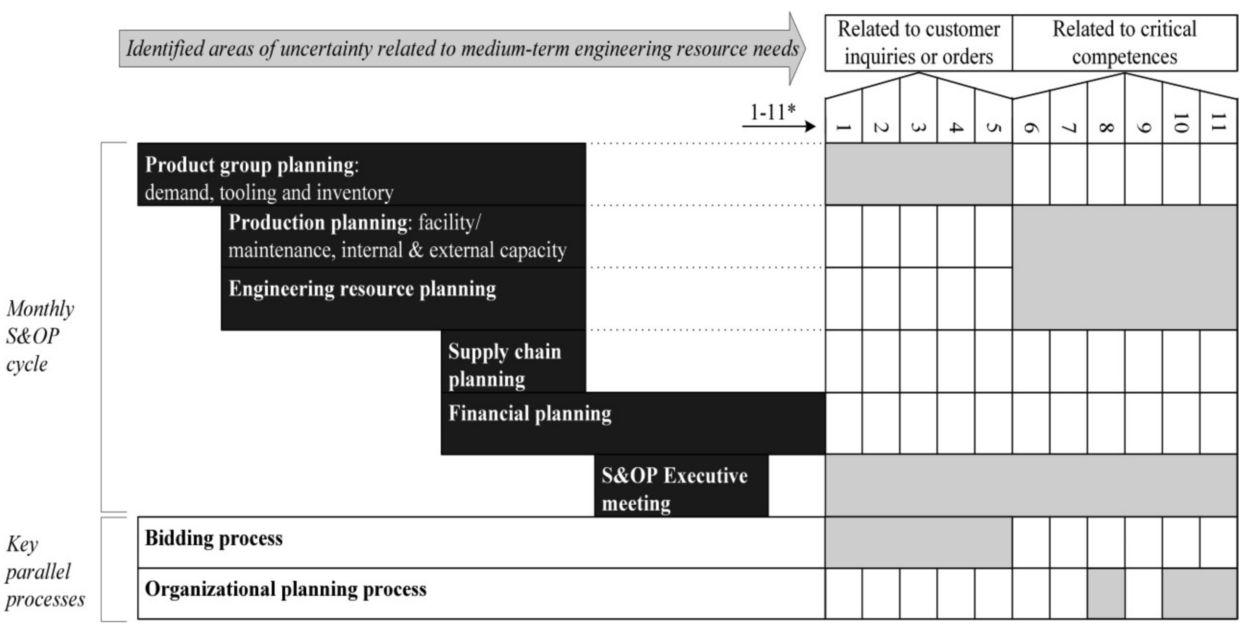
On the other hand, six areas of uncertainty stem from critical competences including *competence type and quantities*, *the availability of internal and external competences*, *competence qualification period*, and *inter-resource equivalences*. Product group takes the responsibility of detailing the consequences of the updated demand on tools and equipment, which in turn shapes the future need of production infrastructure and engineering competence. The product groups, through representatives from engineering and production functions – chief manufacturing engineers (CMEs) and chief design engineers (CDEs), respectively – define the specific engineering capacities required for production and product design. CMEs and CDEs rely on the inputs from the updated reviews of demand, tooling and facility. However, *how such inputs are transformed into* *future needs of engineers* is not explicitly documented, but rather based on rules of thumb and personal experiences. Furthermore, the identified needs are often generic specifying high-level skills or expertise, which arguably increases the uncertainty about *if these identified engineering resource needs perfectly match the actual need* of the updated demand. Such uncertainty increases the possibility of having either under- or overcapacity in engineering resources. It is even possible to experience scenarios of both under- and overcapacity, where overqualified engineers (with broader skillsets than needed) are recruited, but still do not live up to the quantity needed to fulfil the actual demand. Here, the case company will incur the cost of excess capacity that is not well utilized, and the cost of potential delay in form of penalties, for instance.

CMEs and CDEs use a roadmap to visualize how the required engineers need to be aligned with the ongoing and future parallel projects. Moreover, they use a workforce planning tool to communicate the type and quantity of competences that will be requested from engineering by each product group. These requests are processed by the various engineering divisions given the internal competence availability. Similar to the way the engineering resource needs are identified, the engineering divisions assess the availability and suitability of internal competences against the requests raised by CMEs and MQEs from product groups. Controlling the availability of engineering resources is not different from other labour categories. That is, the *uncertainty about engineering workforce availability* rests in unforeseeable absenteeism due to, for instance, injury, sickness and contract termination. These risks are typically mitigated through building excess capacities whereby engineering assignments temporarily can be performed temporarily by one or more individuals. However, the suitability of available engineers compared to the requests is still based on subjective judgment, meaning that there is *uncertainty about whether the internal resources being continually configured to best meet the future demand* with maxim utilization and to avoid the scenarios of under- and overcapacity.

The engineering function consists of divisions. Each division identifies the types and quantities of competences that are lacking and escalate deficits to the higher management level. Here, the second-line managers, the head of engineering and the external resource manager address the different options to secure the supply of engineering workforce. This includes recruiting new engineers, acquiring consultants, and reorganizing the engineering resource base. The latter option is based on the outcomes of a parallel process for planning the organizational structure that is aimed at determining how the organization should evolve given the strategic business objectives. This includes foreseeing the probable changes in the resource base such as the retirements and promotions of individuals. Usually, *the consequences of promoting a group of engineers on future demand are uncertain*. However, the S&OP process and the organizational planning process are not formally or coherently linked to each other.

As for *external resources*, the case shows that there is always *a lack of knowledge concerning the type and quantities of competences* that can be found externally. Consulting and newly recruited engineers are different in nature, i.e. in terms of skills, expertise and personalities. Therefore, the time needed to prepare such engineers in line with the respective task requirements varies, meaning that *the preparation period* also represents an area of uncertainty. The interviewee from the engineering department emphasized that there is much uncertainty concerning *how a group of engineers can be allocated in equivalent configurations of teams to produce the same effect*, which allows for advantageous flexibility. That is, engineering resource planning within S&OP is mainly done through individuals from each division, which limits the visibility of the embedded flexibility and equivalences among engineers across the different divisions. The higher-level managers who review the respective plans still see this more comprehensive picture of how all engineers are allocated. Again, these managers rely on their own experience and ad-hoc approaches to optimize such resource plans.

The case company partially measures the S&OP performance through indicators from few activities including forecast accuracy, customer scheduling adherence, inventory turnover, and service level. That is, the performance of S&OP as a whole is not measured due to the lack of consensus on the effect to be measured. Some participants consider the periods the S&OP process is able to address beyond the budgeted activities as an indicator, while others relate the S&OP performance to the progress made on strategic goals. On the other hand, the interviewees confirmed that the performance of S&OP had been assessed at least against maturity criteria to identify major gaps. Consequently, a dedicated team of 10 members prioritized the improvement of activities, which were not followed up according to an action plan in each S&OP cycle, but rather used as guidelines. Involving engineering in S&OP is an example of such improvements. Another example is improving the processing conditions and clarifying the descriptions of several sub-processes. The team continuously refines the data that should be prepared upfront before the executive S&OP meeting to enable quicker and better decisions. That includes how the data should look like as well as how and when the data should be communicated. Figure 2 presents the areas of uncertainty related to engineering resources and the S&OP activities through which these areas are captured and addressed (i.e. the grayed out cells).




*1. Sources of customer orders
*2. Timing of customer orders
*3. Customer order specification
*4. Probability of winning orders
*5. Customer reliability
*6. Competence quantity
*7. Competence Type
*8. Internal competence availability
*9. External competence availability
*10. Competence qualification period
*11. Inter-resource equivalences

*Figure 2 – Areas of uncertainties related to engineering resources within S&OP*

## Discussion

The case analysis explores how to manage ETO challenges in an S&OP process, in terms of *people & organization*, *process & methodologies*, and *performance measurement*. It also explores how the S&OP integration with other processes is important in this context.

As revealed from the case analysis, the frequent engineering changes caused by incoming demand calls for incorporating a function for identifying and tracking the medium-term needs of engineering competences in addition to what has been referred to in previous literature (e.g. Wallace and Stahl, 2008) as a traditional *S&OP organization*. By involving engineering representatives in the demand planning conducted by product groups, the S&OP organization facilitates the translation of demand plans into engineering resource needs. However, within the engineering functional organization, the hierarchical gap between management levels can be reflected from limiting the respective cross-hierarchical communication to certain escalation conditions. When this applies, top managers are often not able to question such escalations and thus delay related decisions as they are not fully aware of the grounds on which the identification of engineering needs were based. This corresponds to a general need and absence of early communication of uncertainties and structured communication of assumptions as part of a demand management and S&OP process (APICS, 2019). We see that such need of early and structured communication is critical in ETO environments. In accordance with the cross-functional integration framework of Oliva and Watson (2011), we also see that S&OP may enable improved engineering information quality and constructive engagement even within the engineering function – cross-hierarchically.

As for the *processes and methodologies* used in S&OP, to address the uncertainty areas identified in Figure 2, the case company seems to rely on assumptions and implicit ad-hoc approaches. For instance, the translation of engineering workload requirements into man-hour per engineering skill is based on subjective judgements, rules of thumb, and personal experiences. Findings show that the uncertainties stemming from an ETO environment require more structured/advanced methods of capacity planning compared to other contexts. While such identification of engineering needs can be “good enough” as claimed by an interviewee, the lack of method transparency still hinders making quick decisions by higher-level managers and does not allow for establishing a consistent engineering planning process among product groups and engineering divisions. The lack of using systematic methods to plan capacity for job shops was also discussed by Tenhiälä (2011). This lack was attributed to the practitioners being often unaware of the possibilities RCCP methods can bring. Apart from that, there seems to be a strong requirement on the integration between the key sub-processes of S&OP (i.e. demand and supply planning) in ETO settings as to be able to run the S&OP cycle in a monthly basis despite the extra need of continually identifying engineering needs. The case company enables considerable integration between demand and supply planning through a matrix organization that takes the form of product groups, which in turn serve as collaborative cross-functional platforms. The cross-functional teams from the respective product groups are involved in almost all demand and supply planning events of S&OP, which ensures that both planning processes are somehow integrated throughout the process.

*Information technology* (IT) has been recognised in several S&OP literature as a key process enabler in many contexts, and the case analysis shows that ETO settings are not an exception. The case company dedicates internal databases of business intelligence and tools for competence road mapping and collaborative workforce planning, which is – according to the interviewees – far from being enough to deal with several ETO challenges. The dominant type of information that can be made available in ETO settings is highly descriptive due to the uniqueness and ambiguity embedded in demand. Manipulating and processing such type of information requires considerable manual human work as information systems are not yet mature enough to automatically arrange descriptive information into systematic codes (Evers, 2018). Instead, findings show that the information systems used in ETO environments for S&OP should at least enable intuitive explicating of the ad-hoc approaches used by individuals to define the required engineering workload given a certain demand, the required type and quantity of engineering competences given a certain workload, and the possible allocation(s) of competences to fulfil the requirements of a certain workload given their availability. Besides, ETO environments are surrounded with several risks and assumptions such as engineering critical resource absenteeism, and IT tools that support scenario planning is much needed under such circumstances. High-performing firms use scenario planning in S&OP (Danese et al., 2017). The scenario-planning support for S&OP in ETO settings also needs to enable modelling the consequences of recruiting new engineers, acquiring consultants, and reorganizing the engineering resource base as these activities are frequently performed. Consequently, our findings indicate relative high IT needs for S&OP in ETO settings, already on lower maturity levels.

As for *S&OP performance*, the case shows an evident lack where limited performance indicators are used such as scheduling adherence and forecast accuracy. According to Hulthén et al. (2016), the performance of S&OP can be measured through measuring the efficiency of, for example, respective meetings. Meetings are highly important to make timely decisions in ETO settings, especially when it comes to approving the recruitment of additional engineering competences. This is because certain engineering competences need long-lasting preparation and training before they can be properly utilized. The S&OP process in large is also more complex in ETO settings (e.g. more functions involved, more supply planning activities) which may motivate a need for measuring process efficiency.

Finally, the case emphasizes the importance of tightly *integrating certain planning processes* in ETO contexts. Since the majority of ETO markets are based on tendering (Hicks et al., 2001), the bidding process plays a crucial role in shaping the medium-term demand. This calls for having S&OP and bidding highly integrated. Similarly, the lifecycle of products also influences the timing and volume of future demand, which is extremely important for ETO environment as discussed earlier, and thus needs to be tightly integrated into S&OP. Apart from that, S&OP outcomes should be integrated into organizational plans as S&OP captures in a monthly basis the potential future competence gaps that the organizational plans need to be aligned with.

## Conclusion

This study explores how S&OP manages the uncertainty associated with the dynamic medium-term needs of engineering resources in an ETO environment. A relevant single case study was investigated leading to three main areas of contribution. The first contribution is to the ETO planning environment. Eleven areas of uncertainty were identified and related to customer orders and critical competences, as shown in figure 2.

The second contribution is to explore the role of S&OP in relation to the identified areas of uncertainty. To mitigate for these areas of uncertainty, we explore the role and maturity dimensions of S&OP. The S&OP organization needs to integrate an additional function concerned with engineering resource planning. Such growth of the S&OP organization calls for more coherent integration of S&OP sub-processes that enables to run S&OP within reasonable timeframes. Arguably, this is possible through the early involvement of engineering resource planning actors in that cross-functional teams dedicated to measure and follow up the performance of demand and supply planning. The engineering resource planners need to explicate the approaches they use to identify the required engineering workloads and corresponding competences needed as a first step towards learning about and standardizing relevant know-how knowledge and best practices. In this respect, the IT tools used in S&OP should at least intuitively support such knowledge elicitation from individuals on top of the need to support reliable scenario planning capitalizing on companywide data. That is, in ETO settings, the need for IT and information sharing is relatively high even at lower S&OP maturity levels

The study also identifies a need to continuously improve the short-term performance of S&OP through measuring the efficiency of the key events of the S&OP activities such as important meetings. Within longer terms, the maturity assessments are suggested to identify the significant deficiencies and develop action plans accordingly.

The third contribution is related to the role of S&OP in other processes. The alignment of S&OP with the bidding process and organizational development seems to be highly important in ETO settings due to the recurring exchange of inputs and outcomes between these processes. Further, S&OP seems to have cross-hierarchical integrative potentials within large engineering organizations, which is manifested by improved information quality and constructive engagement and suggested for future research. Studying S&OP in other ETO settings with different complexity is also highly recommended to further explore, validate and generalize the findings of this study. Another trajectory is to more deeply study the requirements on and the potentials of one or more S&OP dimensions to manage one or more areas of uncertainty related to engineering resource planning.

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