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Engaging with 'Engineer for Supply Chain' (EfSC): insights from two engineer-to-order manufacturers

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ABSTRACT

The practice of 'Design for Supply Chain' (DfSC) aims at integrating strategic sourcing into manufacturers' new product development (NPD) processes. The literature on this topic, however, mainly focuses on contexts involving high-volume, standardised products, while the engineer-to-order (ETO) context has received only limited attention. As argued in this paper, this constitutes a gap in the literature since the findings from high-volume, standardised contexts may not be directly applicable to the ETO context. To support this claim, a case study approach is used to explore DfSC in two ETO manufacturers. This paper terms this practice 'Engineer for Supply Chain' (EfSC) and identifies four dimensions that it comprises: (1) consideration of strategic sourcing in NPD, (2) representation of the sourcing function in NPD, (3) collaboration between the R&D and sourcing functions, and (4) adoption of methods for considering strategic sourcing in NPD. Although these dimensions partly overlap with the literature on DfSC, the characteristics of EfSC differ—most notably by requiring the consideration of strategic sourcing before the product design stage of NPD, as well as procedures that encourage this consideration. Finally, the study identifies relationships among the dimensions and develops a holistic four-step process for engaging with EfSC.

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1. Introduction

Increased customer demands have led to greater product diversity, in turn making supply chains increasingly complex and vulnerable to disruptions (e.g. the COVID-19 pandemic) (Handfield, Graham, and Burns 2020; Linton and Vakil 2020; van Hoek 2020). To reduce the risk of such disruptions, a proper fit between product designs and strategic sourcing (e.g. selection of critical suppliers) is required (Caniato and Größler 2015; Inman and Blumenfeld 2014; Reitsma, Hilletofth, and Johansson 2023). This can be facilitated with 'Design for Supply Chain' (DfSC), which is a practice aimed at integrating strategic sourcing into manufacturers' new product development (NPD) processes (Lee 1993; Lee and Sasser 1995). It includes, for example, analytical models for dealing with the constraints imposed by potential suppliers on product design choices such as component selection (e.g. Claypool, Norman, and Needy 2014; Feng, Wang, and Wang 2001; Gokhan, Needy, and Norman 2010). Thus, DfSC helps to avoid designing products that are unnecessarily complex and for which there are only a few expensive suppliers (Claypool, Norman, and Needy 2014; Feng, Wang, and Wang 2001; Gokhan, Needy, and Norman 2010).

The DfSC literature mainly focuses on manufacturers of high-volume, standardised products targeted at consumers (Gosling et al. 2015; Gosling and Naim 2009; Reitsma, Hilletofth, and Johansson 2023). However, as argued by previous studies (e.g. Cannas et al. 2020; Cannas and Gosling 2021), it is unclear to what extent assumptions and best practices from manufacturers of high-volume, standardised products apply in the ETO context. Specifically, ETO products—such as turbines and advanced aerospace systems—are low-volume, engineering-intensive, and developed on the basis of single customer requirements (Hobday 2000; Hobday, Rush, and Tidd 2000; Willner et al. 2016). Meeting these requirements involves sourcing a large variety of distinct, innovative items (e.g. components and systems) and services (e.g. research and technology development and manufacturing operations) originating from globally dispersed suppliers (Alfnes et al. 2021; Cannas et al. 2019; Willner et al. 2016). This poses risks for ETO manufacturers since a need for more items or services increases the chances of supply chain disruptions (Inman and Blumenfeld 2014; Vachon and Klassen 2002). Furthermore, the customer-specific requirements often change throughout the NPD process, forcing ETO manufacturers to continuously monitor and adjust their approaches to strategic sourcing (Emblemsvåg

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2014; Hicks, McGovern, and Earl 2000; Vaagen, Kaut, and Wallace 2017). As an example, Moretto et al. (2022) present a real-life case of an aircraft fuel systems manufacturer that involves the sourcing function as early as possible in supplier decisions, as this allows a flexible response to customer requirements and avoids problems later in the NPD process.

As the discussion above indicates, NPD in the ETO context involves high levels of product complexity and unpredictability, for which reason findings from the DfSC literature focusing on high-volume, standardised products are not directly transferable to the ETO context. This gives rise to the following research question:

> *How can ETO manufacturers integrate strategic sourcing into their NPD processes?*

To investigate this question, the present paper uses a case study approach to explore the dimensions of DfSC in two ETO manufacturers, which we term 'Engineer for Supply Chain' (EfSC). Through analyses of the collected data, the paper develops a model that describes and connects the most important dimensions of EfSC. Through the conceptualisation of EfSC, the study provides future research with clarification of the differences between DfSC in contexts involving high-volume, standardised products and the ETO context, and practitioners with increased clarity regarding possible approaches to engaging with EfSC.

The remainder of the paper is structured as follows. To begin with, a literature review is presented in Section 2, after which the research design is described in Section 3. The empirical data are analysed in Section 4, followed by a discussion of the empirical findings in the context of prior literature in Section 5. Conclusions and future research avenues are presented in Section 6.

2. Literature review

To lay out a basis for investigating the practice of EfSC, this section first discusses NPD and strategic sourcing in the ETO context, after which the literature on DfSC is summarised.

2.1. NPD and strategic sourcing in the ETO context

Although there is no clear consensus on the definition of ETO (Willner et al. 2016), it is commonly agreed that the manufacturing stage of an ETO product is driven by actual customer orders, with the decoupling point located at the product design stage (Cannas and Gosling 2021; Gosling and Naim 2009). ETO products can range from low-volume and highly customised products to those that require limited order-specific engineering and share many characteristics with make-to-order products, which merely require configuration within a pre-defined solution space (Amaro, Hendry, and Kingsman 1999; Gosling and Naim 2009; Wikner and Rudberg 2005; Willner et al. 2016). ETO products, on which the present research focuses, share four key characteristics: (1) they are ordered in low volumes and are engineering-intensive (Hobday, Rush, and Tidd 2000; Willner et al. 2016); (2) their design activities are, for some parts, performed before receiving orders, while they are completed according to the specifications of individual customers (Maffin et al. 1995); (3) their order-specific engineering activities require a substantial amount of time (Hobday 2000; Hobday, Rush, and Tidd 2000; Little et al. 2000); and (4) they typically address capital goods markets, which tend to be dominated by a few manufacturers due to entry barriers (Willner et al. 2016).

NPD is a key capability for ETO manufacturers (Hobday, Rush, and Tidd 2000), especially when competition in the industry becomes more intensive due to the entry of latecomers (Lee and Yoon 2015). Therefore, ETO manufacturers usually organise NPD with projects (Davies et al. 2011; Hobday 2000) and use a formalised process that divides the NPD stages into prescribed, multi-functional, and parallel activities with gates that act as quality control checkpoints (e.g. Cooper and Kleinschmidt 1993; Pahl and Beitz 1984). ETO manufacturers often involve various supply chain actors (e.g. customers and suppliers) in the product design stage of the NPD process (Alfnes et al. 2021; Brady and Davies 2014; Crespin-Mazet, Romestant, and Salle 2019; Hobday 2000). Specifically, as customer requirements are specified or changed, offers from different suppliers are typically obtained (Birkie and Trucco 2016; Gosling et al. 2015; Wikner and Rudberg 2005). This leads to NPD involving many inputs (e.g. items, services, and knowledge) from suppliers that can be globally dispersed or scattered across multiple tiers (Cannas et al. 2022; Hobday, Rush, and Tidd 2000). Since more inputs are needed, the chance of supply chain disruptions increases (Inman and Blumenfeld 2014; Vachon and Klassen 2002).

The integration of strategic sourcing into NPD processes plays an important role in preventing supply chain disruptions and mitigating the risks stemming from product complexity (Caniato and Größler 2015; Inman and Blumenfeld 2014; Reitsma, Hilletofth, and Johansson 2023). Strategic sourcing is an essential component of supply chain management (van Hoek and Thomas 2021) and although it has various definitions, the literature (e.g. Fine 2009; Fine, Golany, and Naseraldin 2005; Noori and Georgescu 2008; Wynstra, Weggeman, and van Weele 2003) generally agrees that three sourcing activities are of strategic importance and should therefore be integrated into NPD processes: (1) make-or-buy analysis, (2) supplier selection, and (3) supplier collaboration. The make-or-buy analysis focuses on balancing internal and external sourcing (Fine 2009; Fine, Golany, and Naseraldin 2005). This concerns both the acquired physical items (e.g. components and systems) and services associated with items (e.g. research and technology development and manufacturing operations) (Fine, Golany, and Naseraldin 2005; Wynstra, Weggeman, and van Weele 2003). Supplier selection concerns the choice of which suppliers to involve in NPD (Fine 2009; Fine, Golany, and Naseraldin 2005). This requires evaluations of whether supplier capabilities align with the characteristics of the outsourced items or services (Petersen, Handfield, and Ragatz 2005; Song and Di Benedetto 2008). Supplier collaboration refers to the involvement of suppliers in NPD activities such as product design (Fine 2009; Fine, Golany, and Naseraldin 2005). This requires determining expectations with suppliers regarding, for example, goals, rewards, incentives, governance, responsibilities, communication, and documentation (Gosling, Hewlett, and Naim 2021; Wynstra, Weggeman, and van Weele 2003).

2.2. The DfSC practice and its dimensions

The practices used to integrate strategic sourcing into NPD processes fall under the umbrella practice of DfSC (Claypool, Norman, and Needy 2014; Gokhan, Needy, and Norman 2010; Lee 1993; Lee and Sasser 1995). The DfSC literature focuses mainly on manufacturers of high-volume, standardised products targeted at consumers, as opposed to ETO manufacturers (Gosling et al. 2015; Gosling and Naim 2009; Reitsma, Hilletofth, and Johansson 2023). Given the lack of ETO-oriented literature on the topic, the DfSC literature is used as a foundation in the present study.

DfSC is a specific type of 'Design for X' (DfX) practice. DfX practices are used to design a product simultaneously with X, or to explore how the design of a product affects X (Huang 1996). 'X' can represent many different activities, depending on a manufacturer's objectives; the 'D' in DfX refers to (product) design. DfX may not only stand for designing a product for X, as it can also stand for the simultaneous design of the product and X. This means that DfX practices are used to perform activities and make improvements related to a product and to X (Huang 1996). Since a manufacturer can have various objectives, it is possible to use two or more DfX practices simultaneously with multiple purposes (for overviews of DfX practices, see Kuo, Huang, and Zhang 2001 and Arnette, Brewer, and Choal 2014).

DfSC is a particularly important DfX practice for manufacturers, as considering strategic sourcing only after product design can result in a lengthier time-to-market and sub-optimal overall product profitability (Claypool, Norman, and Needy 2014; Gokhan, Needy, and Norman 2010). Lee (1993) was one of the first to demonstrate the benefits of DfSC, and since then, many others have recognised the importance of this DfX practice (e.g. Appleyard 2003; Gokhan, Needy, and Norman 2010; Hillebrand and Biemans 2004; Hult, Tomas, and Swan 2003; Hundal 1993; Joglekar and Rosenthal 2003; Petersen, Handfield, and Ragatz 2003). For example, according to Gokhan, Needy, and Norman (2010), DfSC can reduce the cyclic procedure of designing a product, generating the supply chain, evaluating the supply chain, and redesigning the product to a single iteration.

The literature describes four dimensions of DfSC, which are shown in Table 1 and subsequently discussed.

The first DfSC dimension concerns the R&D function (e.g. industrial designers, design engineers, and CAD engineers) considering strategic sourcing in the product design stage (i.e. concept and detail design) of NPD (e.g. Chiu and Kremer 2014; Gokhan, Needy, and Norman 2010; Lee and Sasser 1995). This facilitates achieving the full benefits of DfSC (Dowlatshahi 1999; Lee and Sasser 1995). For example, it allows the anticipation and management of potential supplier selection constraints (e.g. limited supplier availability) when designing or selecting product concepts (Chiu and Kremer 2014).

The second DfSC dimension concerns the representation of the sourcing function in NPD activities (e.g. Arnette and Brewer 2017; Dowlatshahi 1996). In this context, Arnette and Brewer (2017) argue that an extended role for the sourcing functions in NPD allows manufacturers to more effectively utilise internal resources, as well as increase supplier involvement, and ultimately improve product performance. For example, the sourcing function knows how to build a strong supplier network and which suppliers can contribute when brought into NPD (Brewer and Arnette 2017). Dowlatshahi (1999, 1996) even argues that the sourcing function should be given an essential role as the key player in NPD. This requires delegation of legitimate authority and power to the sourcing function, and top management should genuinely encourage its involvement (Dowlatshahi 1999, 1996).

The third DfSC dimension concerns the collaboration between the R&D and sourcing functions (e.g. Dowlatshahi 1996; Gokhan, Needy, and Norman 2010). Such collaboration can be supported by well-defined information requirements and exchanges, allowing the sourcing function to communicate the potential benefits or risks of strategic sourcing to the R&D function on a timely, accurate, and relevant basis (Dowlatshahi 1996, 1999). As DfSC aims at balancing the activities of the R&D and sourcing functions, trade-offs between functional interests may also prevail (Dowlatshahi 1996, 1999). For example, trade-offs may occur between the R&D function's preferences regarding product functionality and the sourcing function's regarding, for example, supplier availability, cost, quality, or lead times (Dowlatshahi 1996, 1999).

The fourth DfSC dimension concerns the adoption of methods for strategic sourcing (e.g. Dowlatshahi 1996; Lee 1993). Specifically, most DfSC methods include analytical models that support the R&D function in considering strategic sourcing during product design (van Hoek and Chapman 2006). These models typically quantify the benefits (e.g. lower costs, lower inventory, or shorter lead times) of changing a product design based on sourcing constraints (e.g. supplier availability) (Lee 1993), which ultimately provides valuable input to decision-making processes (Lee, Billington, and Carter 1993). For example, Yadav et al. (2011) propose a model aimed at minimising supplier costs and product design complexity, while maximising the sales profits of the end products (for more DfSC models, see Yao and Askin 2019). DfSC models—explicitly or implicitly—define the new product by using the bill of materials (BOM) and express the supply chain as a network comprising the connections among supplier, manufacturing, distribution, and customer nodes (Yao and Askin 2019).

As indicated at the beginning of this section, the DfSC literature does not account in much detail for what occurs in the ETO context (Gosling et al. 2015; Gosling and Naim 2009; Reitsma, Hilletofth, and Johansson 2023). It has, however, been argued that this context deserves special attention due to its high degree of complexity and unpredictability (e.g. Cannas et al. 2020; Cannas and Gosling 2021). Specifically, the ETO context often involves innovative, customer-specific requirements that change throughout the NPD process, leading to continuous sourcing adjustments (Cannas et al. 2019;

Table 1. Four dimensions of DfSC.

DfSC dimension	References (e.g.)
Consideration of strategic sourcing during product design.	Appelqvist et al. (2004); Arnette and Brewer (2017); Arntzen et al. (1995); Brewer and Arnette (2017); Chiu and Kremer (2014); Chiu and Lin (2016); Claypool, Norman, and Needy (2014); Dowlatshahi (1996, 1999); Feng, Wang, and Wang (2001); Gokhan, Needy, and Norman (2010); Lee and Sasser (1995); Mather (1992); Yadav et al. (2011)
Representation of the sourcing function in NPD.	Arnette and Brewer (2017); Brewer and Arnette (2017); Claypool, Norman, and Needy (2014); Dowlatshahi (1996, 1999); Gokhan, Needy, and Norman (2010); Lee and Sasser (1995); Mather (1992)
Collaboration between the R&D and sourcing functions.	Dowlatshahi (1996, 1999); Gokhan, Needy, and Norman (2010); Lee (1993); Mather (1992)
Adoption of BOM-based models for considering strategic sourcing.	Appelqvist et al. (2004); Arntzen et al. (1995); Chiu and Kremer (2014); Chiu and Lin (2016); Claypool, Norman, and Needy (2014); Dowlatshahi (1996, 1999); Feng, Wang, and Wang (2001); Gokhan, Needy, and Norman (2010); Graves and Willems (2005); Huang et al. (2005); Lamothe et al. (2006); Lee (1993); Lee, Billington, and Carter (1993); Lee and Sasser (1995); Yadav et al. (2011)

Emblemsvåg 2014; Hicks, McGovern, and Earl 2000; Vaagen, Kaut, and Wallace 2017). By investigating the ETO context, the present study aims to determine the extent to which existing knowledge of DfSC can be applied to this context and whether this knowledge should be extended.

3. Research design

This research is grounded in the research paradigm 'critical realism' (Bhaskar 1978; Easton 2010) and therefore aims at identifying the mechanisms influencing the integration of strategic sourcing into NPD processes, as well as how they are affected by contextual conditions. This can be achieved by looking for causal explanations and using qualitative methods to interpret the processes of social actors in a particular context (Bhaskar 1978; Sayer 1992). To answer the research question of how ETO manufacturers can integrate strategic sourcing into their NPD processes, the characteristics of DfSC in the ETO context (i.e. EfSC) are investigated through a case study approach. The arguments for this choice concern the appropriateness of case studies when the actors' behaviours cannot be controlled (Yin 2018), the research goal is explorative in its nature (Miles and Huberman 1994), and the research focuses on the mechanisms and conditions that generate outcomes (Bhaskar 1978; Easton 2010).

3.1. Case selection

The case study includes two 'instrumental' cases, which means that cases were chosen and studied to '*provide insight into an issue or to redraw a generalisation*' (Stake 2003, 137). Following the advice of Easton (2010) and Flyvberg (2006), case selection was guided by the objectives of the present research and case suitability for uncovering mechanisms, conditions, and outcomes. Specifically, five selection criteria were applied: (1) manufacturer of physical products, (2) having an NPD process, (3) operating in the ETO context, (4) recognising the need for considering strategic sourcing in NPD, and (5) having the motivation and resources to contribute to the research. Two large European manufacturers—referred to as 'TurbineCo' and 'AeroCo' for confidentiality reasons—met these criteria and were chosen for this research. The key characteristics of these manufacturers are shown in Table 2, after which the following two sections provide further information.

3.1.1. TurbineCo's NPD process

TurbineCo designs and manufactures turbines that customers use for power generation or industrial applications. NPD of a turbine can take up to 10 years and involves considering customer-specific operating conditions (e.g. pressure and temperature). For example, application-oriented designs of items (e.g. blades) are needed for optimal turbine performance. To meet demanding customer requirements, NPD mainly involves representatives from the R&D function (e.g. industrial designers, design engineers, and CAD engineers).

Apart from a turbine meeting technical requirements at the right cost, lead time is a major order winner for TurbineCo. This leads to NPD involving strict promises regarding customer delivery dates. These dates are fixed, making lead time reduction, on-time deliveries, and proactive quality assurance important focus areas. To manage these challenges, TurbineCo's R&D and sourcing functions are involved in three stages of the NPD process. The first stage is 'pre-study', which involves identifying and analysing customer requirements, based on which product requirements are specified. Afterwards, the main NPD targets are set, and detailed NPD budgets and plans are formulated. The second stage is 'concept design', which involves designing and evaluating alternative product concepts (regarding market, technology, and financial considerations). After choosing the preferred concepts, essential product specifications are documented, reviewed, and approved. The third stage is 'detail design', which involves creating and reviewing detailed documentation required for manufacturing and sourcing of items that are part of the product.

Strategic sourcing activities (i.e. make or buy analysis, supplier selection, and supplier collaboration) have become increasingly important in TurbineCo's NPD process. While the manufacturer traditionally single-sourced items or services from small, local suppliers, it now also promotes multiple sourcing from remote suppliers located in low-cost regions. Despite being a large manufacturer, TurbineCo is a relatively small customer for these suppliers. Therefore, suppliers may not be equally interested in lead time reduction, on-time deliveries, and quality. As another challenge, a single turbine consists of around 5000 components. Changing one of them

Table 2. Key characteristics of the case companies.

Case company Characteristic	TurbineCo	AeroCo
Type of products	Turbines that are used for power generation or industrial application	High-precision products that are used in aircraft engines, space rockets, and turbines
Roles in the supply chain	NPD process owner and product design and manufacturing	NPD process owner and product design and manufacturing
Main NPD stages	Pre-study, concept design, and detail design	Pre-study, concept design, and detail design
Main sourcing challenges	A dependency on supplier competencies, a small supplier base, limited leverage with suppliers, and strict customer delivery dates	A dependency on supplier competencies, a small supplier base, limited leverage with suppliers, and suppliers may become competitors

can have many knock-on effects. For example, setting new tolerance requirements for one component may require new tooling, materials, or suppliers.

3.1.2. AeroCo's NPD process

AeroCo designs and manufactures advanced high-precision products for manufacturers of commercial and military aircraft engines, space rockets, and industrial turbines. These products require leading-edge technology and are engineering-intensive and customised for individual customers. Therefore, AeroCo develops new products in close cooperation with suppliers and customers and faces long NPD lead times (up to 20 years).

Customisation further leads to high demands on manufacturing processes and the supply chain, especially since AeroCo's products must comply with strict quality requirements. If products fail quality tests, engineering changes are required until customer requirements are met. To manage these challenges as effectively and efficiently as possible, AeroCo's R&D and sourcing functions are involved in three stages of the NPD process. The first stage is 'pre-study', which involves investigating technical and commercial possibilities. Furthermore, functional product requirements are identified, and an overview of the resources needed for NPD is created. The second stage is 'concept design', during which customers provide technical requirements related, for example, to interfaces, cost, and reliability. These requirements are assessed in terms, for example, of their risks and feasibility. Afterwards, product concepts are designed and assessed. The third stage is 'detail design', during which a detailed product design is established, verified, and used for prototype manufacturing. Also, product specifications are reviewed for certification by aerospace authorities.

Strategic sourcing activities (i.e. make or buy analysis, supplier selection, and supplier collaboration) play an important role in AeroCo's NPD process. Most notably, many key items and services must be sourced from at least two suppliers, certified by aerospace authorities, and approved by the final customer. However, it is difficult to find enough suitable suppliers and create a competitive supplier base. For example, AeroCo is dependent on a large supplier that almost has a monopoly position in the market. Despite AeroCo being one of its largest customers, the supplier has the power to dictate the terms on which it will do business. As an additional challenge, when the ownership structure of a supplier changes, it potentially becomes a competitor of AeroCo. This requires selecting a new supplier, which is a demanding process in terms of time and cost.

3.2. Data collection

The case study is based on qualitative data, in the form of interviews and documents. The interviews were conducted with employees from TurbineCo and AeroCo with expert knowledge about the practice of EfSC, which were selected in collaboration with the companies. To capture the perspectives of other relevant informants, 'snowball' sampling was used, which involved asking the interviewees to identify other relevant interviewees in relation to the research question (Scarbrough et al. 2004, 1586). These were progressively identified and approached once the case study had commenced. Table 3 provides an overview of the interviewees involved in the case study, who include individuals from the R&D and sourcing functions, as well as general managers and project managers.

Guided by Section 2.2, the interviewees were asked to explain how they integrate strategic sourcing activities (i.e. make or buy analysis, supplier selection, and supplier collaboration) into NPD, as well as how strategic sourcing challenges are accounted for, the process context of such challenges, and possible ways to overcome any associated issues (see the interview guide in Appendix 1). The interviews were retrospective, encouraging interviewees to recall and make sense of past instances and outcomes of engaging with EfSC, as well as the associated experiences. Furthermore, the interviews were semi-structured to allow interviewees to expand on unexpected topics and issues or provide more details on challenges they considered important (O'Leary 2017). Each interview lasted from 30 to 60 minutes, involved two to five interviewees at a time, and was audio recorded and transcribed. For ethical reasons, all interviews were voluntary, and interviewees were asked for permission to be recorded, informed about the research objectives, and anonymised in the data analysis process. After the interviews, data analysis drafts were shared with the interviewees for discussion and revision, resulting in the clarification of statements and correction of misinterpretations.

The use of group interviews had both advantages and drawbacks. On the positive side, the answers from participants in the group interviews helped other participants recall events that they would likely not have recalled in individual interviews. Furthermore, the use of group interviews provided insights into relevant employees' ways of interacting with each other. On the other hand, group interviews can be

Table 3. Interviewees.

Case company	Interviewee	No. of interviews involved in	Time (h)
TurbineCo	Chief Engineer	4	4
	R&D Manager	2	1.5
	Project Manager R&D	2	1.5
	Manager Order Execution	2	1.5
	Supply Chain Developer	2	1.5
	Global Demand Planner	6	6
	S&OP Manager	6	6
	Strategic Buyer	2	2
	Procurement Engineer	6	5.5
	Head of Production Technology	6	6
	Procurement Engineer	3	2.5
	Procurement Manager	3	2.5
	Manager Manufacturing Support	2	2
AeroCo	Logistics Specialist	5	5
	Procurement Lead	5	4.5
	Project Manager	4	3.5
	R&D Engineer	4	3.5
	Quality Manager	4	3.5
	NPI Lead	4	3.5
	Supply Chain Manager	4	3.5
	Head of Logistics and MPC	4	3.5
	Material Control	3	2.5
	Procurement Manager	2	1.5
	Chief Manufacturing Engineer	5	4.5

associated with bias as a consequence of group dynamics (Coughlin 1990; Scheibe and Blackhurst 2018). In the present context, the company culture and the questions asked should be considered. Specifically, bias in relation to the interviews was less of a threat because the persons included in the group interviews were part of a company culture where it was normal to disagree and discuss disagreements, and the questions asked focused more on actual events than opinions. Furthermore, to increase validity, the answers provided during the interview were cross-checked with information from other interviews and documents (i.e. triangulation) (Yin 2018). The documents mainly included stage-gate models, checklists, process charts, work procedures, and process descriptions, which provided detailed information on how TurbineCo and AeroCo integrate strategic sourcing activities into their NPD processes.

3.3. Data analysis

To answer the research question and identify the dimensions of EfSC, the analysis process began with reading the interview transcripts several times and writing summary reports (Miles and Huberman 1994). Afterwards, a data extraction form was created using Microsoft Excel, and the three-step procedure of Gioia, Corley, and Hamilton (2013) was followed.

The first step focused on reporting relevant understandings on the part of the interviewees regarding the phenomenon under investigation (Gioia et al. 2022). This involved identifying potentially relevant quotes and importing them into the created template (Gioia, Corley, and Hamilton 2013). This reduced the interviews to short paragraphs and sentences. The second step focused on reporting research-based understandings of the data (Gioia et al. 2022), which involved organising relevant quotes into higher-level themes by searching for similarities and differences among the quotes (Gioia, Corley, and Hamilton 2013). The DfSC literature discussed in Section 2.2 guided this step. In the third step, the themes were grouped into 'aggregate dimensions' (Gioia, Corley, and Hamilton 2013). Throughout these steps, 'cross-case synthesis' (Miles, Huberman, and Saldana 2014) was employed to combine findings from the two cases. As argued by Cannas et al. (2022), this approach allows the identification of similarities and differences between the different cases across themes, as well as the development of clear chains of reasoning, interpretations, and conclusions. In other words, by including two cases instead of one, more solid conclusions may be drawn in relation to the dimensions of EfSC.

After this grouping of the interview data in a summary table, the interview summary reports were revisited to explore how the data dimensions relate to one another. Specifically, mechanisms, conditions, and outcomes should be understood in relation to one another in a coherent whole or configuration (Dubois and Araujo 2007), which requires '*a continuous moving back and forth between the diverse stages of the research project*' (Verschuren 2003, 132). In this context, the exploration of relationships between data dimensions involved abductive reasoning towards the 'most likely' explanation (Mantere and Ketokivi 2013).

4. Findings

4.1. Identification of EfSC dimensions

The results of the analytical process are shown in Table 4, which includes quotes from TurbineCo and AeroCo describing EfSC, organised under themes and dimensions. As seen in the table, the cross-case synthesis revealed that the quotes identified during the first step of analysis could be organised under the same eight themes in both cases. The following sections discuss and compare the cases for each theme.

4.1.1. Dimension 1: consideration of strategic sourcing in NPD

The first theme of the first dimension concerns the R&D function's consideration of strategic sourcing before the product design stage of NPD. In this context, TurbineCo's sourcing function stressed that the R&D function should share not only product-related information, but also potential sourcing constraints during the NPD kick-off meeting. Examples of such constraints include the time needed for supplier selection and collaboration. The consideration of sourcing constraints was argued to be especially important when the R&D function assesses the customer's delivery time requirements and sets the time-to-customer deadline. Otherwise, there would not be enough time later in NPD, for example, to optimally select or collaborate with suppliers. As stated by TurbineCo's Global Demand Planner: '*Supply chain lead times are not properly considered when the R&D function plans NPD. This affects many decisions of the sourcing function, including supplier selection, and affects the overall way*

Table 4. Organising quotes under themes and dimensions.

S*	Quotes	Themes	Dimensions (D)
TC	• *"During the kick-off of NPD, the R&D function mainly discusses product-related information, which means that there is no focus on potential sourcing constraints."* • *"When setting time-to-customer deadlines in the business case for NPD, the R&D function does not bear in mind that concurrent engineering with suppliers and the supplier selection process can take several years."*	The R&D function should consider strategic sourcing before product design	**D1** Consideration of strategic sourcing in NPD
AC	• *"The R&D function should consider sourcing constraints in the planning stage of the NPD process."* • *"When making the business case for NPD and setting cost targets, the R&D function focuses too much on product cost, which often constrains the choice of resources, including, for example, suppliers. Since this leads to sub-optimisation, the R&D function needs to consider landed cost and aim for more realistic business cases."*		
TC	• *"Of course, the R&D function is crucial in designing good products, but many order winners, such as delivery time, cost, inventory, are created by the sourcing function. So, the R&D function should consider the availability of suppliers and whether a new product requires developing or selecting new suppliers."* • *"The R&D function either creates a drawing for components themselves and sends it out to three to five suppliers to see who comes back with the best comments, or chooses for concurrent engineering with suppliers, which means that the R&D function works with two or three suppliers."*	The R&D function should consider strategic sourcing during product design	
AC	• *"The R&D function should consider the availability, lead times, and costs of suppliers when establishing a preliminary product structure."* • *"The R&D function should consider supplier costs and make plans for changing the product concept when the cost target is exceeded."*		
TC	• *"The sourcing function knows that it can be involved in NPD. But if you look at the number of representatives of the sourcing function in NPD, the sourcing function can assign more people to NPD."* • *"The sourcing function should be represented by people who speak a technical language so they can communicate with the R&D function."*	The sourcing function should assign sufficient and suitable representatives to NPD	**D2** Representation of the sourcing function in NPD
AC	• *"The sourcing function should select people who can properly represent its interests in NPD and should ensure that these people are available for NPD."* • *"The sourcing function should be represented by the right people with the right attitude. For example, they should be technical experts with producibility know-how."*		
TC	• *"The sourcing function has the responsibility to make sure that its representatives are properly prepared. For example, representatives should be informed which meetings to attend."* • *"During NPD, representatives of the sourcing function should know for which sourcing matters they are responsible."*	The sourcing function should clarify the responsibilities of representatives in NPD	
AC	• *"The sourcing function needs to customise the attendance of its representatives during the different NPD stages, depending on the skills needed."* • *"The sourcing function needs to set clear expectations on the contribution of its representatives in NPD, both regarding deliveries and way of acting."*		
TC	• *"The R&D function should invite the sourcing function to meetings where product design decisions are discussed. Because, at these meetings, it is often the only chance for the sourcing function to stand up and say, wow, I don't like the sound of this or can we do this a bit differently."* • *"The sourcing function should get review material two weeks before the product design reviews, so they can prepare."*	The R&D function should inform the sourcing function about its activities	**D3** Collaboration between the R&D and sourcing functions
AC	• *"There should be open and clear communication with the sourcing function about important decisions."* • *"The R&D function should notify the sourcing function about product design changes. Otherwise, it is difficult to*		

(*continued*)

Table 4. Continued.

S*	Quotes	Themes	Dimensions (D)
	secure the support and gradual introduction of a new product into the organisation."		
TC	• *"The R&D function is only responsible for the first few products that are part of NPD and, afterwards, the product's responsibility is handed over to the sourcing function. During NPD, the sourcing function should avoid the R&D function's decisions being optimised for (only) the few products that are part of NPD."* • *"The sourcing function should make sure that the R&D function does not only pursue its own functional interests or agenda."*	The sourcing function should provide the R&D function with feedback on its activities	
AC	• *"The sourcing function should inform the R&D function of the consequences of product-related decisions."* • *"The sourcing function should avoid the R&D function making decisions while only considering the project or individual components. Instead, the R&D function should make decisions with the line organisation or assembled product in mind."*		
TC	• *"Instructions for the NPD process were made with little to no input from the sourcing function. Also, the instructions around the NPD process require a lot of experience to truly understand and remember. That's why the sourcing function should create more digestible instructions that cover strategic sourcing activities."* • *"The sourcing function can ensure that strategic sourcing activities are accounted for by having simple checklists that can be used by representatives of the sourcing function during product design review meetings."*	The sourcing function should adopt procedures for considering strategic sourcing	**D4** Adoption of methods for considering strategic sourcing
AC	• *"The sourcing function has created a separate and formalised process, which instructs how to consider strategic sourcing throughout the NPD process."* • *"The instructions for the NPD gate meetings should have checkpoints that cover strategic sourcing activities, and the sourcing function should avoid important sourcing topics not being present in the documents that describe the NPD process."*		
TC	• *"The sourcing function makes a development BOM that contains 'imaginary' components. These are replaced once the 'real' components are known. This development BOM acts as input to an Excel-based model that can be used for assessing delivery lead-time constraints and planning the supply chain resources needed for a new product."* • *"The sourcing function uses the BOM of a new product to model the 'should cost', including any future commercial risks, of suppliers for components when the 3D CAD drawings are finished."*	The sourcing function should adopt BOM-based models for considering strategic sourcing	
AC	• *"The sourcing function has numerical models that use a development BOM to estimate supplier costs. We then have a 'should cost'."* • *"We do not have so many suppliers, so we cannot really bargain. The suppliers say take it or leave it. The sourcing function therefore uses the development BOM to model and assess whether the R&D function should or can make product design changes."*		

*S: Source, TC: TurbineCo, AC: AeroCo.

strategic sourcing activities are handled, because there is not much time to think things through'.

AeroCo's sourcing function also called for the R&D function's consideration of strategic sourcing before the product design stage. Specifically, it was explained that this requires the R&D function to consider not only product cost, but also the costs of potential suppliers when assessing the customer's cost requirements. This aims at setting more realistic cost targets for NPD and enables the sourcing function to choose from more suppliers later in NPD.

The second theme concerns the R&D function's consideration of strategic sourcing during the product design stage of NPD. TurbineCo's sourcing function argued that this could create order winners, such as optimal delivery time, cost, and inventory. Therefore, they stressed the importance of the R&D function considering the manufacturing capability of suppliers during product design, which requires inviting suppliers to provide feedback on or co-design the product. Due to TurbineCo's multi-sourcing strategy, a Procurement Engineer suggested that the R&D function should especially consider the availability of suppliers during product design: '*The R&D function should not search online for a coating and select one without thinking about consequences such as limited supplier availability'*.

Similarly, AeroCo's sourcing function argued for the R&D function's consideration of supplier availability, lead times, and costs during product design, as well as making product design changes when exceeding cost targets. For example, the Procurement Lead suggested that the R&D function should consider the availability of suppliers when selecting manufacturing solutions for the new product: '*The R&D function decided to use a new alloy with which components have never been forged before. Since the forging process is unproven and unstable, the delivery performance is affected negatively. Also, the alloy is patented with only one supplier and only a few forging suppliers have made prototypes, which results in low to no competition within the supplier base*'.

4.1.2. Dimension 2: representation of the sourcing function in NPD

The first theme of the second dimension concerns the sourcing function's assigning of representatives to NPD. Regarding this theme, TurbineCo's sourcing function suggested involving more of its representatives in NPD. However, despite having the possibility to do so, they tend not to assign enough people to NPD, which results in being outnumbered by the R&D function. As stated by the Head of Production Technology: '*The sourcing function is outnumbered by people from the R&D function who do not have the best knowledge or interest in strategic sourcing. As a result, the topics that are discussed in NPD are not sourcing topics*'. Besides assigning sufficient representatives to NPD, TurbineCo's sourcing function argued for selecting representatives who have the adequate technical knowledge and are located at the same site as the R&D function. This was said to promote effective communication and a joint understanding of NPD goals and objectives.

AeroCo's sourcing function also mentioned being outnumbered by the R&D function in NPD. As stated by a Logistics Specialist: '*NPD is dominated by the R&D function and therefore by people who lack a supply chain perspective and competence*'. Therefore, like TurbineCo's sourcing function, it was suggested that the right number and type of sourcing representatives should be assigned to NPD. This entails ensuring that these representatives include people who are available for NPD and have producibility know-how, the right attitude, and various appropriate levels of expertise.

The second theme concerns the sourcing function clarifying the responsibilities of its representatives in NPD. TurbineCo's sourcing function detailed that this requires informing its representatives about relevant NPD meetings, what strategic sourcing activities to cover, and whom to contact to acquire background on NPD. However, a Procurement Engineer explained that NPD complexity could make this difficult to achieve: '*There can be around ten NPD meetings each week. I tried to create an overview of who should attend which meeting. This was impossible so that attendance of a meeting has to be assessed on a case-by-case basis*'.

AeroCo's sourcing function also mentioned the difficulty of clarifying the responsibilities of its representatives. As stated by the Procurement Lead: '*It is challenging to secure and allocate the required representatives at the right place and time*'. Therefore, AeroCo's sourcing function argued for customising the attendance of its representatives during the different NPD stages, depending on the skills required. This includes removing representatives from NPD only when their duties are completed, not simply when a certain deadline has passed.

4.1.3. Dimension 3: collaboration between the R&D and sourcing functions

The first theme of the third dimension concerns the R&D function informing the sourcing function about its activities. TurbineCo's sourcing function indicated the desire to be invited to meetings where the R&D function reviews product design decisions. It was also explained that, before these meetings, the sourcing function should receive all available and relevant preparatory materials. However, TurbineCo's Procurement Manager mentioned that the R&D function does not consistently invite the sourcing function to meetings: '*The sourcing function does not always receive notice when product design reviews occur*'. Even when invited to such meetings, the sourcing function often receives incomplete preparatory materials or is not given enough time to review them. As stated by a Procurement Engineer: '*Preparation materials for product design reviews are often incomplete and the sourcing function is given little time to review the materials that will be discussed with the R&D function*'. This Procurement Engineer continued that this leads to the sourcing function not being fully aware of the R&D function's decisions, which complicates their interactions during NPD meetings: '*Due to poor preparation, the sourcing function is often unable to answer questions from the R&D function during product design reviews, which results in the reviews not being finalised*'.

AeroCo's sourcing function also argued for open and clear communication from the R&D function about product design decisions. It was explained that this enables identifying decisions that conflict with strategic sourcing activities and creates support for the introduction of the new product into the organisation. However, as in TurbineCo, a Logistics Specialist of AeroCo explained that the R&D function does not always inform the sourcing function about important decisions: '*Often, the R&D function takes decisions that affect the supply chain without informing the sourcing function*'.

The second theme concerns the sourcing function providing the R&D function with feedback on its activities. TurbineCo's sourcing function explained that this includes evaluating whether the R&D function's activities conflict with strategic sourcing activities. The Head of Production Technology argued that this prevents the R&D function from pursuing only its own interests or optimising activities only for the first few products that are part of NPD: '*The sourcing function should challenge the make-or-buy strategy more, since the R&D function often thinks too short term. The R&D function frequently decides to produce internally what the sourcing function intends to outsource after NPD. However, the implementation is then paid twice, and supply chain resources are used that should not be used*'.

AeroCo's sourcing function also argued for informing the R&D function whether product design activities conflict with strategic sourcing activities. Otherwise, as in TurbineCo, the R&D function will pursue only its own interests during product design. As stated by the Procurement Lead: '*There are* *different interests between the R&D function, which operates and reports to the NPD project organisation, and the sourcing function, which operates and reports to the line organisation'.*

4.1.4. Dimension 4: adoption of methods for considering strategic sourcing

The first theme of the fourth dimension concerns the sourcing function adopting procedures for considering strategic sourcing. Concerning this theme, TurbineCo's Global Demand Planner argued for creating and using understandable work instructions that visualise and explain how strategic sourcing should be considered in NPD: '*When NPD instructions for considering strategic sourcing are too detailed, there is a high risk that they will not be followed. There should not be too much to grasp or take too much time to understand'*. However, since TurbineCo lacks sufficient procedures for considering strategic sourcing, the Procurement Manager proposed creating simple checklists, which list the strategic sourcing activities that should be considered when sourcing representatives meet and review product design decisions with the R&D function: '*For representatives of the sourcing function, especially newcomers, a checklist can provide support during product design reviews. It acts as a kind of memory aid by showing what strategic sourcing activities should be discussed with the R&D function'*.

AeroCo's sourcing function also highlighted the importance of adopting practical procedures for considering strategic sourcing. However, as stated by a Logistics Specialist, AeroCo's current procedures tend to be difficult to understand: '*The sourcing function should be able to contribute to the creation of NPD instructions. Currently, instructions are too theoretical and not followed since they require too many explanations'*. AeroCo's Chief Manufacturing Engineer mentioned another issue, which concerns the coverage of strategic sourcing in the documents supporting NPD: '*There are extensive checklists for important NPD meetings such as gate meetings and industrialisation reviews. However, these checklists are mainly concerned with technical issues and strategic sourcing should be covered better'*.

The second theme concerns the sourcing function adopting BOM-based models for dealing with strategic sourcing. According to TurbineCo's Global Demand Planner, this requires creating a development BOM for product concepts: '*It is difficult to consider strategic sourcing when the finished product or components are unknown. To be able to have something to look at during the development of product concepts, the sourcing function makes a development BOM that contains historical or look-alike components'*. This BOM enables modelling and considering strategic sourcing. For example, TurbineCo's sourcing function suggested using the BOM to assess supplier costs and the future commercial risks of selecting certain suppliers.

AeroCo's sourcing function also mentioned the importance of using the BOM to model and consider strategic sourcing. For example, the Procurement Lead proposed using a development BOM to estimate supplier costs as early as possible in NPD. Since AeroCo does not have many suppliers to choose from, such a BOM-based model is said to be used mainly for evaluating whether product design changes are needed.

4.2. Identification of interrelationships among the EfSC dimensions

Having identified four dimensions of EfSC, the interview transcripts were revisited in order to understand their interrelationships. This process first involved identifying quotes from the interviewees of TurbineCo and AeroCo that suggested relationships among the dimensions shown in Table 4. This process produced a number of quotes that were organised according to which dimensional relationships they pointed to. In total, five types of relationships were identified. Examples of quotes pointing to the relationships are shown in Table 5.

The identified dimensions and their relationships are shown in the model in Figure 1.

5. Discussion

To understand how the characteristics of EfSC identified by the present study differ from the accounts of DfSC found in the literature, the findings in Tables 1 and 4 were compared. This process revealed three types of contributions to the literature: (1) extensions (adding to the literature), (2) confirmations (confirming the literature), and (3) combinations of the two. This is shown in Table 6, after which a more detailed account of the arguments associated with the comparison is provided.

The first dimension of EfSC recommends that the R&D function considers strategic sourcing before and during the product design stage of NPD. This finding partially overlaps with the DfSC literature (e.g. Arnette and Brewer 2017; Gokhan, Needy, and Norman 2010; Lee and Sasser 1995; Yadav et al. 2011), which also argues for the R&D function's consideration of strategic sourcing in the product design stage of NPD (e.g. concept design). The finding also extends the DfSC literature by suggesting that, in the ETO context, strategic sourcing also needs to be considered before the product design stage. Specifically, in the ETO context, the R&D function often makes cost and lead-time commitments to a customer when making the business case before the product design stage (Alfnes et al. 2021; Brady and Davies 2014; Crespin-Mazet, Romestant, and Salle 2019; Hobday 2000). When strategic sourcing is appropriately considered during these planning activities, this leads to more realistic cost or lead-time targets and, in turn, the sourcing function becomes less restricted in its activities (e.g. supplier selection) (as suggested in Section 4.1.1).

The second dimension of EfSC recommends that the sourcing function assigns sufficient and suitable representatives and clarifies their responsibilities in NPD. This finding corresponds to the DfSC literature (e.g. Arnette and Brewer 2017; Brewer and Arnette 2017; Dowlatshahi 1996), which argues for proper representation of the sourcing function in NPD. The finding also extends the DfSC literature in two ways. First, it specifies that in the ETO context, it is crucial that the sourcing function assigns sufficient and suitable representatives to NPD. Since the ETO context is engineering-

Table 5. Identifying relationships among the EfSC dimensions.

Example of interview quote	Interpretation	Identified relationship
"We have an 'NPD toolbox' that contains a whole bunch of process descriptions and representatives of the sourcing function need to make sure that these documents are continuously updated. For example, I have been asked to revise the 'work instruction document', which looks particularly at the interface between the sourcing and R&D functions in NPD." (Procurement Engineer, TurbineCo)	When represented in NPD, the sourcing function can ensure that NPD includes sourcing-oriented work instructions.	The representation of the sourcing function in NPD (**D2***) increases the adoption of methods for considering strategic sourcing (**D4**).
"In the past, it was decided by the R&D function who would be invited to the reviews. At the beginning of this year, the sourcing function said that its representatives should be included in every review. This resulted in these representatives being part of more reviews and asking the R&D function many more questions than in the past." (Procurement Engineer, TurbineCo)	When represented in NPD meetings, the sourcing function can exchange information with the R&D function.	The representation of the sourcing function in NPD (**D2**) improves collaboration between the R&D and sourcing functions (**D3**).
"We export a BOM from SAP to Excel, and use a Gantt chart to show the flow of items, including the customer order decoupling point, to the R&D function. It is important for the sourcing function to find such a tool to be able to communicate sourcing constraints to the R&D function." (Global Demand Planner, TurbineCo)	By adopting BOM-based models, the sourcing function can identify and communicate challenges to the R&D function.	The adoption of methods for considering strategic sourcing (**D4**) improves collaboration between the R&D and sourcing functions (**D3**).
"Important sourcing activities should be present in the NPD process model. For example, all NPD gates should have checkpoints that cover these activities. This avoids the R&D function being too product-focused and not thinking about supply chain consequences." (Procurement Lead, AeroCo)	The adoption of sourcing-oriented procedures avoids the R&D function being too product-oriented and disregarding sourcing challenges in NPD.	The adoption of methods for considering strategic sourcing (**D4**) enhances the consideration of strategic sourcing in NPD (**D1**).
"The sourcing function now receives a list from the R&D function of all the parts that they intend to print, which makes it possible to create an awareness of sourcing constraints. For example, when printing requires new suppliers, we will send other stuff to our old suppliers to keep them floating, or should we rather get rid of them? Or what happens if we find out that the printed parts don't last that long, and we need to go back to the old suppliers?" (Procurement Engineer, TurbineCo)	When the R&D function exchanges information with the sourcing function, sourcing challenges can be anticipated and managed in NPD.	Collaboration between the R&D and sourcing functions (**D3**) improves the consideration of strategic sourcing in NPD (**D1**).

*D: Dimension.

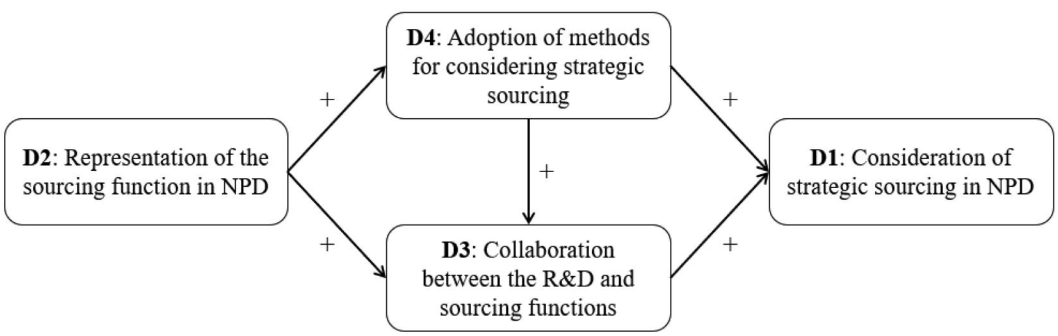

Figure 1. Relationships among the EfSC dimensions.

intensive and mostly involves people originating from the R&D function (Hobday, Rush, and Tidd 2000; Willner et al. 2016), there is otherwise a risk that the sourcing function will not understand or be completely outnumbered by the R&D function (as shown in Section 4.1.2). Second, the finding specifies that the sourcing function needs to clarify the responsibilities of its representatives. This is necessary since, in an ETO context, NPD can take many years, involves many stakeholders, and consists of multi-functional activities that require different skills and competencies (Davies et al. 2011; Hobday 2000; Willner et al. 2016).

The third dimension of EfSC recommends that the R&D function informs the sourcing function about its activities, enabling the sourcing function to provide feedback on these activities. This finding corresponds to the DfSC literature (e.g. Dowlatshahi 1996, 1999; Gokhan, Needy, and Norman 2010; Lee 1993), which argues for substantial collaboration between the two functions. However, although the DfSC literature (e.g. Dowlatshahi 1996, 1999) argues for a delegation of legitimate authority and power to the sourcing function, the ETO context is usually R&D-dominated (Hobday, Rush, and Tidd 2000; Willner et al. 2016). Therefore, the finding also extends the DfSC literature by showing that in the ETO context, the R&D function can at least adequately involve the sourcing function in its activities. The finding further corresponds to the DfSC literature (e.g. Dowlatshahi 1996, 1999) by showing the importance of the sourcing function providing feedback on the R&D function's activities. Since NPD in the ETO context is typically organised with projects (Davies et al. 2011; Hobday 2000), Section 4.1.3 shows that the R&D function may otherwise optimise activities for an individual project and disregard the long-term goals of the sourcing function.

The fourth dimension of EfSC recommends that the sourcing function adopts procedures and BOM-based models for considering strategic sourcing. This finding partially overlaps with the DfSC literature (e.g. Arntzen et al. 1995; Chiu and Kremer 2014; Lee and Sasser 1995), which also

Table 6. The identified EfSC dimensions and their contribution to the literature.

Identified EfSC dimension	Theme	TC*
Consideration of strategic sourcing in NPD.	The R&D function should consider strategic sourcing before product design.	E
	The R&D function should consider strategic sourcing during product design.	C
Representation of the sourcing function in NPD.	The sourcing function should assign sufficient and suitable representatives to NPD.	C + E
	The sourcing function should clarify the responsibilities of its NPD representatives.	C + E
Collaboration between the R&D and sourcing functions.	The R&D function should inform the sourcing function about its activities.	C + E
	The sourcing function should provide feedback on the R&D function's activities.	C + E
Adoption of methods for considering strategic sourcing.	The sourcing function should adopt procedures for considering strategic sourcing.	E
	The sourcing function should adopt BOM-based models for considering strategic sourcing.	C

*TC: Type of Contribution, C: Confirmation, E: Extension.

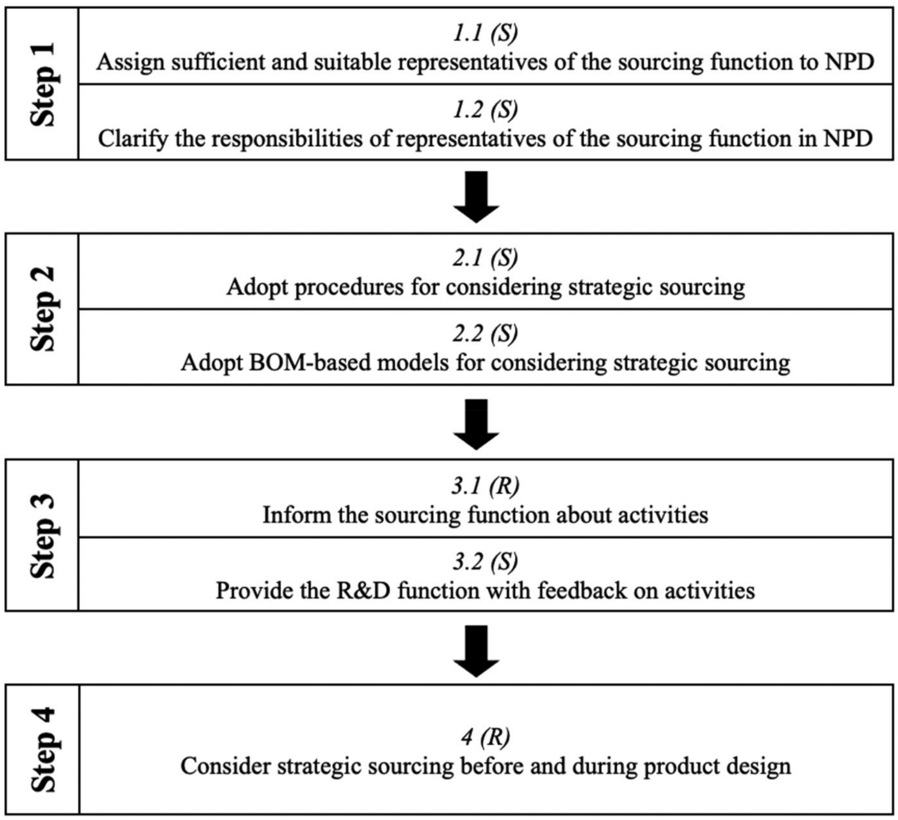

Figure 2. A process for engaging with EfSC.
Note: S = The sourcing function's responsibility; R = The R&D function's responsibility

argues for the adoption of BOM-based models, which ensure that the items forming part of a product effectively address sourcing constraints. The finding also extends the DfSC literature by demonstrating the potentially vital role of procedures in the ETO context. Since the ETO context involves high levels of uncertainty and complexity (Cannas et al. 2020; Cannas and Gosling 2021), Section 4.1.4 shows that formal procedures can support and guide the consideration of strategic sourcing. The finding further extends the DfSC literature by suggesting that the sourcing function needs to take the lead in ensuring the adequate adoption of such procedures. Since the ETO context mainly involves representatives from the R&D function (Hobday, Rush, and Tidd 2000; Willner et al. 2016), Section 4.1.4 shows that NPD otherwise mainly includes engineering-oriented procedures.

Based on the relationships (as shown in Table 5 and illustrated in Figure 1), a four-step process for engaging with the practice of EfSC can be developed, as shown in Figure 2. It should be noted that, although this process suggests a sequential process, the included steps may be carried out simultaneously. For example, parallel to clarifying the responsibilities of the sourcing function's representatives in NPD (Step 1.2), the sourcing function can start the adoption of procedures for considering strategic sourcing (Step 2.1).

6. Conclusion

To add to the sparse DfSC literature focusing on the ETO context, the present paper used a case study approach focusing on two ETO manufacturers. This resulted in two main research contributions. First, the study contributes to the DfSC literature (e.g. Chiu and Kremer 2014; Claypool, Norman, and Needy 2014; Lee, Billington, and Carter 1993; Lee and Sasser 1995) by distilling empirically grounded dimensions of DfSC in the ETO context, in this study termed 'EfSC'. These dimensions are: (1) consideration of strategic sourcing in NPD, (2) representation of the sourcing function in NPD, (3) collaboration between the R&D and sourcing functions, and (4) adoption of methods for considering strategic sourcing in NPD. The study, thereby, clarifies the differences between DfSC in contexts involving high-volume, standardised products and the ETO context. Specifically, although the dimensions of EfSC partly overlap with the ones in the DfSC literature, this study demonstrates that their characteristics differ (Table 6). Most notably, EfSC involves the consideration of strategic sourcing before the product design stage of NPD, as well as the adoption procedures that encourage this consideration.

The second main contribution concerns the identification of relationships among EfSC dimensions (see Figure 1), which in the literature are typically investigated in isolation. For example, studies tend to focus either on the representation of the sourcing function in NPD (e.g. Arnette and Brewer 2017; Di Benedetto et al. 2003; Dowlatshahi 1996), or the adoption of BOM-based models for considering strategic sourcing in NPD (e.g. Chiu and Kremer 2014; Claypool, Norman, and Needy 2014; Gokhan, Needy, and Norman 2010; Lee and Sasser 1995). The identification of these relationships challenges the literature by suggesting that, instead of focusing on individual dimensions, it should more critically explore how their interaction affects DfSC or EfSC effectiveness.

For practitioners, the study provides a detailed account of the dimensions that ETO manufacturers should pay attention to when engaging with EfSC (Table 4). The study may, thereby, encourage practitioners to reflect on what is easily taken for granted in daily work and consider alternative routes of action. Thus, the paper may contribute to the creation of 'reflective practitioners' (Schön 2017) who are considerate when integrating strategic sourcing into NPD processes. The study also explains the relationships among the identified dimensions, enabling ETO manufacturers to consider these in conjunction, which, as shown by the study, is crucial when engaging with EfSC. To support this approach, a process for engaging with the practice of EfSC was defined (Figure 2), which may support NPD process owners, as well as R&D and sourcing functions of ETO manufacturers in integrating strategic sourcing into NPD processes.

The work is, however, not without limitations. First, the study used a two-case study approach to gain an in-depth understanding of the phenomena. On the other hand, this approach does not produce statistically generalisable results, for which reason generalisations have to be made analytically (Yin 2018). In this context, the two manufacturers selected for the study share central characteristics with other ETO manufacturers, which increases the potential for analytical generalisation (Stake 2003). There is, therefore, a basis for assuming that the identified EfSC dimensions and their relationships, to a large extent, also apply to other ETO manufacturers.

Given that the present study is the first to conceptualise EfSC, there are several avenues for future research, four of which are subsequently discussed. First, future research may conduct longitudinal studies of ETO manufacturers to provide more knowledge about how the practice of EfSC unfolds and evolves throughout the NPD process. Such research could use real-life observations and ethnographic methods to explore the very ways in which practitioners engage with EfSC and whether they result in successful or unsuccessful manifestations of EfSC. This promises the identification of incoherence, inconsistency, conflict, and dilemma, which are phenomena that offer major contributions to both the literature and practice (Blackler 1993).

Second, future research may analyse EfSC through different theoretical lenses. For example, contingency theory (Ginsberg and Venkatraman 1985) could be used to explore how EfSC is contingent (dependent) and shaped by a manufacturer's internal and external conditions. Research focusing on internal conditions may reveal that manufacturers with a strong product orientation engage differently with EfSC than those with a strong supply chain orientation. Such research could also explore the effects of the roles, competencies, and approaches of practitioners engaging with EfSC, as well as the organisation of NPD projects and processes. Similarly, the dimensions of EfSC may be affected by different types of innovation (e.g. radical or incremental) and external conditions such as crisis situations (e.g. the COVID-19 pandemic).

Third, through additional qualitative studies, future research may develop testable hypotheses around the connected dimensions of EfSC (Table 5) as a basis for employing survey studies that investigate the effects of the dimensions of EfSC. This could provide insights related to the effects of the EfSC dimensions, as well as the contextual conditions under which EfSC is applicable.

Fourth, to provide a better understanding of the scope of EfSC, future research may investigate EfSC outside traditional ETO contexts, such as assemble-to-order manufacturers and ETO manufacturers providing less technologically advanced products. This may reveal that, although EfSC is associated with the ETO context, its dimensions and the process presented in Figure 2 could apply in other contexts.

The pursuit of these research initiatives may alleviate many of the barriers to the integration of strategic sourcing into ETO manufacturers' NPD processes, and ultimately improve the fit between product designs and supply chains.

Disclosure statement

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Data availability statement

The authors confirm that the data supporting the findings of this study are available within the article [and/or] its supplementary materials.

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Appendix 1: Interview guide

- Please introduce your company and its products.
- Please describe your role in the company, main responsibilities, and experience.
- Please describe your company's NPD process.
- What are the main sourcing challenges in NPD?
- How is the sourcing function involved in NPD?
- What are the responsibilities of the R&D function in NPD?
- What are the responsibilities of the sourcing function in NPD?
- How do the R&D and sourcing functions collaborate in NPD?
- When do the R&D and sourcing functions collaborate in NPD?
- What approaches, methods, or techniques are used to ensure collaboration between the R&D and sourcing functions in NPD?
- How does your organisation ensure that strategic sourcing activities (i.e., make or buy analysis, supplier selection, and supplier collaboration) are integrated into NPD processes?
- What are the main challenges related to collaboration between the R&D and sourcing functions in NPD?
- What are examples of situations during which strategic sourcing activities (i.e., make or buy analysis, supplier selection, and supplier collaboration) were adequately integrated into NPD processes?
- What are examples of situations during which strategic sourcing activities (i.e., make or buy analysis, supplier selection, and supplier collaboration) were inadequately integrated into NPD processes?