Small-series supply network configuration priorities and challenges in the EU textile and apparel industry

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Abstract

Purpose – Technology and market pressures are encouraging localized and small-series production in customer-driven industries. The purpose of this paper is to explore and understand the supply chain-, product- and process-design factors for small-series production in EU's textile and apparel industry, to understand configuration decisions, priorities and challenges.

Design/methodology/approach – An interview study was undertaken with ten companies that represent diverse small-series production models and value chain roles. Interview data was analysed to identify supply network configuration characteristics, decision priorities and challenges.

Findings – Three small-series production models emerged from the analysis, differing with respect to adoption of process postponement and customization. The findings confirm and extend past research regarding diverse decision priorities and product, process, supply chain structure/relationship configurations. Challenges identified relate to planning (priorities) and implementation (configuration). Whereas competence availability and digital technology challenges are common, several difficulties are linked to production model like tensions related to priorities and small volumes, which are not found with customization.

Research limitations/implications – Future research can make comparisons with other industry and location contexts; adopt dynamic approaches to distinguish between design and reconfiguration processes; and address indicated paradoxical-tensions.

Practical implications – The study findings can provide guidance for companies regarding identification of priorities and management of (planning/implementation) challenges impacting small-series production in T&A.

Originality/value – The paper brings a configuration perspective at the supply chain level to the problem of small-series production implementation, which demands holistic and context-specific understanding.

Keywords Supply network configuration, Supply chain design, Customization, High-cost countries, Supply chain management

Paper type Research paper

1. Introduction

In recent years, supply chain vulnerabilities and changing customer demands are encouraging supply chain and production reconfiguration. Macro-economic dynamics related to trade policies and global risks like COVID-19 have exposed the vulnerabilities of global supply networks emphasized for years, e.g. by Christopher and Holweg (2011, 2017), etc. Customers increasingly demand product customization and greater responsiveness

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(Gunasekaran *et al.*, 2018; Min *et al.*, 2019), e.g. via investments into digital technologies and supply chain localization (Brennan *et al.*, 2015; Andersson *et al.*, 2018; Culot *et al.*, 2020). The textile and apparel (T&A) industry is highly exposed to such disturbances, thus in process transitions towards digitalization, nearshoring and smaller order sizes will likely accelerate (Lund *et al.*, 2020; Mcmaster *et al.*, 2020). In high-cost locations like the EU [1], technology developments and the growth of e-commerce models are crucial enablers and drivers of T&A production relocation for improved speed, quality, customization and sustainability (Andersson *et al.*, 2018; Sirilertsuwan *et al.*, 2019; Culot *et al.*, 2020). Thus, the relationships among customer-driven market strategies like small-series production, supply chain configuration and local production is a crucial issue (Macchion and Fornasiero, 2021).

Research has touched on interrelationships among these production, supply chain and location decisions, and some notable findings have illuminated both positive interactions and challenges. While literature has stressed alignment among flexible manufacturing, supply chain integration, innovation and customization (Marsillac and Roh, 2014), combining such factors for mass customization is associated with complexity. Zhang *et al.* (2019) find complex interactions between internal and external integration and product modularity, and Salvador *et al.* (2015) find flexible manufacturing resources (including product modularity), digital product management technologies and customer integration are required at certain threshold levels for combined benefits but cancel each other out at high levels. While through these studies product and process design factors are well-researched, interrelated supply chain design issues are less understood (Suzić *et al.*, 2018). While studies focused on other industries have recently linked customization with supply chain design factors, like supply chain integration (e.g. Wu *et al.*, 2019; Zhang *et al.*, 2019), or global and local manufacturing (e.g. Macchion and Fornasiero, 2021), these issues remain to be understood in relation to T&A customization. Although the successful adoption of customization within the industry has been limited, costs can be reduced with new technologies (Senanayake and Little, 2010), which can support production in high-cost locations.

Regarding such location decisions in T&A, research has investigated how or why to manufacture in proximity to markets, headquarters or suppliers, including through a focus on small-series or customized production (e.g. Pal *et al.*, 2018; Sirilertsuwan *et al.*, 2019; Lica *et al.*, 2020). These findings confirm Ketokivi *et al.* (2017) that find complexity of products and processes encourages co-location of supply chain stages like production and R&D, and indicate interdependence in textile manufacturing not found in their study. Beyond product/process characteristics, some decision motivations are found to be associated with challenges to such reconfigurations, like supplier competence availability, which can be either an enabler or barrier (Sirilertsuwan *et al.*, 2019), and diverse priorities, which are difficult to pursue simultaneously like customization, quality and short lead times (Pal *et al.*, 2018). These studies show how decision-making related to small-series production depends on several supply chain-, process- and product-design factors (Suzić *et al.*, 2018), with various decision priorities and challenges. However, as discussed, these issues have largely been addressed through fragmented approaches that separately focus on either customization or high-cost location decisions. Thus, a holistic and industry-specific approach is required (Melnyk *et al.*, 2014; Suzić *et al.*, 2018).

In light of these issues, the purpose of the paper is to explore and understand the supply chain-, product- and process-design factors for small-series production in EU's textile and apparel industry. For a holistic analysis of such design factors in a specific high-cost T&A context, we ground our research to the supply network configuration (SNC) framework prescribed by Srai and Gregory (2008), which includes four elements: value structure, operations, network structures and network relationships. This perspective enables analysis of context-specific configuration decisions and associated complexity, through formulation of the following research questions:

RQ1. What are the key decision priorities for configuring supply networks for small-series production in EU's textile and apparel industry?

RQ2. How do textile and apparel companies configure their supply networks for small-series production in the EU, and what are the main underlying challenges?

The paper is structured as follows. First, section 2 presents background on the key concepts related to the configuration view and SNC. Second, the methods are described in section 3 including research design. The remainder of the paper presents and discusses the findings related to the different small-series production models. The findings regarding SNC, priorities and key challenges are presented and discussed, which highlight various conflicting demands and configuration decisions. Finally, the implications and limitations of the study are discussed with future research opportunities, particularly to address the tensions and challenges associated with such configurations through dynamic and process sensitive studies.

2. Conceptual frame of reference

The configuration view is valuable to study small-series production in high-cost locations, to capture supply networks and the factors that can shape or constrain such configurations. The SNC framework, as presented by Srai and Gregory (2008), provides a convincing lens through its four prescribed elements: value structure, operations, network structures and relationships. The four elements are used to organize the literature on the small-series, high-cost production phenomenon, as addressed in this paper.

2.1 Supply network configuration

While extensive research has addressed SNC, and the closely related concept supply chain design (Pashaei and Olhager, 2015; Calleja *et al.*, 2018), e.g. with increasing volatility (Christopher and Holweg, 2011, 2017), the supply chain perspective is limited regarding small-series production, customization and local manufacturing (Suzić *et al.*, 2018; Macchion and Fornasiero, 2021). While some contributions have stressed holistic alignment among supply chain integration, flexible manufacturing, and product innovation/customization (Marsillac and Roh, 2014), inconsistent findings regarding alignment indicate complexities (Pashaei and Olhager, 2015). This demands in-depth, context-specific analysis (Melnyk *et al.*, 2014).

Within the research addressing high-cost contexts, supply chain design issues are mainly limited to location decision motivations. Specifically, small volume production characteristics are linked with supply chain co-location (Ketokivi *et al.*, 2017; Lica *et al.*, 2020), and in T&A, with proximity manufacturing or reshoring (Pal *et al.*, 2018; Sirilertsuwan *et al.*, 2019). Recent contributions addressing footwear have identified the time/cost benefits of local production, balanced with global production, for small-series and standard products (Macchion and Fornasiero, 2021); this highlights supply chain design for responsiveness (Christopher *et al.*, 2006; Gunasekaran *et al.*, 2018). In T&A, local production is expected to be limited to high margin and niche products, e.g. through increased customization (Culot *et al.*, 2020), which is driven by various technology enablers (Andersson *et al.*, 2018). Thus, a holistic analysis is required to understand supply chain design together with product and process decisions for customization (Suzić *et al.*, 2018) and small-series production.

2.2 Small-series supply network configuration

Several issues from the literature relate to value structures, regarding physical characteristics, customization and product variety. Marsillac and Roh (2014) identify links

among customization, innovation, flexible manufacturing and supply chain integration, and Grandinetti and Tabbaco (2015) find interactions between custom features and location decisions. In high-cost contexts, Vos *et al.* (2018) highlight how customization, through modularity and variety, can enable enhanced sustainable innovation. Regarding apparel, customization is defined based on several points, and new technologies are important to enable higher customization levels (Senanayake and Little, 2010). High product variety is also shown to be a motivation for high-cost location, with the need for small production volumes and short lead times, in fashion (Lica *et al.*, 2020), footwear (Macchion and Fornasiero, 2021) and T&A (Pal *et al.*, 2018; Sirilertsuwan *et al.*, 2019).

Operations issues include process characteristics, with respect to flexibility and production dynamics, like postponement as well as ICT and advanced manufacturing technologies. Marsillac and Roh (2014) show links among flexible manufacturing, supply chain integration, product innovation and customization. Culot *et al.* (2020) find that the maturity of advanced manufacturing technologies and robotics will determine the level of specialization, internalization and geographic distribution of small-series production models. Within T&A, postponement of activities is associated with different product/supply chain strategies and relationship characteristics, e.g. collaboration and information sharing (Chaudhry and Hodge, 2012), and manufacturing technologies are showing rapid development (Andersson *et al.*, 2018).

Network structure characteristics include location, supplier complexity, tier structure, ownership, integration and flexibility. Proximity sourcing is crucial for custom components (Grandinetti and Tabbaco, 2015), delivery and sustainability (Sirilertsuwan *et al.*, 2019). However, Sirilertsuwan *et al.* (2019) find that many apparel companies in Sweden lack the resources to search for local or regional manufacturers, while facing limited competence availability. This suggests industry-specific considerations, which must be understood in relation to the opportunity for small-scale local production models (Culot *et al.*, 2020). Such high variety (on-demand/custom) production models are also associated with increased supplier complexity (Olhager and Prajogo, 2012), and supplier modularity together with product/process modularity and supplier integration (Wu *et al.*, 2019).

Various issues relate to network relationships, particularly regarding complexity, trust, supply chain partner roles and integration. Zhang *et al.* (2019) focus on how supply chain integration upstream, downstream and internally supports product customization. Gu *et al.* (2017) focus on how information system integration and stronger relationships with suppliers support demand-driven (mass customized) operational performance (cost, quality, delivery, flexibility, innovation). Regarding T&A, Chaudhry and Hodge (2012) identify links between apparel postponement strategies and relationship characteristics, e.g. collaborative supply chain relationships, supplier capability development and data sharing. Additionally, supplier size and competence availability are enablers/barriers of proximity manufacturing (Sirilertsuwan *et al.*, 2019). While supplier communication has been highlighted as a driver of proximity sourcing for custom components (Grandinetti and Tabbaco, 2015), such relationship characteristics require further study.

Thus, the literature has separately identified a number of issues regarding production in high-cost locations and small-series production. A SNC-based analysis facilitates holistic understanding of this opportunity within the EU's T&A industry context, in relation to decision priorities and challenges.

3. Methodology

Given the RQs posed, an exploratory study is adopted, based on interviews with managers from 10 T&A companies in the EU, representing diverse approaches to small-series production. Interviews were undertaken with company representatives knowledgeable about

these production models, e.g. CEO, managing director, supply chain manager or project manager. Based on the significance of SMEs, manufacturers and large retailers in EU's T&A industry (e.g. Bruce *et al.*, 2004; European Commission, n.d.), companies were selected to include different value chain roles, e.g. manufacturing and retail/brands, and various company sizes (see section 3.1). This diversity enabled exploration of different network configurations for small-series production. In line with the purpose, interviews targeted identification of the priorities associated with small-series production decisions and understanding how companies configure their supply network for such production models. The four elements of SNC, according to Srai and Gregory (2008), together with competitive priorities from the literature on location decisions (e.g. Sirilertsuwan *et al.*, 2019) and customization (e.g. Gu *et al.*, 2017), provided a guide for structuring data collection, coding and subsequent analysis, as discussed below.

3.1 Company demographics

Due to the importance of different types of firms in the location and industry context (e.g. Bruce *et al.*, 2004; European Commission, n.d.), a sample of ten companies were selected for variety in small-series production, company size, value chain role and location (see Table A1 for details). Company selection targeted information rich companies to identify similarities among diverse approaches like with intensity sampling (Patton, 2015), rather than being representative of different categories. Companies were selected to include various firm sizes, as defined by the European Commission (2003): Micro (2), SME (4) and large (4), due to the importance of both SMEs and large firms in EU's T&A industry (e.g. Bruce *et al.*, 2004; European Commission, n.d.). Additionally, companies were selected to include different value chain roles, to capture the producer perspective (e.g. Suzic *et al.*, 2018), and the retailer/brand perspective (e.g. Bruce *et al.*, 2004). Of the ten companies selected, two are producers (Co2,8), three are producer/brands (Co1,3,4), i.e. manufacturers with an internal brand, and five are brands/retailers (Co5,6,7,9,10). Likewise, to get a broader view of the EU context, companies were selected from several countries: Sweden (4), Italy (3), Germany (1), Denmark (1) and Belgium (1), which overcomes limitations associated with studying a single country context like in previous industry-specific research (e.g. Pal *et al.*, 2018; Sirilertsuwan *et al.*, 2019). Based on the small sample size generalizability is limited (Patton, 2015), and differences should be viewed as preliminary insights.

3.2 Interview protocol and data collection

Interviews were undertaken with informants knowledgeable about the company's small-series products, operations and supply chains; several companies had two representatives present during the interviews (Co2,4,9). Several rounds of interviews, both structured and semi-structured, included open questions to understand company configurations, as detailed below. Interview guides were sent to respondents in advance to clarify topics.

Each company configuration was explored through 2–3 interviews, between September 2019 and February 2021 (see Table A1 for an overview of the process). The interview rounds included questions to understand key characteristics of the small-series production models and SNC interrelationships and related challenges. In the first interview round, initial open questions addressed the company context and small-series production approach. Additional questions were asked to identify and explain interactions among SNC characteristics, including both positive impacts and negative effects. The structure of this data collection was guided by factors identified from the literature, related to SNC elements and priorities, which guided data analysis, as described below. In the second interview round, respondents were asked to confirm and elaborate upon initial results (case write up), regarding small-series production characteristics and challenges, and to discuss reconfigurations and business

environment changes. Lastly, a final round of semi-structured interviews was undertaken with some companies, based on the need for updates regarding specific in-progress changes to configurations. Interviews lasted 60–90 min, in person or over (video) call, and were recorded and transcribed for coding and analysis, as discussed below. Some secondary data was gathered per direction from the respondents during the interview process, to understand the company background, product offerings, etc.

3.3 Data analysis

The interpretive data analysis involved two stages, first to analyse each company and then to identify similarities and differences. The initial analysis of the interview data focused on identifying key SNC characteristics, products or offerings, operations, relationships and structures, in line with Srai and Gregory (2008)'s framework; then, priorities and challenges. Within the SNC elements, factors identified from the literature supported data coding, with an iterative approach to identify similarities and differences between data and concepts from the literature. Competitive priorities emphasized in the literature regarding proximity manufacturing (e.g. Sirilertsuwan *et al.*, 2019) and customization (e.g. Gu *et al.*, 2017), such as cost, quality, delivery, flexibility, innovation and sustainability, guided coding of decision priorities. Section 4 presents these findings, and details are provided in Table A2.

The interviews were coded using NVivo software and summarized using colour-coded tables; selected quotes *(deemed as best fit by authors to narrate any particular observation)* presented in section 4 clarify the links between data and analysis. To briefly exemplify data analysis, the interview excerpt, "*In our system we can offer innovations (new material, style options and fits), which are manufacture-able in an efficient way (. . .)*" was coded under "innovation" because it highlights the priority as new product/feature introduction, and under "internal integration", because it indicates the criticality of the company production system to enable this innovation. Data summaries were presented to respondents throughout the different interview stages for verification and elaboration. The summarized findings were used to compare configurations and identify emerging patterns, regarding SNC, priorities and underlying challenges.

4. Findings

Three small-series production models (*SS-A*, *SS-B* and *SS-C*) emerged from the analysis, which differ in terms of the level of customization in the products and process postponement. *SS-A* companies (Co2,4,5,8) pursue production and sourcing postponement strategies, but do not produce on-demand for end customers. *SS-B* companies (Co1,3,9,10) pursue both on-demand production and postponement strategies, while *SS-C* companies (Co6,7) offer only customized or on-demand products. For the detailed data, that was the basis of the findings sections below, see Table A2.

4.1 SS-A: small-series through postponement

SS-A show diverse priorities that must be juggled by producers and brands. Such priorities are associated with brand nearshoring decisions, e.g. responsiveness goals i.e. quick replenishment demanding flexible supplier set-ups, selected for quality, cost and the ability to offer specialized/sustainable materials (Co5). This aligns with the producers' need to balance cost, quality and flexibility. While producers focus on offering certified and sustainable products, the extent of focus on sustainability goals depends on having an internal brand, as stated, *"Managing the sustainability is something that only brands can do"* (Co2). While innovation priorities frequently target enhanced sustainability, they also drive close customer relationships, based on demands for advanced production technologies (Co2) and

collaboration (Co8). One producer emphasized supplier trust, gained through long-term relationships and consistent performance, as a priority for local sourcing (Co2).

Value structure characteristics highlight specialized and sustainable materials, interrelated with certification and new product introduction. For one brand, special materials are associated with component (fabric) sharing for product variety and sustainability, e.g. sourcing *"(. . .) existing materials used by the suppliers' bigger customers, because it secures the quality, and will always be in stock"* (Co5). Operations characteristics highlight common focus on flexible manufacturing by producers and brands, enabled by innovative production technologies. Such small volume production setups are considered crucial for e-commerce sales (Co5), and are pursued with in-house fabric manufacturing (Co4,8), or fabric sourcing for full-package solutions (Co2,5). Network structure characteristics show a shared focus on proximity, with a key emphasis on fabric-production co-location for improved logistics (Co8), trust (Co2), sustainability (Co4) and responsiveness (Co5). Only the e-commerce brand uses design strategies such as sourcing relocation to avoid customs/duties costs, dual sourcing to reduce dependence, and supplier rationalization. As stated, *"We have tried to move to a smaller, more stable set up, with long term relationships; so we can have stable quality and try new things"* (Co5). Network relationship characteristics show that customer-centricity is associated with higher levels of transparency, and cross-functional working groups targeting improved turn rate, termed flow performance. More broadly, close supplier relationships are important for sustainability, as local suppliers provide trust in certifications (Co4), and long-term supplier relationships are required to make significant operational improvements (Co5).

While diverse challenges are found, key difficulties are associated with interrelationships among macro-economic volatility, conflicting demands, sustainable materials, competence availability, digital technologies, communication and transparency. Other issues are specific to either brands, e.g. the difficulty balancing small volume production, brand power and supplier dependence (Co5), or producers, e.g. finding workers for sewing (Co8). The volatile business environment challenges supply chain designs, as it takes extra time to react (Co5). Conflicting requests are key issues for producers, e.g. *"(. . .) delivery as soon as possible, with reduced cost and increased quality, which is not possible"* (Co2). Special materials and small volume production face limited competence availability and innovation levels, which lead to restricted variety, e.g. through component sharing (Co5). Additional challenges relate to low levels of IT system integration (Co2) and communication. With customers, difficulties are related to product complexity, whereas different departments are explained to be *"(. . .) speaking about the same problem, but with different language"* (Co4). The transparency demanded by customers relates to risks of openness, e.g. supplier base visibility (Co5), which is why company discussions are addressing how to communicate without increasing risks.

4.2 SS-B: small-series through postponement and on-demand

SS-B, configurations show similar diverse priorities and focus on sustainable innovation. The various demands that must be juggled frequently include high quality, process flexibility and sustainability, with premium (Co3) or technical products (Co10), and brand implementation (Co1). Innovation priorities target enhanced flexibility and reduced waste in design and production, e.g. through digitalization (Co3). Key differences relate to cost focus, which is important with product innovation through repatriated production, as stated,

> *We need to control the processes for a (new) customized product, with a particular quality, speed and price (. . .) The final cost is the only point to decide if we can take part of the production from China to Europe* (Co9).

Likewise, only higher priced technical products, e.g. with flame retardant, can be produced in Europe (Co10).

Value structure characteristics show new products to enhance sustainability, functional performance or implement production on-demand. However, only one company uses component sharing to maximize efficiency of planning, purchasing and production, by reducing style and material complexity (Co3). Operations characteristics show the link between manufacturing on-demand and development, or expansion, of digital sales, with high technology suppliers (Co9) or brand implementation (Co1). Digitization of design and production supports reduction of time and waste through enhanced flexibility (Co3). Network structure characteristics highlight proximity manufacturing/sourcing, for luxury, sustainable and on-demand (Co1,3), and for late-stage custom features and technical fabrics (Co10). When implementing customized production, dual sourcing structures are required to reduce dependence on a specific supplier (Co9). Network relationship characteristics show common focus on supplier integration for digitalization and sustainable materials (Co3), production relocation (Co9) or technical fabrics (Co10), due to the need for long-term commitments and trust. Internal integration, e.g. *"(. . .) open communication between different departments, and integrating systems in the company"*, is associated with customer-centricity (Co3), and digital customer relationships (Co9).

Key challenges are related to conflicting demands, special materials, digitalization, competence availability and various small volume product/process difficulties. Balancing priorities such as flexibility and short lead times is challenging with certain materials (Co9), and sustainability is associated with several trade-offs, with premium quality, due to short-fibre staple lengths (Co3), and with personal protection (Co10). In addition to data security considerations (Co9), digitalization processes are challenging due to resource requirements,

> *(. . .) because it takes longer to do things and learn new processes. Which is not easy in a large company, and requires a lot of investment time and money on our side and on theirs (the supplier)* (Co3).

Other challenges relate competence availability, e.g. for technical fabrics (Co9) and certified producers (Co3), which relates to dependence on specialized suppliers (Co10). Several other product/process issues challenge small volume production in general, related to minimum order sizes, production volumes and flexibility. High minimum order quantities with functional materials (Co10), and inconsistencies with overstock materials (Co1), are challenging. Volumes and flexibility costs are key barriers, as high company volumes make it *"(. . .) almost impossible at the moment to transfer all production to Europe"* (Co9), and extra costs make it *"(. . .) very tough to make any money if the volumes are too small"*, which drives increased volumes (e.g. >300 pieces) with functional products (Co10). Additionally, internal brand production implementation is a challenge due to reduced flexibility, i.e. the capacity to take on many different (B2B) customer orders (Co1).

4.3 SS-C: small-series through on-demand or customization

SS-C shows multiple priorities with particular focus on juggling high quality, sustainability and flexibility. Supply chain design is focused sustainable transportation and minimizing costs (Co6). Additionally, these consumer-driven digital business models are associated with product/process innovation priorities, specifically, *"(. . .) bringing new products to market and reducing waste in our supply chain"* (Co7), which is enabled by digital production systems, as stated,

> *In our system we can offer innovations (new material, style options and fits), which are manufacture-able in an efficient way. We can enrich our configuration offerings with these new features, as we produce in lean manufacturing plants* (Co6).

The supporting IT systems are designed to facilitate communication, co-design and collaboration between the brand, customers and suppliers.

Value structure characteristics include new products focused on certified and high-quality materials and advanced technologies, but with differences related to component sharing, which is only found with jersey/knit products, to increase the variety of products/features and reduce inventory (Co7). Operations characteristics show business models based on flexible manufacturing competence (technology and skilled workers) and digital processes (e.g. automatic pattern generation and data transfer), which are core competences (Co6,7). Network structure characteristics highlight material/production proximity, for closeness to markets (Co7) and to manage costs related to changing trade agreements (Co6). Dual sourcing is possible with well-established jersey products, and development experience has supported 3D knitted product implementation (Co7). Network relationship characteristics show close relationships throughout the supply chain, e.g. with suppliers, due to joint ownership, fabric co-branding (Co6), collaborative development and being the biggest customer (Co7). Fabric co-branding is expected to enhance transparency and supply chain relationships, as stated,

> *We think that co-branding is positive for the transparency of the fabrics, collaboration between the weaver and the manufacturer, for the brand to attract customers, and to build up the weaver brand. It's a win-win* (Co6).

Certification strategies also support transparency and sustainability (Co6,7). Close customer relationships are the focus of IT system designs, to provide the customer a *"(. . .) seamless journey, to track and trace his order; when it's out of production, when it's on the truck. That openness gives a lot of trust"* (Co6).

Key challenges highlight resource constraints on new products/processes in general, while one company faces high exposure to changing trade agreements, in part due to the importance of the UK market (e.g. BREXIT), high marketing costs and cyber security issues (Co6). Development requirements constrain new product introduction, as one respondent explained,

> *Our customer demand would be able to maintain a ton of categories, it is a R&D limitation, we need to develop those products first, and it takes time to develop them in a quality that lives up to our standards* (Co7).

In part, this is due to competence availability, as the respondent stated, there is limited to no availability of suppliers with the required knowledge, which demands significant investments. Specific competence issues were also the biggest challenges in the past, e.g. refining pattern-making competence and integrating new processes in the production flow, e.g. embroidery. Likewise, machinery is described as the key constraint for scaling production up and down, as stated, *"I can easily find contractual workers for sewing, but I cannot easily buy extra (digital) cutters"*, and significant investments are required *"(. . .) to improve consumer-driven, on-demand printing, by having it in the same geographic location as the cutting"* (Co6), e.g. through external funding.

5. Analytical discussion

The analyses of different small-series production models (in sections 4.1-4.3) reveal several notable similarities and differences regarding priorities and SNC, with associated challenges. Diverse priorities are confirmed throughout these models, similar to the diverse priorities for proximity apparel manufacturing (Sirilertsuwan *et al.*, 2019), as sustainability goals are considered together with traditional business priorities like quality, delivery and innovation. In addition to proximity sourcing/manufacturing, several SNC characteristics are commonly identified with these priorities, including new product development, close supplier relationships and flexible manufacturing resources. The findings confirm interdependence among such characteristics as suggested in previous research (Marsillac and Roh, 2014), and further reveal challenges at two levels (planning and implementation). Regarding planning,

the findings extend previous research by suggesting customized production is not significantly exposed to conflicting priority challenges. With respect to implementation, findings both align with and diverge from extant research. As expected, competence availability and digital technology challenges are commonly found. Several additional difficulties are identified within and between production models, including tensions regarding special materials, small volume risks or barriers, flexibility constraints, and varied supply chain design and relationship challenges, as discussed below.

5.1 Small-series production decision priorities and challenges

SS-A companies show diverse goals such as quality, flexibility, cost, innovation and sustainability. However, with postponement models (*SS-A*), high-level sustainability goals are associated with brand ownership, and innovation levels are varied. Innovation priorities are linked to sustainability goals for brands (Co4), whereas producers offer technologies and collaboration for support (Co2,8). Similar evidence is found with *SS-B*s and *SS-C*s, which show similar diverse priorities, including sustainability and innovation related to new products (*SS-B*: Co9,10; *SS-C*: Co6,7), process development and digitalization (*SS-B*: Co3; *SS-C*: Co6,7), sustainable production (*SS-B*: Co1) and reshoring (*SS-B*: Co9), whereas key differences are related to challenges. Producers are exposed to challenges related to conflicting priorities (e.g. costs and diverse customer demands) (*SS-A*: Co2,8). *SS-B* brands also face difficulties when balancing divergent priorities, e.g. sustainability with premium quality (Co3) or functional performance (Co10), and short lead times with special materials (Co9), but *SS-C* brands do not. This finding indicates a possibility to overcome such tensions, or make them less salient, with custom products and digital business models, thus highlighting technological developments to overcome cost challenges (Senanayake and Little, 2010). Sustainability and innovation priorities and tensions are found throughout the different production models with well-established goals like quality and flexibility in line with previous research in similar contexts (Sirilertsuwan *et al.*, 2019); frequently, innovation to develop sustainable products like in Ashby (2016), and digitalization (Culot *et al.*, 2020).

5.2 Small-series supply network configuration and challenges

With respect to how companies undertake small-series SNCs and what are the main underlying challenges, several crucial characteristics emerge from the findings.

Value structures show common focus on product development throughout the different small-series models, often targeting sustainability improvements or certified products (*SS-A*: Co4,5,8), customization/on-demand (*SS-B*: Co1,3; *SS-C*: Co6,7) as well as functionality (*SS-B*: Co10). This confirms the relationship between product innovation and customization suggested in previous studies (Marsillac and Roh, 2014), and further highlights sustainability and functionality as crucial drivers of development. With such product development, special materials and certifications are crucial (*SS-A*: Co4,5; *SS-C*: Co6,7), but several challenges are indicated, e.g. limited internal/external resources (*SS-A*: Co4,5), material availability and long lead-times (*SS-B*: Co1,9), and sustainability trade-offs with premium quality (*SS-B*: Co3), etc. This aligns with literature stressing proximity sourcing for sustainable and special materials together with barriers related to limited industry competence (Sirilertsuwan *et al.*, 2019), and identifies specific material-related trade-offs and tensions faced by large companies. Several small volume risks and barriers are found, related to minimum order quantities (*SS-B*: Co1,10), costs (Co10) and overall company volumes (Co9). However, the findings indicate that mixed production models more often face these tensions, and no such tensions were found with customization (*SS-C*). Limited use of component sharing is found throughout different models, often associated with tensions related to limiting variety (*SS-A*: Co5; *SS-B*: Co3). Thus, several product characteristics are associated with challenges or tensions related to

materials, competence barriers, volumes and variety. Our findings additionally suggest costs challenge functional products, whereas fashion products face material quality and variety trade-offs.

Operations show flexible manufacturing systems (skilled labour, flexible machinery and advanced processes) are crucial throughout the different production models for both brands and producers (*SS-A*: Co2,4,5,8; *SS-B*: Co9; *SS-C*: Co6,7). Several challenges are indicated, due to development/investment requirements (*SS-C*: Co6,7), limited worker availability (*SS-A*: Co8) and flexibility trade-offs (*SS-B*: Co1), which show how flexible resources constrain development and expansion. Digital processes are associated with some degree of on-demand production (*SS-B*: Co1,3,9; *SS-C*: Co6,7), with the focus being on online sales, with automated and digitally supported design and production processes. Several challenges related to digitalization are indicated; producers have low levels (*SS-A*: Co2,4), and brands must make significant investments and deal with data management and security issues (*SS-B*: Co3,9; *SS-C*: Co6). This illuminates difficulties with implementing digital technologies for small-series production (Culot *et al.*, 2020) that differ based on production ownership. Our findings additionally offer insights regarding the balance of flexible resources, digital technologies and customer integration. While many companies show high levels of either flexible resources or digital technology, high levels of all three are found with customization. This contrasts with previous research regarding manufacturers (Salvador *et al.*, 2015) and indicates brands with outsourced production may experience fewer difficulties balancing these issues.

Network structures show that proximity is common throughout the different production models for sustainability (*SS-A*: Co4; *SS-B*: Co1,3), logistics benefits (*SS-A*: Co8), responsiveness (*SS-A*: Co5) and customization (*SS-B*: Co9; *SS-C*: Co6,7). The key challenge is availability of regional competence, e.g. for sustainable or special products and materials (*SS-A*: Co4; *SS-B*: Co3,9), and small-series production (*SS-A*: Co5; *SS-C*: Co7). This confirms competence availability as a common challenge to localization for sustainability (Ashby, 2016; Sirilertsuwan *et al.*, 2019) and small-series production. Limited competence availability can explain why few companies target dual sourcing. Other structural challenges highlight supply chain design difficulties due to volatility and limited control (*SS-A*: Co2,5,8; *SS-C*: Co6), which add to previously identified challenges like resource constraints to search and select local/regional suppliers (Sirilertsuwan *et al.*, 2019). These issues are likely to be increasingly relevant as COVID-19 and other global supply chain vulnerabilities demand increased adaptability (Christopher and Holweg, 2011, 2017), through increased proximity to customers (World economic forum, 2021).

The importance of supplier relationships is stressed throughout all models; specifically, trust and long-term relationships and co-branding (*SS-A*: Co2,4,5; *SS-C*: Co6), for sustainability and digitalization (*SS-B*: Co3), technical materials (*SS-B*: Co10) and customization (*SS-B*: Co9; *SS-C*: Co6,7). This aligns with literature stressing supplier collaboration for sustainability (Ashby, 2016) and customization (Grandinetti and Tabbaco, 2015; Marsillac and Roh, 2014; Zhang *et al.*, 2019), and highlights supplier co-branding. Internal integration, e.g. shared metrics and digital systems, is found throughout different production models, but large brands targeting customer-centricity and transparency show the highest levels (*SS-A*: Co4,5; *SS-B*: Co3,9). This confirms the importance of internal integration (Zhang *et al.*, 2019), but indicates higher relevance for brands rather than manufacturers. Close relationships and digital connections with customers are associated with on-demand production and transparency (*SS-A*: Co5; *SS-B*: Co3,9; *SS-C*: Co6,7), which confirms the impact of customization on customer integration (Zhang *et al.*, 2019), and additionally highlights transparency goals.

While no relationship challenges are common, varied difficulties are found. Upstream, supplier dependence risks (*SS-A*: Co5; *SS-B*: Co10) are due to limited supplier alternatives, i.e.

competence availability barriers (Sirilertsuwan *et al.*, 2019), and supplier priorities for larger volumes. This highlights relationship tensions, as dependence leads to risks that consequently demand enhanced trust. Internal and downstream challenges differ based on production model, as brands offering customization face data security and cost challenges with customer integration (*SS-B*: 9; *SS-C*: 6), whereas large companies face transparency and communication difficulties more broadly (*SS-A*: 4,5). Thus, diverse challenges are found.

6. Conclusions

The paper presents an interview-based study to understand priorities and challenges associated with small-series SNC decisions in the EU's T&A industry context. Three specific contributions emanate from this study. First, the analysis revealed three small-series production models achieved through process postponement (*SS-A*), on-demand or customization (SS-C) and by combining postponement and on-demand production (*SS-B*).

Second, the study confirms and extends previous research carried out in similar contexts, related to: decision priorities and SNC characteristics. In terms of decision priorities in small-series production, the study adds emphasis to items prescribed in previous research like Pal *et al.* (2018) regarding high-cost textiles/clothing manufacturing, by highlighting the prioritization of innovation (Marsillac and Roh, 2014) and sustainability goals (Sirilertsuwan *et al.*, 2019). Regarding key SNC characteristics, several extensions to extant research are revealed. Notably, while research has suggested high levels of flexible manufacturing resources, digital technologies and customer integration lead to cancellation effects for manufacturers (Salvador *et al.*, 2015), such complexity is not found with customized brands. New product development is found to be driven by sustainability and functionality in addition to innovation and customization, with links to special materials. Diverse relationships are found; whereas supplier relationships are often crucial, internal integration is more relevant for brands, and customer integration is associated with on-demand production (Zhang *et al.*, 2019) and transparency goals.

Third, the identification of various challenges regarding planning (priorities) and implementation (SNC) offers insights not covered in previous studies. Challenges related to conflicting priorities are quite well-established in related extant literature, such as tensions between costs and value-driven priorities (Macchion and Fornasiero, 2021; Pal *et al.*, 2018), and between sustainability and quality (e.g. functionality), etc. In this context, our study suggests that customization can reduce such tensions. This adds strength to literature emphasizing production of some percentage of small volume production locally to overcome conflicting performance goals (Macchion and Fornasiero, 2021). Challenges related to implementation, such as competence availability and digital technology challenges, are confirmed from related proximity manufacturing literature (Sirilertsuwan *et al.*, 2019). Additionally, our study suggests several difficulties are associated with different production models and company sizes. Material challenges, supplier dependence and small volume-related tensions are not found with customization; whereas custom brands and large companies are shown to be more likely to face internal/external communication and transparency difficulties; however, sample size limitations should be noted with such insights.

6.1 Managerial implications

The findings of the study can provide guidance for companies to identify decision priorities and manage (planning/implementation) challenges that impact small-series production in T&A. Regarding planning, to overcome priority-related tensions, brands can consider focusing on customization with digital customer relationships. However, customization is

exposed to competence and digital technology implementation challenges, thus companies must invest in flexible supplier relationships and cyber-security, etc. Broadly, companies who want to pursue localization for resilience to disruptions e.g. related to COVID-19 (e.g. Lund *et al.*, 2020) must make investments to overcome competence limitations, particularly related to sustainable materials and small-series production.

6.2 Limitations and future research directions

The limitations of the study present several opportunities for future research. First, the identified priorities, configurations and challenges can be investigated in other industry and location contexts. Second, the issues revealed in the study can be explored in-depth in future research to distinguish between design and reconfiguration processes. This can be enabled by adopting a dynamic approach, e.g. through longitudinal or process-sensitive case studies. Additionally, because the findings indicate differences, e.g. between small-series production models, company sizes and value chain positions exposure to tensions, future research should confirm suggested differences and address how different managers view and manage these issues throughout the value chain. Paradox theory can facilitate elaboration of relevant tensions, as well as offer a dynamic approach to analyse tensions at different levels (e.g. Smith and Lewis, 2011). Finally, while supply chain design difficulties were not commonly found, these issues are likely to become increasingly relevant to address with increasing environmental volatility (e.g. World economic forum, 2021), thus demanding exploration of SNC adaptation, e.g. using a lens like structural flexibility (Christopher and Holweg, 2011, 2017).

Note

1. High-cost is defined in line with Ketokivi *et al.* (2017), based on GDP per capita due to the importance of relative labour costs; the EU region is high-cost as the GDP per capita of countries at the low-end of the range, e.g. Poland, Estonia and Romania, is at least three times higher than countries like Vietnam or Bangladesh. Wages within the garment industry are ~35 to ~125 times higher in European countries than in Bangladesh (Sardar *et al.*, 2016).

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Appendix 1

Table A1.
Overview of company details and interview process

Company	Location	Size*	Small-series and total product offering/Value chain position	Interview rounds with indicative questions
Co1	Sweden	Micro	*On-demand* brand to supplement core flexible/*small volume* production (~100%) *Producer/brand* (Sewing-CMT-Cut-make-trim) of various textile/apparel products for external brands, Brand offering denim products (on-demand)	Round 1. CONTEXT** (1) What are the products currently offered in small-series, and how? a. What production dynamics are used? (e.g. MTO, MTS) b. What percentage of total production is offered this way? (2) What are the potential products that could be offered this way in the future (short/medium term)? (3) How does (or could) this type of production interact with the standard offering? SUPPLY NETWORK CONFIGURATION (1) What is required for small-series textile/apparel production throughout the supply network? (2) How do those required elements relate to (influence) each other? a. How can you explain this influence? (positive/negative impacts)** Round 2. *Presentation of results to verify and elaborate upon:* SMALL-SERIES PRODUCTION CONTEXT** (1) Business case (2) Small-series production model (3) Supply network configuration interrelationship explanations ENVIRONMENT and RECONFIGURATION** (1) How has the business environment changed from the past, and how do you foresee it changing in the future: a. What changes to downstream demand, upstream supply? b. What changes to Performance outcomes, Products, Operations, Relationships, Structures? Round 3. *Updating and clarification of changes (if any)***: - Follow-up on in-progress small-series production model reconfigurations or planning - Environmental changes and impacts
Co2	Italy	Medium	*Small volume* production using classic and innovative technologies (100%) *Producer* (Sewing-Full-package) of fashion womenswear-outerwear	
Co3	Germany	Large	*Small volume and personalized* apparel/shoes (small %) *Producer/brand* focused on global and local production/sourcing of fashion products for women and men	
Co4	Italy	Large	*Small volume* brand focused on sustainability (100% of apparel) *Producer/brand* of complex fashion products for men, and *Producer* of woven fabric	
Co5	Sweden	Large	*Small volume* nearshore sourcing growing (~12% of apparel) *Brand/retailer* sourcing fashionwear and shoes for women and home/interior nearshore and globally, with external brand sales	
Co6	Belgium	Micro	*On-demand* apparel with proximity sourcing (~100%) *Brand* focused mainly on made-to-measure woven apparel	
Co7	Denmark	Small	*On-demand* apparel with proximity sourcing (~100%) *Brand* offering made-to-measure apparel (jersey and knit fabrics)	
Co8	Sweden	Medium	*Small volume* production using knitting technologies (~100%) *Producer* of jersey fabric, and apparel for men, women, children	
Co9	Italy	Large	*Small volume* and *on-demand* with proximity sourcing implemented (max 5-10%) to supplement standard products *Brand* offering sportswear, apparel, and accessories through mainly global sourcing, and reshoring key products	
Co10	Sweden	Medium	*Small volume* (~5%) and late-stage *custom features* (~100%) *Brand* offering functional workwear through global/local sourcing	

Note(s): *Company size based on number of employees (European Commission, 2003): <10 = micro, <50 = small, <250 = medium, >250 = large
**Key question(s) for this study

Appendix 2

	SS-A: Small-series through postponement		SS-B: Small-series through postponement and on-demand		SS-C: Small-series through on-demand or customization	
Priorities Juggling diverse priorities concurrently, such as high quality, cost, flexibility, sustainability	Co2,4,8	• Need to balance costs with high quality, flexible and certified production (e.g. ISO 14001) (Co2,8), and key sustainability priorities (Co4)	Co1	• High-quality and sustainable products on-demand, balanced with flexible production for short lead times	Co6,7	• High-end made-to-measure products, with supply chain design targeting low cost, sustainable transportation, delivery speed, and efficiency (no finished goods inventory) (Co6), and focus on quality, i.e. custom fit, sustainable materials, short lead times and price control (Co7)
	Co5	• Nearshore sourcing goals to offer "quick repeats" and improve stock turn; Suppliers chosen for quality and flexible set ups (e.g. for small volume), and sustainable material goals (100% better materials, e.g. recycled, organic, etc.); Focus on budget and margins	Co3	• Customer-centricity driving personalization (e.g. made-to-measure) and fast replenishment; Sustainability goals (e.g. local, organic, recycled materials) balanced with premium quality		
			Co9	• Balancing priorities, e.g. cost, quality, flexibility, delivery, and material sustainability, when developing high-quality small-series/on-demand regional production		
			Co10	• Technical products with high functionality, increasingly balanced with sustainability; Regional sourcing selected for flexibility when required		

(*continued*)

Table A2.
Overview of company priorities, SNC and challenges

Table A2.

	SS-A: Small-series through postponement		SS-B: Small-series through postponement and on-demand		SS-C: Small-series through on-demand or customization
*Conflicting demands/cost challenges**	*Co2*	• *Trade-offs due to conflicting demands (e.g. cost, flexibility, delivery and quality), demanding collaboration*	*Co3*	• *Trade-offs between premium quality and sustainability (e.g. recycled and organic fibres) of fashion products*	
	Co8	• *Conflicting demands for low costs and high-quality levels require motivation to customers*	*Co9*	• *Challenging to achieve short lead times with technical fabrics due to long lead times, demanding producer flexibility*	
			Co10	• *Sustainability goals are increasingly important, but must be balanced with personal protection-the top priority*	

(*continued*)

Table A2.

	SS-A: Small-series through postponement		SS-B: Small-series through postponement and on-demand		SS-C: Small-series through on-demand or customization	
Innovation	Co8 Co2 Co4	• Product innovation as a driver of collaborative development with customers • Process innovation, e.g. new production technologies, as a key motivation for customers • Low level of innovation at suppliers (e.g. for sustainable product/process) driving process development in-house	Co1 Co3 Co9,10	• Brand/product innovation driving sustainable products, e.g. materials like overstock fabrics and circular design • Digital process innovation driving enhanced flexibility in design/production • Product innovation driving new product development for customization and sustainability (Co9), or functionality (e.g. fire resistant) (Co10)	Co6 Co7	• New products/materials demanded driving increased variety enabled by digitized processes and flexible capacity (e.g. cutters, skilled workers) • Process innovation focus driving reduced waste and new products enabled by advanced technologies (e.g. 3D knitting)
Relational trust	Co2	• Trust in consistent delivery performance drives the focus on long-term, local fabric supplier relationships				

(*continued*)

Table A2.

	SS-A: Small-series through postponement		SS-B: Small-series through postponement and on-demand		SS-C: Small-series through on-demand or customization	
Environment						
*Macro-economic volatility**	Co*2*	• *Volatility in the business environment and conflicting demands require extremely high level of flexibility*			*Co6*	• *Trade policy and currency changes challenge one piece production, encouraging regional material sourcing to avoid high customs/duties costs*
	Co*5*	• *Volatility (e.g. trade policies, currency) challenges supply chain design, due to time requirements*				
SNC characteristics/design decisions						
Value structure						
New products	Co4,5,8	• Product development focused on sustainability improvements, e.g. through certification (Co4,5), high quality and certified products (e.g. Oeko-tex, GOTS, Fairtrade, ISO 14001) (Co8)	Co1	• Brand to supplement CMT-Cut-make-trim production, focused on high value, product sustainability and circular design (e.g. design for repair and resale)	Co6,7	• New product development for environmental sustainability, e.g. through co-branding with high-end material suppliers (Co6), and 3D garment knitting technology (Co7)
			Co,3,9,10	• New products for sustainability and personalization (Co3), customization or high value products (Co9), new or improved functional requirements (e.g. fire resistant) (Co10)		
*New product development requirements (R&D/ Technology)**					*Co6*	• *Challenges to overcome include new product development based on integrating new technologies, e.g. digital printing on-demand*

(*continued*)

Table A2.

	SS-A: Small-series through postponement		SS-B: Small-series through postponement and on-demand		SS-C: Small-series through on-demand or customization	
Special materials, sustainability and certification	Co2	• High-quality products and certified production focus (e.g. ISO 14001)			Co6,7	• Certification to communicate the level of quality and sustainability to customers (Co6, 7)
	Co4,5	• Product sustainability through certification and domestic sourcing (Co4,5)				
*Sustainable/technical materials quality and availability**	*Co4*	• *Low level of supplier innovation for sustainable and certified products/ components demands competence development*	*Co1*	• *Consistent availability of sustainable materials (e.g. overstock fabrics) is a barrier to recreate successful products*		
	Co5	• *Sustainable material goals (e.g. recycled) are challenged by the need to evaluate and select trusted suppliers and certifications*	*Co3*	• *Sustainable materials are relatively new and challenge premium quality (e.g. short staple cotton)*		
			Co9	• *Technical materials have long lead times; Certain materials are not available regionally*		
Component sharing	Co5	• Specialized fabrics (e.g. sustainable or full-package) shared among different fashion products for variety and long term supplier relationships	Co3	• Fabric sharing to distribute costs over multiple products, and increase efficiency (e.g. through larger volumes)	Co7	• Fabric/material sharing is to reduce inventory with jersey and knit products, and offer product/feature variety
*Reduced variety with component sharing**	*Co5*	• Fabric sharing of supplier fabrics (with full-package offerings) and sustainable materials constrains variety	*Co3*	• *Fabric standardization challenges relate to designer resistance to reduce product variety*		

(*continued*)

Table A2.

	SS-A: Small-series through postponement		SS-B: Small-series through postponement and on-demand		SS-C: Small-series through on-demand or customization	
Customization			Co3,9 Co10	• Made-to-measure/custom products offered with small volume production/ sourcing (Co3,9) • Late-stage customization (e.g. features like pockets and branding)	Co6,7	• Made-to-measure/custom products as the focus of the brand product/offering (Co6,7)
*Small volume risks and barriers**	*Co5*	• *Small order sizes reduce brand power in supplier relationships, and can constrain sales of popular products*	*Co1,10* *Co9* *Co10*	• *Minimum order quantities are unpredictable with sustainable materials (e.g. overstock fabrics) (Co1), and are high with technical fabrics (Co10)* • *Large company volumes limit the maximum proportion of small-series production which can be implemented* • *For technical products, the high costs of flexibility are challenging for production orders <300 pieces*		

(*continued*)

Table A2.

	SS-A: Small-series through postponement		SS-B: Small-series through postponement and on-demand		SS-C: Small-series through on-demand or customization	
Operations						
Flexible competence (advanced technologies and skilled workers)	Co2,4	• Advanced assembly technologies like thermal welding and seam sealing to supplement traditional sewing (Co2), and complex products (Co4)	Co9	• High technology suppliers selected, for small product volumes without high labour costs	Co6,7	• Flexible systems based on digital production technologies and skilled workers (Co6,7), cutter capacity as key constraint (Co6)
	Co5	• Flexible suppliers selected for capacity to handle small quantities (e.g. 5–20 machines, digital printing) and full-package offering (e.g. no need for fabric sourcing)				
	Co8	• Flexible knitting technologies with low labour levels, and sewing stages with high labour content				
*New competence (advanced technologies) development requirements**					*Co6,7*	• *Investments required for new competence development as challenging with limited resources, e.g. for digital printing on-demand (Co6), and can constrain new product introduction (Co7)*

(*continued*)

Table A2.

	SS-A: Small-series through postponement		SS-B: Small-series through postponement and on-demand		SS-C: Small-series through on-demand or customization	
*Worker availability**	*Co8*	• *Difficult to find people to sew in Europe*				
*Reduced flexibility with on-demand**			*Co1*	• *The flexibility of total production capacity is reduced by the introduction of own brand small-series production (on-demand)*		
ICT/Digital processes			Co1,9	• Online sales for internal brand development (Co1), and associated with regional production (Co9)	Co6,7	• Automated processes (e.g. fitting/sizing algorithm and pattern-making), and digital interactions with customers as core competence (Co6,7)
			Co3	• Digitization of design processes, production facilities, and integration with strategic suppliers, e.g. for flexibility and sustainability		
*Digitalization levels, implementation and cyber security**	*Co2,4*	• *Low levels of digital technology/data use (Co2), digital integration/ communication challenges between departments (Co4)*	*Co3*	• *Digitalization is challenging due development time and resource requirements, and some resistance to change*	*Co6*	• *Digitized processes and digital integration lead to various challenges related to customer data handling and cyber security*
			Co9	• *Direct digital sales development requires problem-solving regarding customer data handling etc.*		
Postponement (on-demand)			Co1	• On-demand for own brand, focused on sustainability		
			Co3,9	• On-demand for high-value, made-to-measure products (Co3,9)		

(*continued*)

Table A2.

	SS-A: Small-series through postponement		SS-B: Small-series through postponement and on-demand		SS-C: Small-series through on-demand or customization	
Network structure						
Sourcing and manufacturing proximity	Co2,4,5,8	• Proximity sourcing for trust and reliable delivery (Co2), sustainability (Co4), responsiveness (Co5), and improved logistic performance (e.g. domestic fabric production and regional apparel manufacturing) (Co8)	Co1,3,9, 10	• Proximity sourcing for fabric sustainability (e.g. overstock materials and less transportation) (Co1), sustainable products, made-to-measure and high variety styles, short lead times (Co3), customization and high value products (Co9), technical fabrics and custom features (Co10)	Co6,7	• Proximity sourcing to avoid added customs costs and reduce transportation (Co6), and for co-location of fabric/material and production close to markets (Co7)
*Competence availability and location**	*Co4*	• *Challenging to find certified local/regional suppliers for products/components to meet sustainability targets*	*Co3*	• *Certified suppliers in Asia, e.g. for Cotton made in Africa, as a barrier for European sourcing*	*Co7*	• *Limited availability of suppliers for small volume, on-demand production demands collaborative development*
	Co5,8	• *Limited small-series supplier availability (e.g. 5–10 machines) (Co5), and regional material sourcing, due to the lack of textile infrastructure (Co8)*	*Co9*	• *Some materials are not available in the EU region, which is a barrier to relocating production*		
Dual sourcing	Co5	• Dual sourcing for each product type to reduce dependence on a single supplier	Co9	• Dual sourcing for small-series and custom products to reduce dependence on a single supplier	Co7	• Dual sourcing is used for jersey products for flexibility to handle different product types and volumes
Supplier rationalization	Co5	• Consolidation of supplier portfolio for long-term relationships and to avoid customs/duties costs, e.g. no UK suppliers due to BREXIT				

(*continued*)

Table A2.

	SS-A: Small-series through postponement		SS-B: Small-series through postponement and on-demand		SS-C: Small-series through on-demand or customization	
*Supply chain design difficulties**	*Co5*	• *Supply chain design challenges due to time required to balance volatility-related issues*			*Co6*	• *Difficulty designing supply chains to control costs, due to increasing macro-economic volatility, e.g. related to trade policies and currency changes*
*Low supply chain control**	*Co2,8*	• *Low control without an internal brand, thus producers can be replaced easily (Co8), which demands customer collaboration (Co2)*				
Network relationships						
Close supplier relationships	Co2	• Personal relationships and trust enabled by proximity sourcing	Co3,9,10	• Integration with suppliers for digitalization, recycling processes for sustainability, e.g. through collaborative development and common understanding of goals (Co3), real-time production and logistics data-sharing (Co9), for product functionality and certification (e.g. fire resistant), compared to flexible garment production (Co10)	Co6	• Joint ownership of suppliers through technology investments
	Co4	• Trust, social and environmental sustainability enabled by proximity sourcing			Co7	• Collaborative development with suppliers for made-to-measure production, and closeness due to being the biggest customer
	Co5	• Long-term relationships as the goal of a limited supplier base, and supportive of sustainability improvements				

(*continued*)

Table A2.

	SS-A: Small-series through postponement		SS-B: Small-series through postponement and on-demand		SS-C: Small-series through on-demand or customization	
*Supplier dependence risks**	*Co5*	• *Low supplier dependence is a risk with small order sizes, as producers can prioritize bigger orders/customers*	*Co10*	• *Technical fabrics have low flexibility due to extreme dependence on specialized producers, which demands high levels of trust to support long-term development*		
Internal integration	Co2 Co4 Co5	• Basic content management system used • Higher level of digital integration for fabric manufacturing compared to apparel manufacturing • Internal communication and shared metrics to improve sourcing and efficient order flows	Co3,9	• Internal digitalization, communication and shared goals for flexibility, sustainability (e.g. circular design principles, reduced complexity), customer-centricity (Co3), customer integration and customization (Co9)	Co6	• Internal IT systems connecting fabric inventory with customer configuration and seamless customer journey, production, and fabric sourcing, which facilitates efficient product innovation
Close/digital customer relationships	Co5	• Customer-centricity and customer demands for transparency driving nearshoring, material certification and openness of product and supplier information	Co3 Co9	• Customer-centricity and communication is a key driver of operations, and decisions about customization • Development of digital customer relationships in addition to physical stores	Co6 Co7	• Co-design/configuration, custom size and trust offered to customers through digital services and seamless customer journey; Closeness encouraged by customer vendor model • Seamless digital services (e.g. for custom size); Crowdfunding used with new products/technologies

(*continued*)

Table A2.

	SS-A: Small-series through postponement		SS-B: Small-series through postponement and on-demand		SS-C: Small-series through on-demand or customization	
*Digital customer relationship costs and risks**			*Co9*	• *With increasingly digital customer relationships, and sales, key issues include cyber-security and data management*	*Co6*	• *Costs of digital marketing are high; Customer data handling and cyber security are key issues*
Transparency	Co5	• Transparency strategy focused on communicating material certifications and supplier location/ sustainability			Co6,7	• Transparency strategy communicating certification (e.g. organic materials) and sustainability goals (e.g. no flying) (Co6), industry challenges, supplier information and company goals (e.g. waste reduction) (Co7)
*Transparency and communication difficulties/risks**	*Co4*	• *Communication challenges between departments (e.g. different priorities and terminology), and with customers (e.g. due to product complexity)*				
	Co5	• *Risks of openness (e.g. supplier lists) must be balanced with transparency benefits (e.g. customer demands)*				
Co-branding (fabric)					Co6	• Fabric co-branding to reach customers, offer high value products, and improve transparency

Note(s): **Challenges* in italics

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