Int. J. Production Economics 250 (2022) 108688

Contents lists available at ScienceDirect

International Journal of Production Economics

journal homepage: www.elsevier.com/locate/ijpe

Mapping the supply chain: Why, what and how?

Bart L. MacCarthy[a,*], Wafaa A.H. Ahmed[a], Guven Demirel[b]

[a] Department of Operations Management and Information Systems, Nottingham University Business School, University of Nottingham, Nottingham, NG8 1BB, United Kingdom

[b] School of Business and Management, Queen Mary University of London, Mile End Road, London, E1 4NS, United Kingdom

ARTICLE INFO

Keywords:
Mapping
Supply chain
Supply network
Global Value Chain
Visualization

ABSTRACT

There is now widespread appreciation of the critical role played by supply chains in the global economy. Supply chains are dominant concerns for many organisations, governments, policy makers, and consumers. A primary requirement in addressing many contemporary supply chain challenges is the need to 'map' a supply system. With notable exceptions, much of the supply chain management literature has shied away from providing guidance on the mapping process. In this paper, we stress the reasons for the increased emphasis on mapping. We review the academic literature, highlighting the diversity of mapping exercises conducted by researchers and the lack of clarity about the different types of maps developed. Supply chain mapping has been used as an umbrella term for studies at very different aggregation levels. We define the fundamental elements needed to create a supply chain map and develop a formal hierarchy of supply systems for mapping at different levels of analysis. The hierarchy provides a structured way to consider the diversity of mapping exercises in the literature and to define the unit of analysis for a mapping study. We illustrate the hierarchy with a range of examples from the textile and apparel industry. We identify the primary and secondary data sources that can underpin mapping studies, highlighting the significant challenges in using them. We discuss the emerging commercial solutions to capture, map, and analyse supply systems for different purposes. In an increasingly data rich world, there are many opportunities to develop the supply chain mapping process further.

1. Introduction

The 21st century has borne witness to the fragile nature of globally dispersed supply chains (Demirel, 2022). Supply chain risk management has developed strongly as a research discipline over the last two decades (Ho et al., 2015; Tang and Musa, 2011; WEF, 2022). The emphasis on supply chain resilience has been evident since the global financial crisis (Jüttner and Maklan, 2011), which began in 2007. More recently, there have been significant changes in the global supply chain landscape because of the pandemic, and also because of major geopolitical events and upheavals (Handfield et al., 2020). For instance, in Europe, Brexit immediately raised issues on the operation and regulation of supply chains, a debate that persists (Hutton and Powell, 2021). The election of Donald Trump to the White House in 2016 initiated a new era in reconsidering trade tariffs and US-China trade relations (Mao and Görg, 2020). The Covid-19 pandemic has radically affected supply chains, upending previously stable supply and demand relationships, resulting in many dramatic and critical shortages, and supply chain and logistics disruptions (Handfield et al., 2020; Ivanov and Dolgui, 2020). The combined effects have changed perspectives and mind-sets on many major supply chain issues.

Today, supply chains are very much in the news, gaining strong attention from the public, greater focus than ever from industry, and much more scrutiny from governments (MacCarthy and Ivanov, 2022). The shortages of critical components such as semiconductors and the concerns on the global supply of critical raw materials have shone a spotlight on supply chains, their global spread, and their control (Porcari et al., 2021). Resilience and security of supply are at the top of the agenda. This is exemplified by industry reports on supply chain disruptions and dedicated industry events on how to achieve supply chain resilience, e.g. The Economist (2022a), the setting up of government task forces (Porcari et al., 2021), and increasing supply chain regulation with stringent rules on origin and product provenance (WEF, 2022). These trends emphasize the need for greater understanding, awareness, and knowledge about supply systems (Handfield et al., 2020).

At the core of production economics are the material flows associated with supply, production and distribution. The location of suppliers, production and distribution facilities affects the fundamental economics

* Corresponding author.
E-mail addresses: Bart.MacCarthy@nottingham.ac.uk (B.L. MacCarthy), Wafaa.Ahmed@nottingham.ac.uk (W.A.H. Ahmed), g.demirel@qmul.ac.uk (G. Demirel).

https://doi.org/10.1016/j.ijpe.2022.108688
Received 2 August 2022; Received in revised form 14 October 2022; Accepted 17 October 2022
Available online 21 October 2022

of production. As the global economy changes, the ability to capture and map the changes is a prerequisite for planning, managing, and controlling material flows to improve industrial practice. Many contemporary supply chain concerns give rise to the need for mapping the supply chain (Choi et al., 2020; Mubarik et al., 2021b). Accurate maps are needed for supply chain performance management (Chae, 2009), for supply chain re-design and improvement (Farris, 2010) and for the digitalization of supply chains (MacCarthy and Ivanov, 2022). Maps are also needed for supply chain risk management (Ho et al., 2015) to manage operational risks and many emerging challenges, including sustainability, supply chain cyber security, climate change, and the global shortages of critical raw materials (Cha, 2022; Ghadge et al., 2020; The EU, 2020; WEF, 2022).

The paper focuses on supply chain mapping. It brings to the fore concepts that have been implicit in supply chain management research, providing a structured way to look at the diversity of maps related to supply chains depicted in the literature. We make four important contributions to the literature. First, we demonstrate the need to provide more clarity and rigor on the different levels of mapping of supply systems that are possible. Second, we present a formal hierarchy of supply systems covering the diversity of maps presented in the literature. The hierarchy helps to determine an appropriate unit of analysis for a mapping study. Third, we discuss primary and secondary data sources that can be used by researchers and practitioners to map and analyze supply chains. We underline the significant challenges that arise in creating supply chain maps and note the emerging commercial solutions available to assist in mapping studies. Fourth, we use the hierarchical perspective to illustrate mapping examples at different levels of granularity from the textile and apparel industry. This industry is globally dispersed, highly dynamic in terms of location and presents significant sustainability challenges (Ahmed and MacCarthy, 2021; Gereffi and Frederick, 2010; MacCarthy and Jayarathne, 2012).

The paper is organized as follows. We first examine the contemporary motivations for gaining increased knowledge of supply chains and undertaking a mapping exercise in Section 2 (the Why question). We then review the range of mapping exercises evident in the literature in Section 3. In Section 4, we identify the minimum data elements for a map, presenting a hierarchy of supply systems to assist in identifying the purpose and the focus of a mapping exercise (the What question). We also describe the range of data sets, commercial solutions, and software products that can be used to generate maps, highlighting the opportunities and challenges (the How question). In Section 5, we present map exemplars from the textile and apparel industry to illustrate the hierarchical perspective. We conclude by identifying a number of promising directions for future work.

2. Mapping - why and why now?

Mapping the supply chain is the first stepping-stone for effective strategic supply chain management. Gardner and Cooper (2003) proposed supply chain mapping as a tool to link “corporate strategy to supply chain strategy” for identifying supply chain performance improvement and network redesign opportunities (Farris, 2010; Gardner and Cooper, 2003; Mubarik et al., 2021a). For example, at a detailed tactical/operational level, value stream mapping has been deployed to identify and remove non-value adding activities in supply chains (Hines and Rich, 1997; Suarez-Barraza et al., 2016; Taylor, 2005). Supply chain mapping provides managers with required level of understanding about the configuration of their supply chain to address its impact on supply chain planning, management and control processes. It is also essential to develop the initial knowledge about the supply chain for proper deployment of prominent strategic performance tools, including the SCOR model (Huan et al., 2004) and supply chain key performance indicators (KPIs) (Chae, 2009).

However, supply chain mapping is emerging as a crucial activity not only to fulfil the continuing needs for improvement, but also because of broader trends that are reshaping the post-pandemic global economy and global commerce (Handfield et al., 2020; Lee and Tang, 2018; The Economist, 2022b). Economic, technological, and societal trends have focused public, industrial, and government attention on the configuration, operation, control and management of contemporary supply chains, stressing the need for accurate and useful mapping solutions. We discuss these multiple trends here.

Risks in the supply chain: Although the risks inherent in globally dispersed supply chains became widely apparent in the pandemic, both practitioners and researchers have been strongly concerned about the vulnerabilities in globally dispersed supply chains for over two decades (Harland et al., 2003). Supply chain risk management has developed strongly in academic research and as a practitioner discipline (Tang and Musa, 2011). As well as disruptions and shortages, there are significant concerns about reputational risks arising from engaging in supply chains involving ethical, social and environmental malpractices, which have occurred for instance in garment and mineral supply chains (UNECE, 2021; van den Brink et al., 2020). Supply Chain Cyber Security has also emerged strongly on corporate agendas (Cha, 2022). Companies are interested in developing supply chain maps that can help understand, assess, and mitigate such risks by increasing visibility (Ivanov, 2021). The creation of a digital supply chain twin mirroring the real supply chain with control towers that centrally monitor supply chains are important emerging concepts (Accenture, 2021; Ivanov and Dolgui, 2020) that require supply chain maps.

Technological advancement and digitalization: Technological advancements have always strongly affected how supply chains develop and evolve (MacCarthy et al., 2016). The last decade has seen a rapid rise in the development and deployment of digital technologies for supply chain operations, affecting supply chains in diverse ways (MacCarthy and Ivanov, 2022). Their effects are being felt in smart factories, in Industry 4.0 initiatives, and in warehouses and logistics systems (Ahmed and Rios, 2022; Culot et al., 2020; Kusiak, 2018). Migration to cloud-based systems is affecting how data, computing infrastructure, and software are accessed and used across a supply chain (Zhang et al., 2022). Platform commerce has transformed many sectors, including retailing supply chains with the emergence of omni-channel commerce (Zhang et al., 2021), and business areas such as sourcing and procurement (Kosmol et al., 2019).

A number of emerging digital technologies have the potential to strongly affect the configuration, management and control of supply chains in the future, including Digital Twins, the Internet of Things (IoT) and Blockchain (Ivanov, 2021; MacCarthy and Ivanov, 2022). A Digital Twin provides a live dynamic model closely coupled with an existing real system, allowing safe exploration and simulation to answer “what if” questions (Ivanov and Dolgui, 2020; Zhang et al., 2022). IoT encompasses technologies that provide a connected network of smart objects, bringing a physical dimension to the Internet (Birkel and Hartmann, 2019). Blockchain technology can provide an immutable digital trace of supply chain operations with a host of applications, including product safety, quality, sustainability, and financing (Ioannou and Demirel, 2022; Treiblmaier et al., 2022). Although the architectures, protocols, and platforms to enable these technologies are in the early stages of development (Ahmed and MacCarthy, 2022), their use requires detailed precise knowledge of supply chain configuration. Supply chain maps are needed for strategic decisions on which parts of the supply network may benefit from the deployment of emerging digital technologies (Mubarik et al., 2021a).

Societal and consumer awareness and expectations: Sustainability, incorporating social, economic and environmental dimensions, is a dominant concern for contemporary supply chain management (Bellamy et al., 2020). The increased awareness of environmental and social issues related to supply chains has resulted in more stringent regulatory and reporting requirements for companies (WEF, 2022). The impact of climate change on supply chains is a major global concern, as it may affect the future availability of natural resources, raw materials, food production, and transportation (Ghadge et al., 2020). However, the sustainable development of supply chains presents highly complex and difficult problems.

Consumers and societies ask more questions than ever before about products, their origin and the methods, materials, and people used in their production. Millennials and Generation Z exhibit stronger concerns than previous generations on product origin and authenticity (Francis and Hoefel, 2018). Non-governmental organizations (NGOs) focus on many supply chain issues, channeling and amplifying consumers' and society's concerns about products and supply chains (Peng et al., 2021). Many producers and manufacturers now seek to provide guarantees on the authenticity of products, particularly in the premium and luxury goods and food sectors (Choi, 2019; Donaldson et al., 2020). In all of these contexts, accurate and reliable supply chain maps are needed to reassure consumers, the public, retailers and brand owners about the origin and the authenticity of the products and the practices used in their supply chains.

Regulation and Geopolitics: Some sectors such as pharmaceuticals and food have historically been subject to regulatory regimes that accredit, monitor, or audit aspects of the supply chain (Aung and Chang, 2014). Newer legislation on sourcing from conflict mineral zones emerged in 2010 in the US (Hanai, 2021) and, more recently, legislation on the monitoring of modern slavery in supply chains and the rules of origin have been introduced (WEF, 2022). There has been increasing interest from policy makers, regulators, industry bodies and governments on the configuration, operation and control of contemporary supply chains (Porcari et al., 2021). Discussion on the impact of geopolitics is outside the scope of this paper, but it is clear that security and resilience of supply are dominant considerations in the post pandemic era, for instance with the European Union's identification, listing and analysis of the global value chains of critical raw materials (The EU, 2020). There is heightened interest in active surveillance of supply chains (Brintrup et al., 2022; WEF, 2022). Accurate information-based maps are needed to facilitate risk analysis, monitoring, surveillance, and early detection of supply problems.

3. Supply chain mapping in the literature

We first review the literature on the theory of supply chain mapping in Section 3.1 and then discuss several exemplar maps from the literature in Section 3.2.

3.1. Supply chain mapping as a process

The dictionary defines the word 'map' as a noun ("a diagrammatic representation of an area of land or sea showing physical features, cities, roads, etc.") and a verb ("represent (an area) on a map or make a map of") (Oxford Learner Dictionary, 2022). Similarly, a supply chain map has been defined as a diagrammatic representation, providing a "likeness and a simplified model" of a supply chain with both visualization and information about key features (Gardner and Cooper, 2003). A map of a supply chain should present appropriate and accurate information in a manner that can be easily understood and, at the same time, be sufficiently informative to aid supply chain visibility, analysis, and integration (Gardner and Cooper, 2003; Mubarik et al., 2021a).

A positivist perspective was adopted in early studies, where the supply chain map was defined as "a stand-in for the actual environment" (Gardner and Cooper, 2003), while acknowledging that the perception of the map is person-specific. Fabbe-Costes et al. (2020) demonstrate the diversity of maps of the same supply chain mapped by different employees of the same manufacturer. This presents a challenge for the use of supply chain maps as a reference point for individuals and firms and also as a catalyst of supply chain integration (Fabbe-Costes et al., 2020; Gardner and Cooper, 2003; Mubarik et al., 2021a). Fabbe-Costes et al. (2020) contrast the "network picture" and "boundary object" perspectives with the positivist approach. In particular, the study defines a supply chain map as a boundary object that can be identified, interpreted, and used as a communication tool across firm and functional boundaries with different perspectives. Mubarik et al. (2021a) review the literature on supply chain mapping, using the three perspectives discussed in Fabbe-Costes et al. (2020), and develop a construct for measuring the level of supply chain mapping in upstream, midstream (focal firm), and downstream, according to what information is contained and visualized about suppliers, customers, materials, processes, and technologies, the level of digitalization, and availability and sharing of real-time data. However, these aspects are not measured per se from maps (instead based on questionnaires) and are not precisely distinguished from visibility. Differently from Mubarik et al. (2021a), we argue that the degree of mapping depends on the purpose, hence it is difficult to devise a universal metric for mapping. We instead introduce a classification of supply chain maps based on a hierarchy of supply systems, for which the focus, elements, and attributes vary substantially depending on the purpose, as we discuss below.

To explain the differences in the focus of different mapping activities, Hines and Rich (1997) distinguished between supply chain and value stream, where the former refers to all activities of engaging firms and the latter to a sequence of value-adding activities. Hines and Rich (1997) analyzed seven value stream mapping tools and concluded that the specific tool to be used changes with the targeted waste. Gardner and Cooper (2003) contrast business process mapping, and implicitly value-stream mapping, with supply chain mapping in terms of their orientation/focus (internal, i.e., the focal firm, vs external, i.e., supply chain members), purpose (tactical vs strategic), and level of detail (overall inter-firm processes and performance vs detailed breakdown of activities). However, value stream mapping has often been extended to buyer-supplier dyads and beyond in various studies (Brunt, 2000; Miyake et al., 2010; Suarez-Barraza et al., 2016; Taylor, 2005). Hence, the boundaries are not clear cut, but the contrast with respect to the purpose (tactical/operational vs strategic) prevails, as supply chain maps are mainly used to develop and communicate supply chain strategy between supply chain stakeholders (Fabbe-Costes et al., 2020; Gardner and Cooper, 2003). Furthermore, at a strategic level, there has been a surge of interest in mapping global value chains at an aggregate level between countries and industries (Frederick, 2019), asking questions related to supply chains but at the policy level, not focusing on specific firms.

There has been some discussion on standardizing the supply chain mapping process. Taylor (2005) formalized the value chain analysis as a multi-stage process, which starts with identifying the business purpose, develops an overall supply chain structure map, then moves to the mapping of facilities involved, and finally applies the current and future state mapping tools of value stream mapping. Although this is a very useful framework for linking maps at the strategic and tactical/operational levels, many supply chain mapping studies are purely strategic in nature. Furthermore, this does not consider the breakdown of the supply chain mapping process at the strategic level. Gardner and Cooper (2003) highlight the need for standardizing the mapping process, but it is unclear how this can be achieved, especially considering the diversity of maps developed, which we discuss next.

3.2. Examples of supply chain maps

We discuss a selection of maps from the literature that illustrate the diversity in the purpose, scope, elements, and details captured. At the tactical planning level, Brunt (2000) demonstrated a value stream mapping tool developed in a three-year study of the steel supply chain of a single firm, showing the structure of information and material flows, including production stages, within and between supply chain members. The map identifies processes to be improved, applying lean methods. Suarez-Barraza et al. (2016) applied a similar approach, which they called supply chain value stream mapping, to two manufacturing supply chains in Mexico for glass door display coolers and beverage bottling.

The developed maps are much less detailed and show aggregate lead times and delivery performance. Taylor (2005) used action research to map several red meat supply chains from farm to fork, leading to an aggregate supply chain map that illustrates information flows for production planning between the managers of different firms and material flows between aggregate entities (e.g. farms, abattoir, processors, and retailers), highlighting value-adding and non-value adding activities. Miyake et al. (2010) mapped three supply chains in the Brazilian automotive industry using action research. While the three maps varied vastly in terms of detail and scope, they each aimed to improve performance by lean management methods.

A number of mapping studies were targeted at strategic supply chain decisions (Gardner and Cooper, 2003). Roy (2011) mapped supply chains of three focal firms (a wine producer, olive growers, and a job-shop manufacturer) in New Zealand, through interviews, identifying the key stages of production, lead times, transportation modes, and inventory points, but without detail on operations and performance. Fabbe-Costes et al. (2020) conducted a supply chain mapping case study in the automotive sector, capturing mainly the principal actors, facilities, and flows in the downstream supply chain at an aggregate level. Anastasiadis et al. (2020) conducted interviews with sectoral experts and used secondary sectoral data to map tomato supply chains in Greece, showing the main production steps and the involvement of different stakeholders (producers, government, farm associations, unions, etc.) at different points of the chain, but without details on operations. MacCarthy and Jayarathne (2013) investigated the structure and relationships between prime manufacturers and retailers in the international clothing industry and developed a range of maps to illustrate the level of integration between the principal supply chain partners in the sector, which led to the identification of different supply chain configurations. Choi and Hong (2002) and Kito et al. (2014) both developed maps of the structure of Toyota's supply network, differing substantially in the source of data (primary vs secondary), level of detail (product flow linked to the bill of materials structure vs financial transactions between firms), and their method of analysis (case study vs network analysis).

Mapping of the aggregate global flows of commodities has also attracted interest (de Backer and Miroudot, 2014; Frederick, 2019). Fernandez-Stark et al. (2011a) mapped global flows of fruits and vegetables in a study focused on the role of workforce development initiatives in developing countries. Fernandez-Stark et al. (2011b) mapped the global apparel value chain for the same purpose. Adewuyi et al. (2014) mapped the global chain of cocoa beans and garments to provide insights to policymakers in Nigeria to improve the country's position in the global economy. De Marchi and Di Maria (2019) mapped the global value chain of leather as part of a study that investigates the role of buyers in supporting environmental upgrading of suppliers' products and processes.

The studies above show that there has been significant interest in capturing and mapping supply chain information, but they also exhibit great diversity in what is captured, what is depicted, and how it is depicted. This echoes the observation of Gardner and Cooper (2003) almost twenty years ago about the lack of conventions and the great diversity in supply chain maps, which still persists and is strongly relevant to the focus of this paper. We stress that the diversity noted by Gardner and Cooper (2003) in terms of the geometry and perspectives of maps has persisted, contributing to the fuzziness of the supply chain mapping concept. We highlight three further critical insights. First, the extent of the supply system mapped varies greatly in studies – from the depiction of extensive and deep networks of connected entities involved in supply to focusing on just a few primary actors involved in value creation. Second, the diversity in the purposes of maps has soared, e.g., analyzing patterns of trade in global commodities and products, documenting working conditions of people employed across a supply chain, reporting risk and stability of supply networks, and identifying supply chain improvements and redesign opportunities at different levels of granularity. Third, the studies show that supply chain maps are not 'delivered on a plate' but are often costly, time consuming, and resource intensive to develop.

Overall, although there is an acknowledgement of the variety of maps in the literature, there is still a lack of guidance on the mapping process and ambiguity in how they can be understood and classified. Given the prominence and importance of supply chains in the contemporary global economy, much more formality and rigor is needed to guide the supply chain mapping process and to harness the capabilities of existing information systems, e.g., Geographical Information Systems (GIS) that provide visualization, exploration and analysis of different types of spatial data and information (Bearman, 2020). Supply chain mapping needs to avail of the variety of data sources now available and the emerging software that can assist in the mapping process. We address this gap in this research by providing a structured hierarchical perspective to support and underpin supply chain mapping studies and a review of different data sources and tools for mapping.

4. The mapping process - what and how?

In the following, we first identify the information needed to construct a supply chain map. We then present a hierarchy of supply systems to facilitate the identification of the unit of analysis in undertaking a mapping study. We discuss the data sources, software, and commercial solutions available to support supply chain mapping.

4.1. Content of supply chain maps

Since its inception, a supply chain has been defined as "a system whose constituent parts include material suppliers, production facilities, distribution services and customers linked together via the feed-forward flow of materials and the feedback flow of information" (Stevens, 1989). Thus, a supply chain encompasses all processes involved in producing and delivering a product. However, supply chains are comprised of geographically dispersed and distinct economic entities. In general, no one party owns the supply chain, although dominant players are present.

We first identify the minimum information requirements for a supply chain map, consistent with previous literature. For this, we adopt a network science perspective that models a system as a collection of nodes, i.e., who participates in the supply chain, and links, i.e., how the participants in the supply chain are connected.

- **Nodes:** The primary participants (also called actors or players) are the entities that contribute directly to value-adding activities in the processing stages of a supply chain. Secondary participants may include third party logistics providers, customs agencies, auditors, regulators, financing and insurance companies, etc.
- **Links:** Value is accumulated in a supply chain as a product flows through value-adding stages. Material, information, and financial flows may be important in some studies (Pfohl and Gomm, 2009) as well as the interactions between all three types of flow (Zhang et al., 2020). Information and money can flow in either direction and in reverse logistics products flow upstream. Hence, the type of flow must be captured together with its direction. The different flows can be considered along a serial chain of actors or across a network of all firms that contribute to the supply. Other types of links between entities can also be captured in the map, such as competition (Zhao et al., 2019), contractual relationships (Choi and Hong, 2002), and cooperation and technology transfer (Lomi and Pattison, 2006).

These two information elements may be considered the minimum data requirements necessary to construct a basic supply chain map. However, further elements and attributes can be added to the map, depending on the context and the purpose of the study.

- **Other map elements and attributes:** Supply chains incorporate many physical assets – manufacturing machines and storage and transportation facilities. At a fundamental level the primary data for the supply chain is spatial. Capturing the geographical locations of the primary actors and their facilities, e.g., warehouses, manufacturing plants, distribution centers, and ports, may be important in many contexts. For operational purposes, data related to production plans, performance, production capabilities and capacities, objectives, tools and resources (modes of transport, technologies such as IT systems), and their ownership, including intellectual property rights, can also be captured in a mapping exercise. As discussed in Section 4.3.1, such detailed maps typically require the collection of primary data through the direct involvement of prime entities, while secondary data might be available to substitute or enrich it. Furthermore, material flows are typically incorporated into tactical/operational maps, where the durations of different steps in production or logistics are identified, examples of which are discussed in Section 3.2. Given the above, the range and type of data that are potentially available for a mapping study are almost unbounded. To gain further insights on the problem of what to include, we discuss two issues – (1) the unit of analysis or extent of a map and (2) the level of detail or granularity of information captured.
- **Unit of analysis**: As the literature in Section 3 shows, the unit of analysis, i.e., the boundaries of the supply system mapped, depends on the nature, focus, and scope of the study. It can range from a short segment of a linear chain to a vast network that captures multiple supply lines. Firms deep in a supply network may be crucial to supply chain performance (Yan et al., 2015). Some mapping exercises may therefore need to extend far beyond immediate suppliers and customers, depending on the purpose. However, the sheer size of many supply chains and the limited knowledge that may be available on deeper sub-tier supply network structures present significant challenges in capturing essential data for supply chain mapping (Choi et al., 2020). Furthermore, material flow data may just indicate the connectivity between the primary participants (who supplies whom) or the downstream logistics providers that collect, store and transport a product can also be included.
- **Level of detail:** The level of detail or the granularity of information has had some discussion in the literature (Farris, 2010; Gardner and Cooper, 2003; Mubarik et al., 2021a). The unit of analysis and the mapping purpose influence the level of detail. At any processing stage, in addition to identifying the participant organizations' locations and connections, specific information on their operations (e.g., materials, machines, processes, people), quality (e.g., certification, accreditation, auditing), or environmental, sustainability and broader governance issues (ESG) may be of interest (Anastasiadis et al., 2020). For instance, the increasing efforts in tackling sustainability issues in the supply chain may require capturing, tracking and monitoring various type of data, including CO2 emissions, product recycling processes, and even employment contracts to tackle issues related to modern slavery (Ghadge et al., 2020; WEF, 2022).

4.2. *Mapping hierarchy of supply systems*

As discussed above, maps can be developed for many different purposes and supply chain mapping has been used as an umbrella term for maps at different aggregation levels. Previous literature mainly contrasts strategic supply chain mapping with tactical/operational process mapping (Gardner and Cooper, 2003), but is mostly silent on the subcategories of strategic supply chain maps. Because of this confusion, we develop here a structured classification of maps using a hierarchical perspective of supply systems, illustrated in Fig. 1 and explained below.

At a macro level, a global value chain (GVC) map provides a holistic representation of global production networks and trade flows for commodities or industries on a global scale. Entities in GVC maps are typically at the country and industry levels. GVC maps capture the value-adding stages that stretch globally. They identify the position of countries and regions in the value chain, hence the focus on the concept of value-added trade. They are useful in supporting policy and macroeconomic questions but also provide broader context for supply systems mapped at finer levels of granularity.

At a lower level, products and services are created through multi-tier complex supply networks between distinct firms. Supply networks comprise all value-adding and nonvalue-adding activities and stakeholders involved in the development, production, delivery, and distribution of products and services from conception to consumption. They may have an industry or a firm focus, but in either case they capture entities explicitly at the firm level. Supply network maps mostly focus on studying the overall network topology (who is connected to whom) for strategic purposes.

Although the term supply chain map has been used loosely in the extant literature, we give it a more specific meaning from now on and distinguish it from both global value chain mapping and supply network mapping. We consider a supply chain to be a specific subset of a broader supply network focused on a particular product or product range, where the captured activities, material flows, and participants are involved in

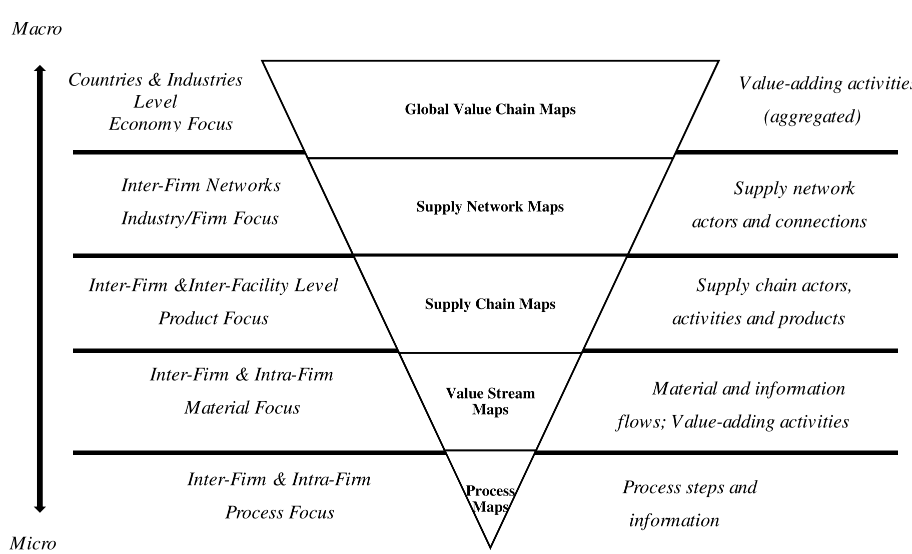

Fig. 1. Hierarchy for supply systems mapping.

the manufacturing and/or distribution of the product, and its constituent parts, components, and materials.

At a finer level of granularity, different kinds of maps can be developed for different purposes. Value stream mapping (VSM) and process mapping are the most common mapping techniques used to develop a representation of material and information flows and business processes within a focal firm or in a buyer-supplier dyad. VSM focuses on identifying value-adding activities and reducing waste through tactical planning. Process mapping provides a detailed mapping of the sequences of a specific process and can be a building block for VSM or business process re-engineering. We now discuss the specific content and features of maps at each level of the hierarchy.

4.2.1. Global value chain (GVC) maps

The value chain is "*the full range of activities that firms and workers perform to bring a product from its conception to end use and beyond*" (Gereffi and Fernandez-Stark, 2016). In the global value chain (GVC), these activities are performed globally, each country differing in the value-added activities and trade they are engaged in (Gereffi and Fernandez-Stark, 2016; Hernández and Pedersen, 2017). Frederick (2019) identify four main parts of a GVC map at a macroscopic level, including (1) the categories of value-adding activities that are essential to bring the product from conception to end users, (2) supply chain stages, presenting the overall input/output structure of the product flow and the processes in the value chain, (3) the supporting environment, comprising of the institutional actors enforcing legal or societal constraints on the participants of the value chain at a local or global level, and (4) end markets.

Different criteria are used to classify the range of activities in a GVC, including (1) the degree of involvement in production processes, i.e., primary or supportive processes, (2) the position in the value chain, (3) the potential for competence creation, i.e., exploration vs exploitation activities, and (4) the potential for being a source of competitive advantage, i.e., core vs non-core activities (Hernández and Pedersen, 2017). Each criterion can be used for different GVC mapping purposes and helps identify the scope of activities to be captured in the map. Analyzing a GVC can help identify the countries involved in global production networks, their position in the GVC, their competitiveness, economic growth, and risks (Alves et al., 2022; de Backer and Miroudot, 2014), which are relevant for non-governmental organizations and individual businesses, as well as governments. Furthermore, GVC mapping can help organizations identify and analyze the overall structure of the industry and the markets within which they operate.

4.2.2. Supply network maps

Although frequently used interchangeably, it is useful to make a distinction between a supply network and a supply chain. Supply networks are theorized as complex systems with capabilities of emergence, self-organization, and adaptation (Pathak et al., 2007; Surana et al., 2005), in which firms do not possess global control, differently from short serial supply chains where there is a (are) dominant player(s). Furthermore, supply networks are more than the sum of constituting supply chains, i.e. they exhibit complex structures, such as network communities and intra-tier connections between suppliers (Demirel, 2022). Therefore, mapping a multi-tiered and intertwined supply network (Ivanov and Dolgui, 2020) is more challenging than mapping unidirectional and shorter supply chains. Such maps provide an understanding of the broader network configuration and topology and can be further analyzed for monitoring, control, risk management, and other strategic decision-making purposes (Bellamy et al., 2020; Demirel, 2022). Here, we refer to supply network mapping as identifying which firm is connected to which firm. This type of mapping provides structural visibility (Wichmann et al., 2020), which is crucial for supply networks involved in the production of complex products, typically spanning multiple industries. Supply network maps can be used to study the overall structure of industry-level networks. They are also used by governments, regulators, industry bodies, and insurance providers to study individual firms to understand their direct and indirect dependencies on other firms (Demirel et al., 2019). For example, in the automotive and aerospace industries, large numbers of suppliers are engaged in the production of automotive or aircraft parts, including dominant actors in the mining, chemicals, and electronics industries (Brintrup et al., 2015, 2017). Such firm-level network maps can be analyzed to identify reliance of the industry on certain suppliers (van den Brink et al., 2020) or to study the impact of network structures, such as intra-tier connections, on stability (Demirel et al., 2019).

4.2.3. Supply chain maps

Differently from a supply network that combines different product ranges of a focal firm and/or multiple prime entities, we define 'supply chain' as the inter-firm chain of activities and stakeholders involved in the production of a specific product. Hence, a supply chain map is a representation of a focused subset of broader and more complex supply networks. Focal firms can use supply chain maps to investigate their inbound and/or outbound supply chains for critical materials, components, or end products, which can form linear chains or a combination of them in tree-like structures, which are sometimes called "supply chain networks" in the literature. While supply network maps essentially provide structural visibility about complex and interconnected networks of actors, supply chain maps provide greater detail on a subset that is difficult to achieve in or comprehend from a network map.

We refer to two recent mapping studies in the same domain to differentiate supply network maps from supply chain maps. Van den Brink et al. (2020) map the extended cobalt supply network to identify potential risks in cobalt supply, considering main actors and their locations (Fig. 2), while Fraser et al. (2020) map the cobalt supply chain of a particular automotive OEM to improve upstream transparency and sustainability in its specific cobalt supply chain (Fig. 3). Different types of information can be depicted in a supply chain map, including data about selected supply chain actors, their information, material, and financial flows, and supply chain business processes (Lambert et al., 1998). Numerous examples in Sections 3 and 5 illustrate how data on flows and processes beyond the minimum mapping elements, i.e., who is connected to whom, can be used in supply chain maps.

4.2.4. Value stream maps (VSM)

The concept of value stream mapping (VSM) emerged in the late 1990s and has been strongly related to lean manufacturing (Hines et al., 1999; Serrano et al., 2008). The focus of VSM is tactical and is usually implemented at the intra-firm level, though many studies have undertaken cross-boundary value stream mapping, sometimes called extended or supply chain value stream mapping (Brunt, 2000; Miyake et al., 2010; Suarez-Barraza et al., 2016; Taylor, 2005). As a tool, VSM helps capture and analyze the material flows and the associated information flows through the different production stages down to the end customer (Rother and Shook, 2003; Serrano et al., 2008). VSM analysis may facilitate identifying non-value-adding stages and different types of waste to be removed (Rother and Shook, 2003). Data are captured in a systematic way using standard symbols (Suarez-Barraza et al., 2016). Mapping typically involves the development of a current state map and designing a future state map with different flows and material control rules, e.g., implementing Kanban systems (Brunt, 2000; Frandson et al., 2013).

4.2.5. Process maps

Process mapping is one of the oldest mapping techniques with origins in industrial engineering and ergonomics. It was proposed by Frank Gilbreth in the early 1900s (Lee and Snyder, 2007) and is "*used to describe, in workflow diagrams and* supporting *text, every vital step in your business processes*" (Hunt, 1996).

Process mapping has similarities to VSM in visualizing and capturing information about a sequence of processes (Hunt, 1996; Lee and Snyder,

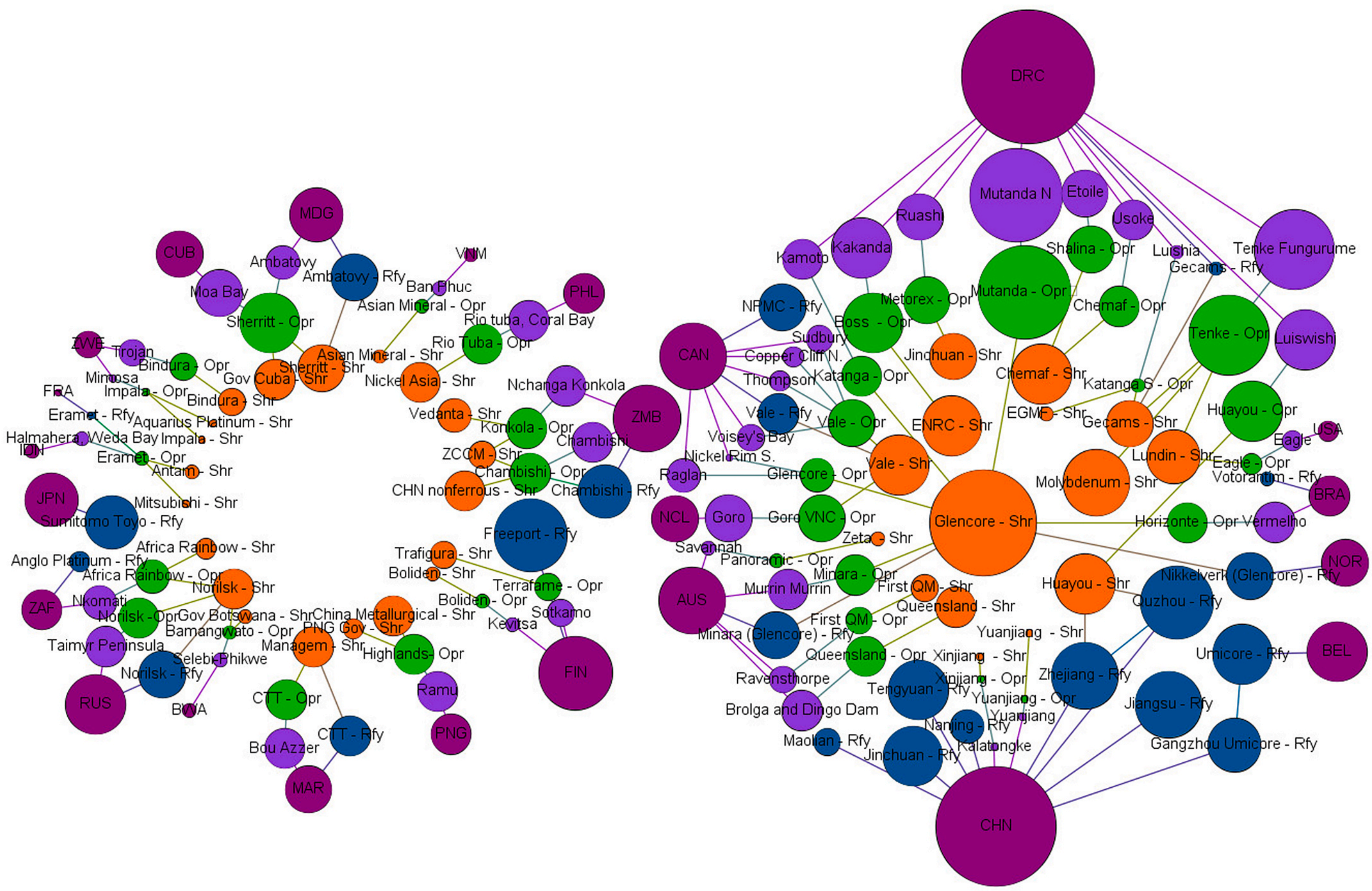

Fig. 2. Example of a supply network map - Cobalt supply network. Source: van den Brink et al. (2020).

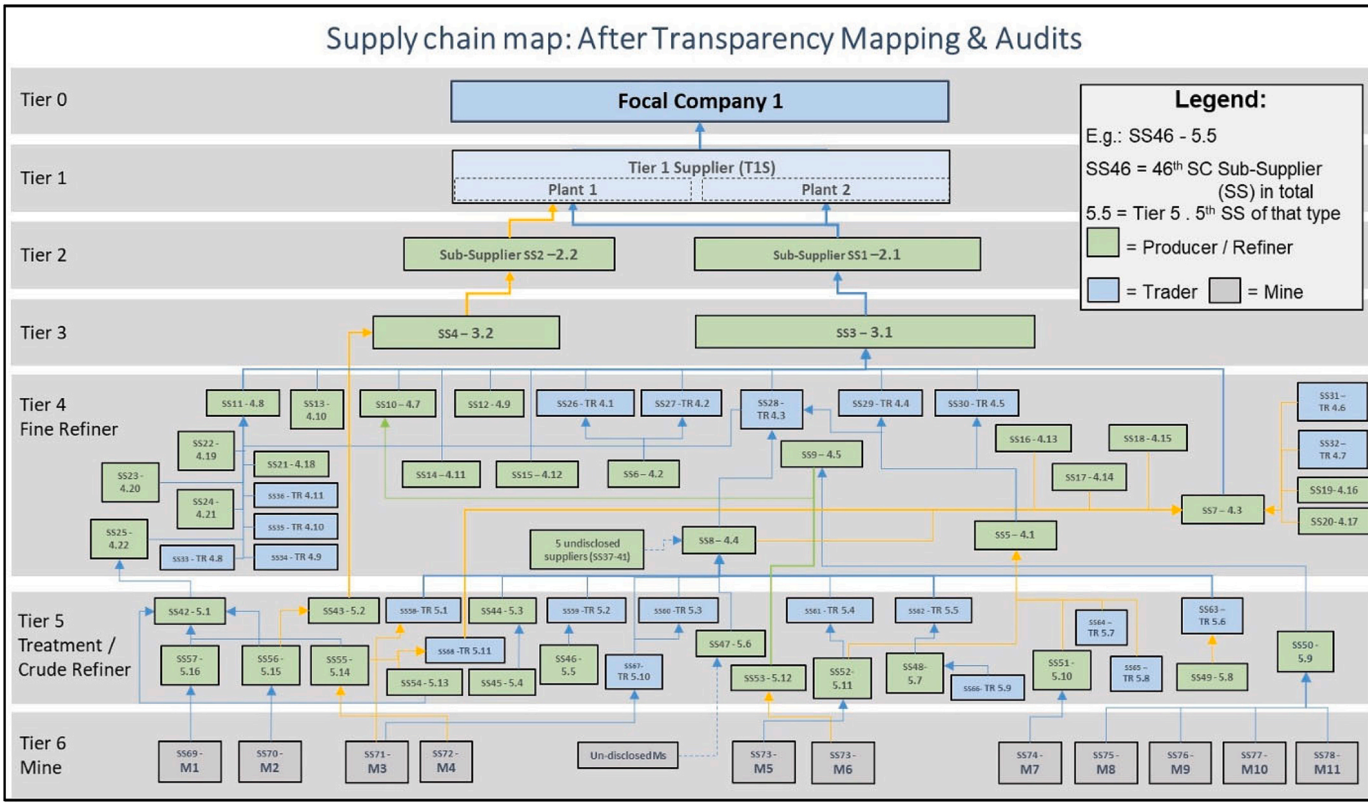

Fig. 3. Example of a supply chain map – Cobalt supply chain map. Source: Fraser et al. (2020).

2007). However, there are key differences: (1) VSM provides a streamlined and broader overview of the business processes from external suppliers to external customers, focusing on value addition (Lee and Snyder, 2007), whereas process mapping focuses on visualizing the sequence of events to build a single item of a product (Damelio, 2011; Klotz et al., 2008); (2) VSM has a specific set of symbols each with a specific meaning that requires expertise and knowledge in developing VSM maps (Lee and Snyder, 2007), while process mapping uses conventional flowchart symbols (Damelio, 2011; Haefner et al., 2014); and (3) data in VSM has to be collected systematically to lay the foundation for further analysis using lean tools (Lee and Snyder, 2007), while the level of detail and information captured in process mapping can vary depending on the mapping purpose (Hunt, 1996). Process mapping can be used as an intermediate step to VSM (Klotz et al., 2008).

To conclude, the hierarchy provides a comprehensive and structured approach to understand the focus and the scope of different maps used to depict the complexities of today's supply systems. In the hierarchy of supply systems, the focus shifts from macro to micro as one moves down. Policy questions on where the value is created can be informed by developing GVC maps, while strategic risk, structure, and competitive advantage related questions of firms, concerning their extended networks, can be supported by developing and analyzing supply network maps. At a finer level of detail, firms can use supply chain maps to focus on strategies for specific product flows. At the tactical and operational levels, VSM and process mapping tools help identify intra-firm and inter-firm inefficiencies and waste in the processes.

4.3. Data sources and software for mapping

The right information to present in a supply chain map varies depending on the purpose and the scope of the mapping exercise and the perspective of the mapper (Fabbe-Costes et al., 2020). However, the resources, the data sources, and the tools available to the mapping team will affect the hierarchical level in which a supply system can be mapped and will constrain the information that can be captured and presented. Below, we summarize the different sources of data and software that can be used and combined in contemporary supply system mapping initiatives. We discuss the limitations of different data sources and mapping techniques to help in making informed choices between alternatives.

4.3.1. Data sources – primary and secondary

Once the purpose of mapping is defined, the next step is to find relevant data. Many types of data sources have been used to create maps. We classify these broadly into *primary* and *secondary* data sources. Moving down the hierarchy from the global value chain to the process map requires more detailed and granular information, which will typically require the involvement of more stakeholders and the deployment of more resources in the data collection process to capture the desired mapping elements.

Primary data is collected using interviews, direct observation, company documents, and company information systems (typically ERP systems) and may be used by researchers and firms to map supply systems at different hierarchical levels e.g., as in Brunt (2000), Taylor (2005), Miyake et al. (2010), and Suarez-Barraza et al. (2016). However, collecting primary data is laborious and may require strategic support from senior management and active participation from supply chain personnel (Miyake et al., 2010). Although such detailed mapping initiatives provide invaluable insights e.g., on lead time, performance and risky suppliers, they are typically difficult to conduct due to resource and time requirements of collecting primary data. Additionally, suppliers may be reluctant to share data, given the risks of being cut out of the supply chain or of disclosing valuable competitive information (Farris, 2010; Gardner and Cooper, 2003). Hence, examples of primary data use are more common at the value stream level and for short chains. An exception is Choi and Hong (2002) who collected multi-tier inter-firm data on three auto-manufacturing supply chains through direct observation (site visits to original equipment manufacturers and top first and second tier suppliers), semi-structured interviews (39 interviews in total), and analysis of company documents (Bill-of-Materials, agreements, supplier performance ratings, etc.). The map specified the material and information flows at the product and parts level and was used for network analysis in follow-up studies (Kim et al., 2011). Demirel et al. (2019) mapped supply chains at the individual firm and product level for an industrial engine manufacturer with a team collecting data in a week-long site visit with several follow-up meetings and interviews with company managers for verification. Using the structural flow information, they analyzed instabilities in material flows caused by the structure of the network.

Secondary data has been used mainly at the higher levels of the hierarchy. At the global value chain level, industry and country level data are accessible from various national and international organizations. Frederick (2019) presents a summary of the databases at the macro level and explains the different industrial classification systems, most importantly the Harmonized System (HS) and the International Standard Industrial Classification (ISIC), as well as the links between different systems and databases. UN ComTrade[1] provides monthly international trade data for products grouped under different sectoral levels, specified by the number of digits in the HS code. International trade data is also available from, for instance, EuroStat[2] at a regional level (EU) and FAOStat[3] at an industry level (agri-food). International trade data has been analyzed from a network perspective in various previous studies, using secondary macro data at the country and sector levels. Secondary data may also enrich and provide context for the fundamental primary data that is collected.

Importantly, the international trade databases noted above do not capture connections between different products, i.e., what product is an input to what other products. This is crucial for constructing global value chains and understanding where value is created. Economic input-output tables are used for this purpose as they capture financial flows into and out of different industries within a country. Input-output tables can be extended to a multi-country context, capturing exports and imports between different industries corresponding to different stages in a global value chain. OECD's Inter-Country Input-Output Tables[4] and World Input-Output Database (WIOD)[5] provide such tables. The analysis of global input-output tables has attracted particular interest in the economics literature on production networks (Carvalho and Tahbaz-Salehi, 2019). However, there has been only limited use of input-output tables in the supply chain management literature, mostly restricted to national input-output tables and only in a descriptive way. For instance, Farris (2010) provided visualization of the US input-output tables from the Bureau of Economic Analysis.

Although these secondary data sources are informative at the industry and sector level and allow the activities in different tiers of a supply chain and their locations to be broadly mapped, they do not typically facilitate the identification of specific firms and their connections. One can collect more detailed data by starting with a macro map and searching for major producers of the materials and products in the corresponding countries. For instance, Frederick (2019) identifies the firms involved in different tiers for a specific country (the Costa Rican medical industry). However, it lacks data on interfirm connections. Similarly, van den Brink et al. (2020) map cobalt supply chains using secondary data only, including sector statistics, compiled lists of mining sites, industry reports, and company websites. However, they were not able to identify buyer-supplier relationships.

Similar to primary data collection, such approaches are resource intensive and not guaranteed to discover supply relationships in a systematic way. Wichmann et al. (2020) have made a first step towards automating this manual data extraction process from unstructured text (websites and documents) using Natural Language Processing. However, these methods are still in development and suffer from low recall (percentage of supply relationships truly captured), particularly due to the absence of large, labelled datasets. Furthermore, they potentially suffer from selection bias as not all buyer-supplier relationships are mentioned in public company documents and websites.

Data on buyer-supplier relationships is valuable but hard to collect. Several data providers have developed *curated databases* specifically for supply chains. These include Mergent Online,[6] Compustat Supply Chain Suite,[7] Factset Revere Supply Chain,[8] and Bloomberg SLPC.[9] A fundamental data source for identifying the suppliers of publicly traded US firms are their 8-K, 10-K, and 10-Q filings, which contain the names of major suppliers as the Securities and Exchange Commission (SEC) mandates US companies to report suppliers with expenses that exceed 10% of their revenues. Databases that rely solely on these filings, e.g., Compustat Supply Chain Suite and Mergent Horizon, are biased towards major suppliers and the US economy. Factset Revere Supply Chain and Bloomberg SLPC databases mitigate these biases by providing global coverage and by enriching the data using expert teams' reviews of other data sources, including company documents, presentations to investors, analyst reports, and company press releases. These databases have recently been used in the empirical operations management literature to test the effect of supply network structure on performance and risk (Bellamy et al., 2020; Wang et al., 2021; Zhao et al., 2019). We refer the reader to Demirel (2022) for a more detailed discussion of this literature.

Using *curated supply chain data sets*, one can map industry level supply networks, including connections between firms operating in a selected industry or in a group of related industries. A firm-centric supply network can be generated by snowball sampling, starting with the focal firm, including its first-tier suppliers and buyers, then their suppliers and buyers, and so on. The latter approach has been used for instance by Kito et al. (2014) and Zhao et al. (2019) to capture the extended supply networks of focal firms. However, an important limitation is that it is not possible to disambiguate higher order relations from such databases. What appears as upper-tier suppliers in such databases might not be genuinely so for a focal firm, because there is no information in the aforementioned multi-industry supply network databases on product flows linked through a bill-of-materials structure. Hence, in our hierarchy, they are very useful for supply network mapping but not fully reliable for supply chain mapping. Product level supply chain data is only available in specialized databases, such as Marklines[10] for the automotive sector, but their coverage is mostly limited to the first tier.

In summary, detailed mapping from primary sources requires the involvement of the prime company and the collaboration of their suppliers and customers. Even if it is granted, mapping is frequently a laborious task, which may restrict it to the structural dimension (who is connected to whom). In many cases, obtaining data on the identity of suppliers in the upper tiers may not be possible, in which case one needs to use secondary commercial databases. However, secondary sources may not precisely reveal chains of product flow beyond immediate connections but these might be needed at the supply chain mapping level of the hierarchy. For supply chain mapping, it is advisable for companies to start with secondary data sources for global value chains at the macro level or industry supply networks at the micro level and then to add/remove nodes and links to the best knowledge of the mapper. It

1 https://comtrade.un.org.
2 https://ec.europa.eu/eurostat.
3 https://www.fao.org/faostat.
4 https://www.oecd.org/sti/ind/inter-country-input-output-tables.htm.
5 https://www.rug.nl/ggdc/valuechain/wiod/.

6 www.mergentonline.com.
7 https://wrds-www.wharton.upenn.edu.
8 https://go.factset.com/marketplace/catalog/product/factset-supply-chain-relationships.
9 https://www.bloomberg.com/professional/dataset/global-supply-chain-data/.
10 https://www.marklines.com/.

must be stressed also that supply chains are highly dynamic in nature. Hence, a supply chain map can become outdated, which makes timeliness crucial but difficult to achieve. Emerging digital technologies, such as digital twins, control towers, and blockchain, enable rapid collection, updating, and integration of data that can be used to automate the mapping and the visualization of supply networks in almost real-time, some examples of which we note in Section 4.3.3 below. Methods of network science and system dynamics can be used to analyze and visualize such dynamic networks (Demirel, 2022).

4.3.2. Visualization tools

Once appropriate data have been obtained for a mapping study at any level of the hierarchy, the map needs to be visualized. Some of the desired visual properties of supply chain maps have been discussed in the extant literature (Farris, 2010; Gardner and Cooper, 2003). Farris (2010) illustrates the decoration of graphs by changing the sizes of nodes and the widths of edges reflecting their attributes, using different node symbols for different types of entities. Nuss et al. (2016) and van den Brink et al. (2020) provide examples of visualization to identify risky suppliers in supply networks. Although standardization of icons has been recommended (Farris, 2010; Gardner and Cooper, 2003), this has not been pursued in the literature, particularly for strategic mapping. Discussing the principles of visualization is beyond the scope of this paper, but it is worth mentioning the seminal work of Edward Tufte (1983). Data should be represented faithfully and effectively, directly focusing on the key features evidenced by the data and not adding "chartjunk".

Several software tools can be used for visualization, the choice of which depends on the technical skills, software familiarity of the analyst, and the purpose of the study. At the lower levels of the hierarchy, there are fewer objects in the map, but the types of the elements are more varied due to the higher granularity of the data. Especially for VSM, icons have been standardised and diagramming software such as Microsoft Visio can be used. For supply network mapping, there may be many more entries represented in a map, which presents visualization challenges. One strategy is to highlight important nodes (setting the node size proportional to firm size, market share, or network centrality), important links (using wider edges for higher transaction value), and meso-scale network structures, such as network communities (nodes colored with respect to community membership). There are various network analysis tools, ranging from packages in more general programming languages such as R and Python (iGraph and NetworkX packages) to specialized software with user interface, such as Gephi, Pajek, and Ucinet (see Demirel (2022) for a review).

4.3.3. Commercial supply chain mapping solutions

Several commercial solutions for supply chain mapping and end-to-end traceability have emerged over the past decade, which combine the data sources and methods outlined above with additional proprietary and public data and information systems. Several vendors provide IT solutions and consultancy services to address the contemporary focus on supply chain visibility, traceability, agility, resilience, and sustainability. This is a rapidly developing area (The Economist, 2022c) facilitated by digital technologies to rapidly collect and update data for supply chain maps in an automated manner. We note some illustrative examples only. We do not aim to be exhaustive or to assess the capabilities of individual solutions.

Some supply chain supplier procurement platforms include a supply chain mapping process for end-to-end visibility. Examples of such software vendors include Sourcemap,[11] Achilles,[12] and Resilinc.[13] Enabled by mapping and traceability, they present compliance solutions for regulations on transparency, such as California Supply Chain Transparency Act, UK Modern Slavery Act, Conflict Minerals Reporting (CMRT), and German Supply Chain Due Diligence Act. RiskMethods[14] focuses on supply chain mapping for risk and disruption monitoring in extended networks, using a similar approach.

Several general-purpose enterprise supply chain planning solutions, such as Blue Yonder,[15] SupplyOn,[16] Elementum,[17] Coupa,[18] and E2open,[19] provide supplier visibility and integration solutions by linking the focal firm's planning systems to suppliers' production and performance data. We refer the interested reader to Gardner's Magic Quadrant for Supply Chain Planning Solutions 2021 report for an account and assessment of alternative solution providers in this domain. Typically, the mapping process starts with sending invitations and questionnaires to first tier suppliers to onboard them to the platform. The upper tiers are mapped by cascading the onboarding invitation process up to the raw material level. However, this requires the prime entity to have the power to ensure that its direct and indirect suppliers join the platform. Structural visibility is further supported by data on product flows, which is a key element of supply chain maps, and supplier risk assessments, using third-party financial, geopolitical, meteorological, and slavery risk databases. In the apparel industry, with an emphasis on transparency and collaboration, the Open Apparel Registry[20] initiative seeks to standardize and share data on global supply networks at the firm and facility level, contributed by brand owners, suppliers, NGOs, and certification schemes.

Alternative approaches to mapping supply networks have been developed recently by a number of digital technology start-ups that make use of Big Data, particularly logistics data (The Economist, 2022c). Everstream Analytics,[21] formerly DHL Resilience360, and Altana AI[22] seek to map multi-tier supply networks by merging many data sources on trade, product shipments, bills of lading, and company relationships using data science techniques, which for instance captures facility locations and identifies products that are being shipped. Makersite [23] similarly provides multi-tier visibility solutions by merging different sources using Product Lifecycle Management and procurement data. With a similar focus on sustainability, FRDM[24] uses Artificial Intelligence to predict Bill-of-Materials structure for purchased components. Similarly, OpenSC[25] verifies ethical and sustainable supply claims at the source using technologies and tools, including GIS and deep learning, and then traces individual products using other technologies such as RFID, QR codes, and blockchain, which is then shared with stakeholders, including consumers. Blockchain technology is trialed by organizations to track products, e.g. BlocRice[26]. However, such real-time verification, mapping, and tracking requires the collaboration of different parties and incurs a cost, which may be non-trivial to establish. Furthermore, it typically first requires supply network mapping to be able to identify and include different actors in the supply chain. As an alternative, VersedAI[27] uses and analyses public text data to extract buyer-supplier relationships using Natural Language Processing techniques. However, there are methodological challenges of low recall and high selection bias in such approaches, which are not easy to address.

[11] https://sourcemap.com/.
[12] https://www.achilles.com/.
[13] https://www.resilinc.com/.
[14] https://www.riskmethods.net/.
[15] https://blueyonder.com/.
[16] https://www.supplyon.com/.
[17] https://www.elementum.com/.
[18] https://www.coupa.com/.
[19] https://www.e2open.com/.
[20] https://info.openapparel.org.
[21] https://www.everstream.ai/.
[22] https://www.altana.ai/.
[23] https://makersite.io/.
[24] https://www.frdm.co/.
[25] https://opensc.org/.
[26] https://cambodia.oxfam.org/BlocRice.
[27] https://www.versed.ai/.

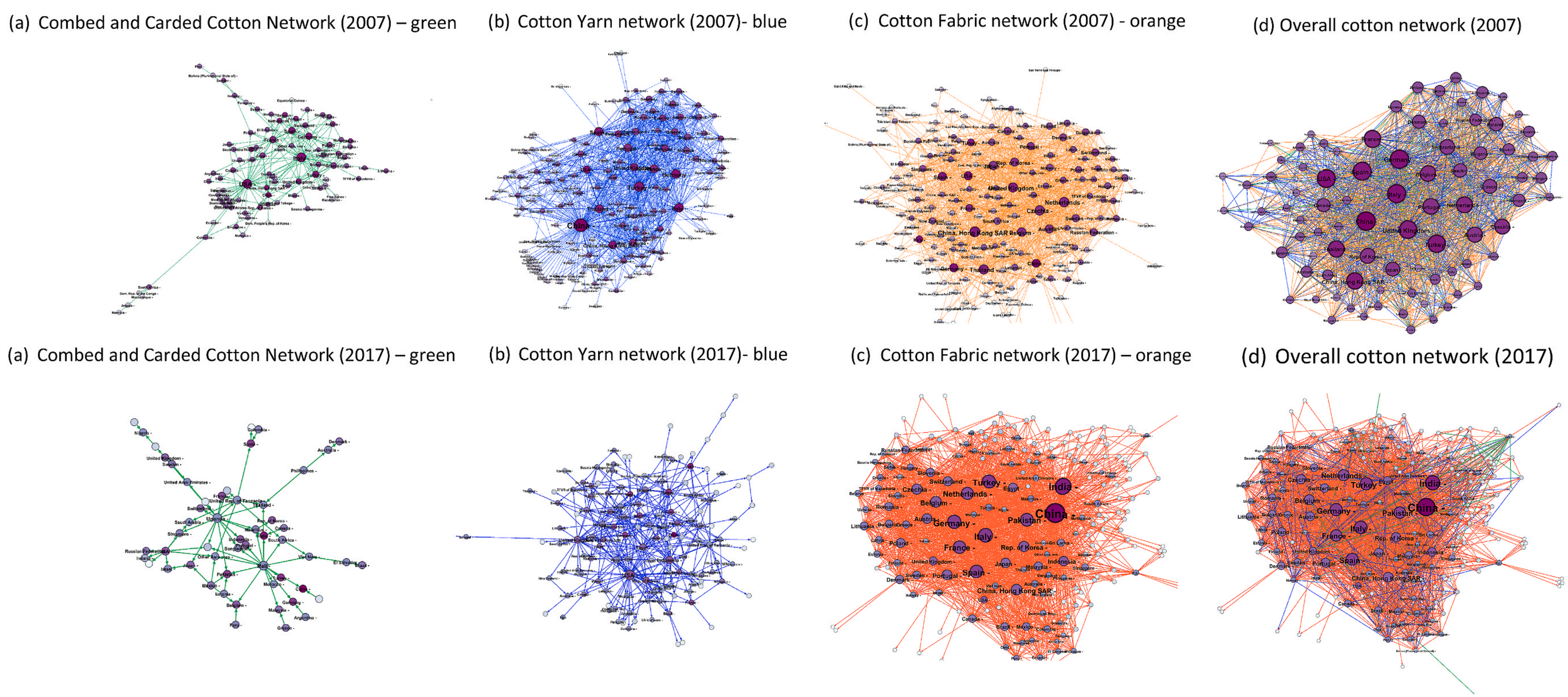

Fig. 4. Cotton global value chain maps.

Table 1
Network metrics- Degree and Betweenness Centrality for cotton GVC.

2007			2017		
Country	Degree	Betweenness Centrality	Country	Degree	Betweenness Centrality
China	200	1816	China	228	3683
USA	154	1397	India	189	1452
Italy	158	890	USA	108	1354
Spain	149	846	Germany	154	1270
China, Hong Kong SAR	147	780	Turkey	161	1168
France	127	745	Italy	158	1000
Germany	155	734	Spain	151	960
Turkey	146	632	United Kingdom	98	673
Thailand	139	496	Egypt	99	633
Colombia	42	427	Russian Federation	67	598
United Kingdom	139	415	Rep. of Korea	114	580
Average Degree	14.15		15.59		
Avg. Betweenness Centrality	65.8		116.7		
Network Density	0.072		0.078		

As evident from many technology companies offering supply chain mapping and visibility solutions, there is a growing market and a plethora of different approaches and data sources used. It remains to be evaluated how accurate the constructed networks are, how they compare with each other and also with maps generated from the secondary supply chain datasets summarized in Section 4.3.1.

5. Illustrating the hierarchy: map exemplars

The hierarchical mapping scheme presented in Section 4.2 can be used to map a supply system in any industrial sector at different levels of granularity or at a specific level to suit the context of the mapping study. Here, we use the global textile and apparel industry to illustrate its application at each hierarchical level. The textile and apparel industry provides a valuable context to illustrate the scheme for a number of reasons. The sector has highly fragmented and dispersed global supply networks (Fernandez-Stark et al., 2011b; Gereffi and Frederick, 2010), presenting significant mapping challenges to capture them accurately. It is one of the most dynamic industries in terms of location (Ahmed and MacCarthy, 2021; Gereffi and Frederick, 2010; MacCarthy and Jayarathne, 2013) with changes in the configuration of supply networks over time. There are also significant sustainability concerns related to raw materials sourcing and apparel production processes (MacCarthy and Jayarathne, 2012; UNECE, 2021), requiring organizations involved in the supply of these products to map their extended supply chains.

5.1. Global value chain map

The GVC of the apparel industry consists of five major segments - raw materials supply, textile companies, garment producing factories, export channels and trade intermediaries, and marketing networks (Fernandez-Stark et al., 2011b). The apparel GVC is known to have dispersed manufacturing with frequent changes in the locations of the most significant apparel end markets (Gereffi and Frederick, 2010). The apparel GVC is buyer-driven, with major buyers, retailers and brand owners, controlling product design, sales, research, and marketing but outsourcing the labor-intensive garment making operations. The global dispersion of these activities has been influenced by the market proximity and the competitiveness of the producing countries, including labor skills, costs, and productivity (Fernandez-Stark et al., 2011b).

To provide an example of the GVC mapping process in this sector, we investigated the trade flows of cotton across the upstream value-adding activities over a ten-year period. Cotton is a critically important textile fiber. Its production includes combed and carded cotton (raw cotton after removing the seeds), cotton spinning (cotton yarn), and weaving (cotton fabric) processes. We extracted data from the UN Comtrade database for 2007 and 2017 (see Appendix - Tables 2 and 3appsec1) and developed illustrative GVC maps using Gephi software (Fig. 4). The nodes represent participating countries on the map, while the edges show the trade flows. Table 1 shows the top countries in the global cotton industry by network metrics (degree and betweenness centrality). The degree centrality is the total number of links (imports and exports) of a particular node, while the betweenness centrality measures the importance of a node in terms of the number of shortest paths between all other node pairs that go through it (Demirel, 2022; Kim et al., 2011). Decreasing network density (fraction of the number of existing links to the maximum) shows reduced global trade flows of combed cotton and yarn from 2007 to 2017, while the number of cotton fabric trade flows have increased over the same period. This may indicate that apparel producing countries (e.g., China, India, Italy, and Belgium) have begun investing more in upstream value-adding activities, including spinning and weaving, and exporting cotton fabrics.

Moreover, there is a change in the positions of some major countries in the global cotton value chain. The United States experienced a significant drop in their combed cotton trade volume, from 48,821 tons in 2007 to 10,237 tons in 2017, while some developing countries took the lead in combed cotton trade (i.e., Mali, Uganda, United Rep. of Tanzania). However, the activities of these developing countries are still limited to exporting unprocessed raw cotton. The key players in the cotton GVC are identified by analyzing their betweenness centrality. China has a strong position in the cotton network, connecting all other actors, while India has become more central over time. Countries like the USA, Turkey, Germany, Italy, and Spain have been well established in the cotton supply network. In general, the global cotton value chain has become more centralized, with fewer critical players in the combed cotton and yarn trade and more in the fabric trade.

There are limitations in using aggregate trade data. It does not include information about countries' domestic production and consumption at the product level. The imports and exports are reported differently, resulting in a mismatch between the reported quantities for the same trade between two countries. There may also be missing data, especially for smaller countries. Nevertheless, when the data is available, it can provide a rich source of information to capture the dynamics of GVCs over time.

5.2. Supply network map

We provide an example of the Hennes & Mauritz (H&M)[28] supply network using secondary data sources. H&M is a top Swedish multinational fashion retailer with a well-established supply network. The company is committed to sustainability and publishes information about its suppliers' names, locations, products, and processes. The company's annual reports provide information about its markets and geographical

[28] https://www2.hm.com/en_gb/index.html.

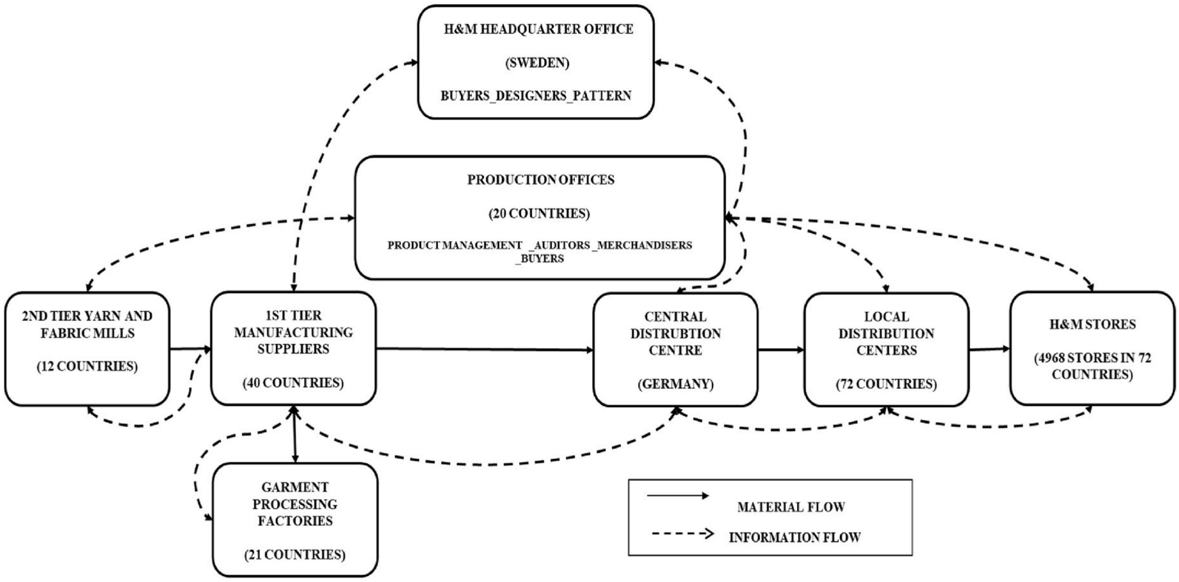

Fig. 5. H&M overall supply network map.

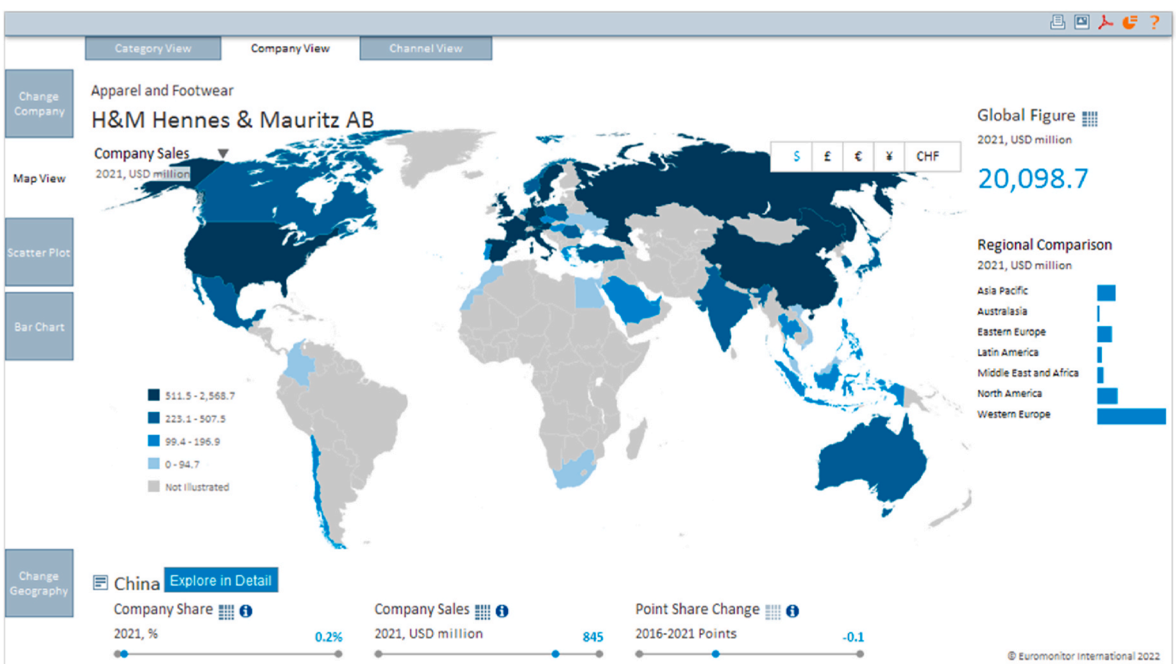

Fig. 6. H&M market geographical map. Source: Euromonitor (2022).

distribution, which constitute rich data for mapping its supply network.

The sustainability website of H&M (H&M Suppliers List, 2019) includes information about the company's first tier manufacturing suppliers (around 850 independent suppliers with over 2500 factories worldwide) and yarn and fabric mills responsible for 65% of its production. In addition, H&M's career website (hm.career, 2019) provides information about the location of the production offices that the company has established in 20 countries to manage and control product development, supplier auditing, procurement, and other supply chain activities.

Various online data sources were researched to find information about H&M distribution centers and markets to map the company's downstream supply network. According to the Bremer construction company website (Bremer, 2019), H&M has a large distribution center in Hamburg, Germany. H&M products are transported to a centralized warehouse in Hamburg and then shipped to regional warehouses in the company's main markets. For market information, H&M's annual reports show the number of opened/closed stores per country, revenue per market, and the number of employees. All this information enabled the development of the overall H&M supply network map presented in Fig. 5.

The supply network of H&M consists of (1) manufacturing suppliers who own manufacturing facilities known as "cut and sew" factories located in 40 countries, mainly in Asia and Europe, (2) processing factories that the manufacturing suppliers subcontract to perform certain activities (indicated by bi-directional links), and (3) second tier suppliers (yarn and fabric mills) (H&M Suppliers List, 2019). This provides a macro-view and we can also visualize the specific supply network at

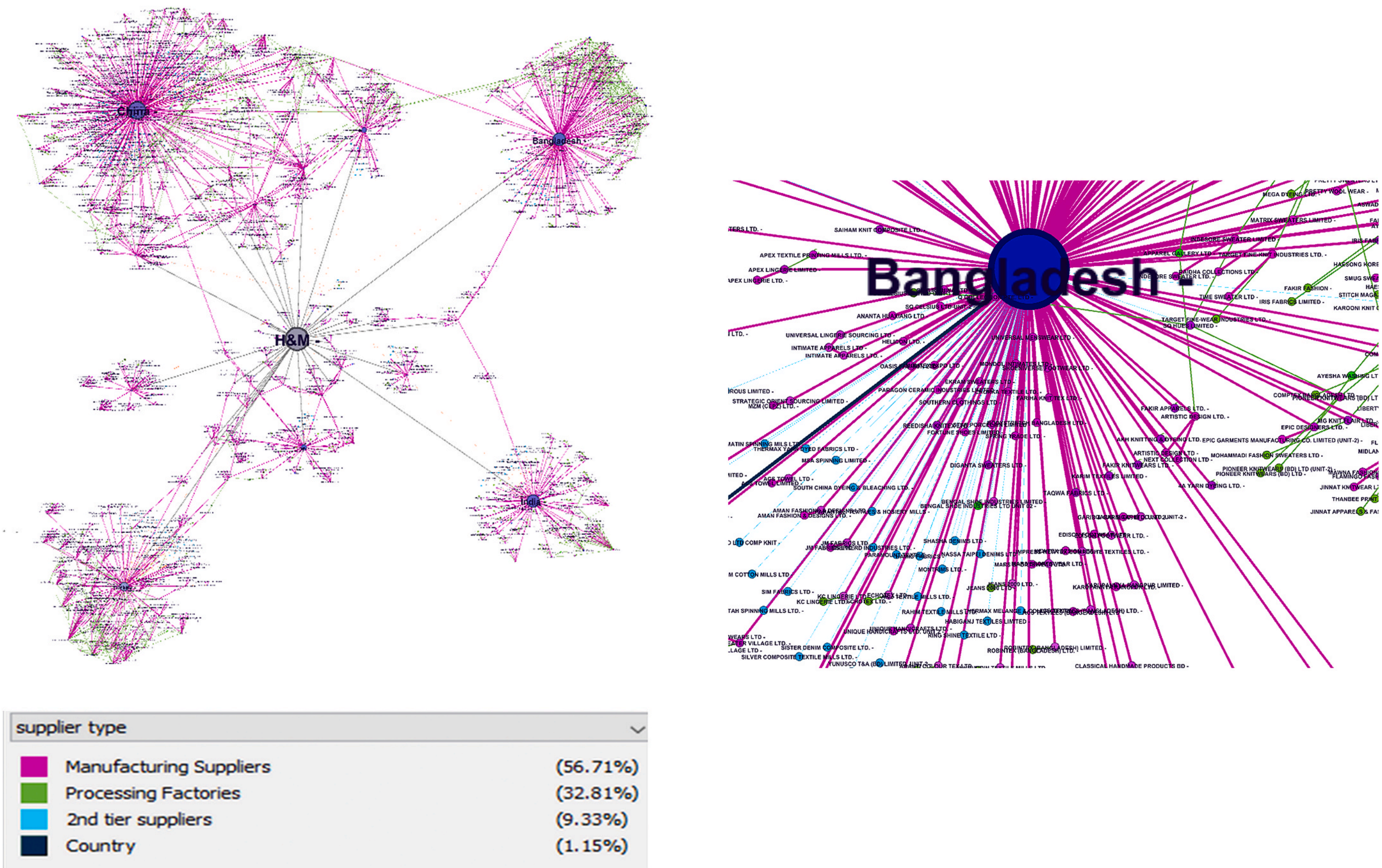

Fig. 7. H&M supply network map. Data source: H&M Suppliers List (2019).

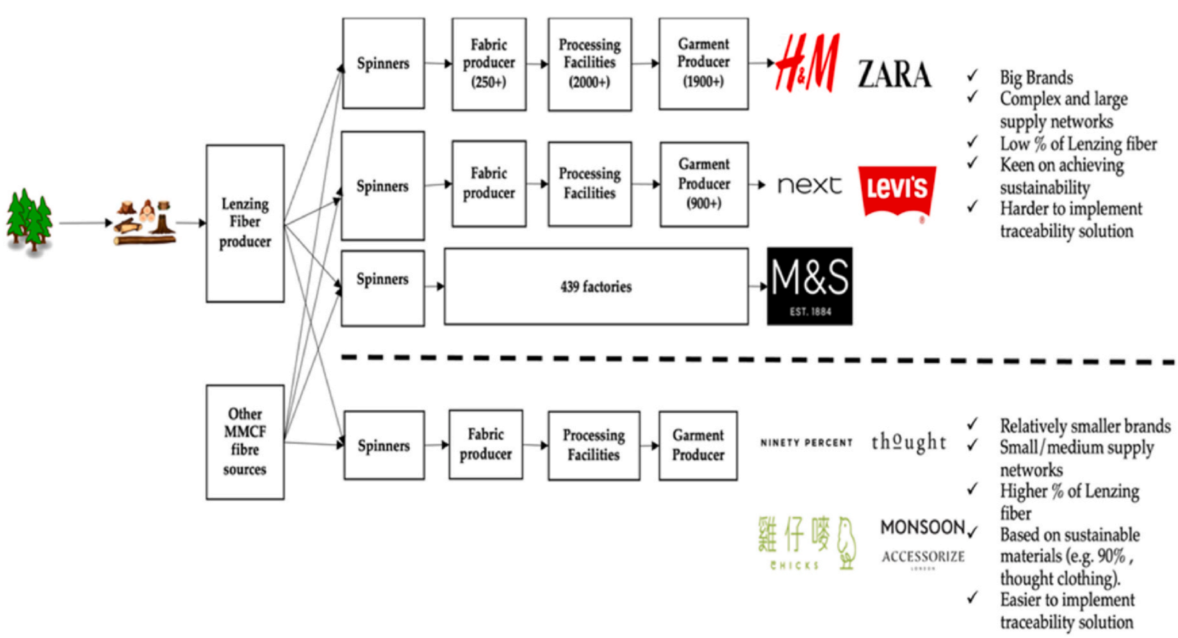

Fig. 8. Lenzing downstream supply network map. Source: Ahmed and MacCarthy (2021).

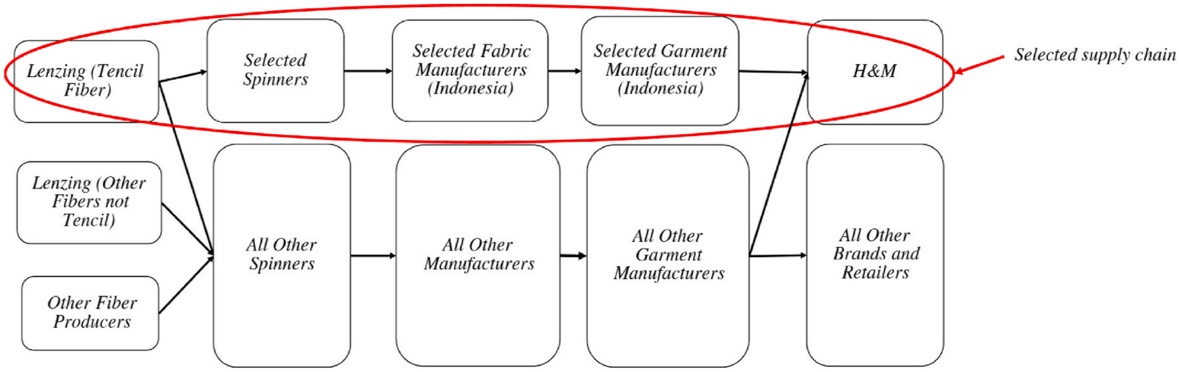

Fig. 9. Lenzing and H&M Indonesian Supply chain as a subset of their global supply networks.

the firm level, which is shown in Fig. 6, also zooming into the sub-network in a specific country (Bangladesh).

H&M's downstream supply network is global. The International Euromonitor database provides geographical maps and market data for specific industries, including some of the major firms. Fig. 7 shows the geographical map of H&M sales in 2021 (Euromonitor, 2022). The company's biggest markets are Western Europe, China, Russia and North America. This example shows that mapping exercises require detailed scrutiny of multiple secondary data sources to capture and verify as much as posible a network at any point in time.

5.3. Supply chain map

As noted in Section 4.2.3, a supply chain map zooms into a subset of a broader supply network and focuses on specific material flows and supply chain participants. As an exemplar of a supply chain map, we refer to Ahmed and MacCarthy (2021) who conducted a case study of Lenzing, a major global manmade cellulose fiber producer. The fiber producer was piloting a blockchain-enabled fiber-to-retail traceability solution in several supply chains, including their downstream - Indonesian supply chain for Tencel (lyocell) fibers - and H&M. This supply chain is a subset of Lenzing's complex downstream textile supply network (Fig. 8) and H&M's complex upstream supply network (Fig. 5). Fig. 9 illustrates the selected supply chain as a subset of the broader supply networks to which it belongs.

Lenzing is one of the many fiber producers in H&M's global upstream supply network. Similarly, Lenzing provides different types of fibers, e.g., Lyocell, Modal and Viscose, to its global downstream textile supply networks, including many brands and retailers in addition to H&M. Different types of data are captured in the developed traceability solution, including location information of the different entities, the fiber percentage used, the amount of waste, and the inventory levels at each supply chain stage (Ahmed and MacCarthy, 2021). To obtain such level of information and enable the adoption of the traceability solution by the right parties, detailed supply chain mapping of Tencel fiber flow in the downstream supply chain is crucial. Supply chain mapping in this case can help develop the necessary understanding of the material flows of Lenzing's fiber, identify the parties involved along with their operational activities and use of fiber, and determine appropriate data capture points and traceability requirements at each supply chain stage.

5.4. Value stream maps

Many researchers have used VSM to study apparel manufacturing processes (Kays et al., 2019; Kumar, 2016; Phuong and Guidat, 2018). Phuong and Guidat (2018) used VSM to map apparel production processes within a company to identify areas for improving the sustainability of these processes using RFID and ergonomics. Kays et al. (2019) used VSM to tackle operational inefficiencies in the ready-made garment sector in Bangladesh.

As an example of VSM in the apparel sector, we consider Kumar (2016), who focused on a production line for single fabric men's jersey trousers. Fig. 10 shows the current state VSM with the material and information flows from when the customer places an order to when the product leaves the cutting section and enters the production line. Information related to the machine type, cycle time, and inventory level are captured at each station the product visits. The authors used the current state map to identify opportunities for waste reduction, considering a cellular layout, single piece flow, and Kaizen principles (Kumar, 2016) and developed a future state map accordingly.

5.5. Process mapping

Process mapping can provide high level information about the workflow of operational processes. A good example in the apparel supply chain context is the work by Thakur et al. (2020), who developed a traceability framework for animal hides in their supply chains. Hides are by-products of meat production and provide the raw material for leather. The study developed a high level process map for hides in the abattoir and tanning processes (Fig. 11). In this example, process mapping is crucial for identifying the right data capture points and the requirements for effective supply chain traceability systems using different identification technologies.

6. Conclusions

Building on the early seminal work of Gardner and Cooper (2003), this paper has taken a contemporary perspective on the mapping of supply systems, highlighting the strong motivations to achieve more accurate supply chain knowledge in the post-pandemic world. Mapping combines elements of art and science but the emphasis should always be on seeking accuracy and clarity to support supply chain management. We have noted the diversity of mapping studies conducted to date in the literature and defined a hierarchy to provide a comprehensive and structured approach for both researchers and practitioners to position mapping studies with respect to their focus and scope. The introduced hierarchy can be used by practitioners to identify the level at which mapping should be conducted and with what type of data, or it can be used to guide a multi-stage mapping process, starting from upper strategic levels and moving down to operational/tactical levels. We highlighted the significant challenges and resource implications in constructing maps using primary data collected 'from the ground up' and noted the potential for greater use of secondary data sources for supply chain mapping exercises.

Notwithstanding the many challenges, we live in an increasingly data rich world with new software tools emerging that have the potential for rapid analysis, visualization and automation of aspects of the mapping process. They will not be a panacea but these exciting

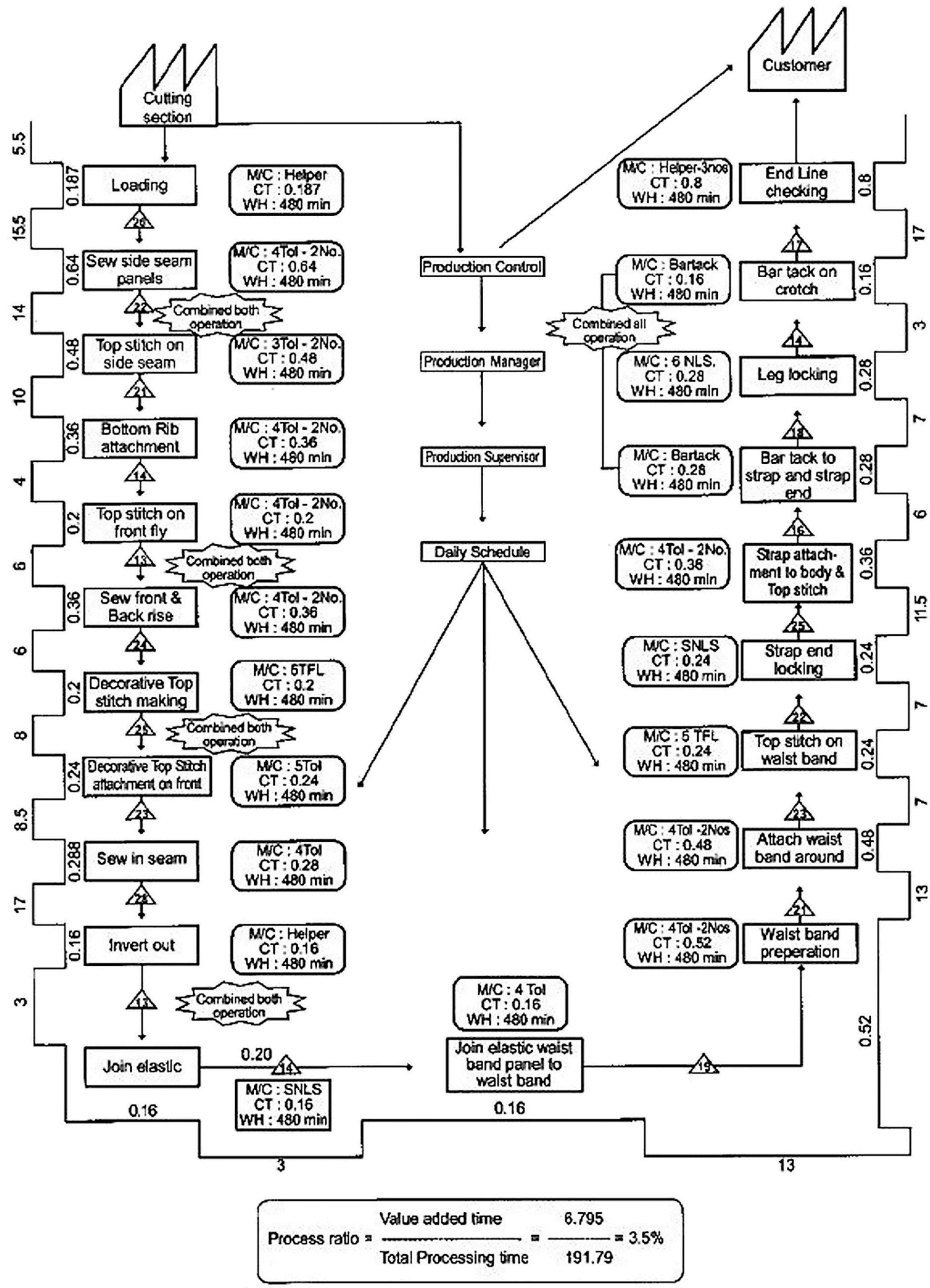

Fig. 10. VSM current state map for an apparel production line. Source: Kumar (2016).

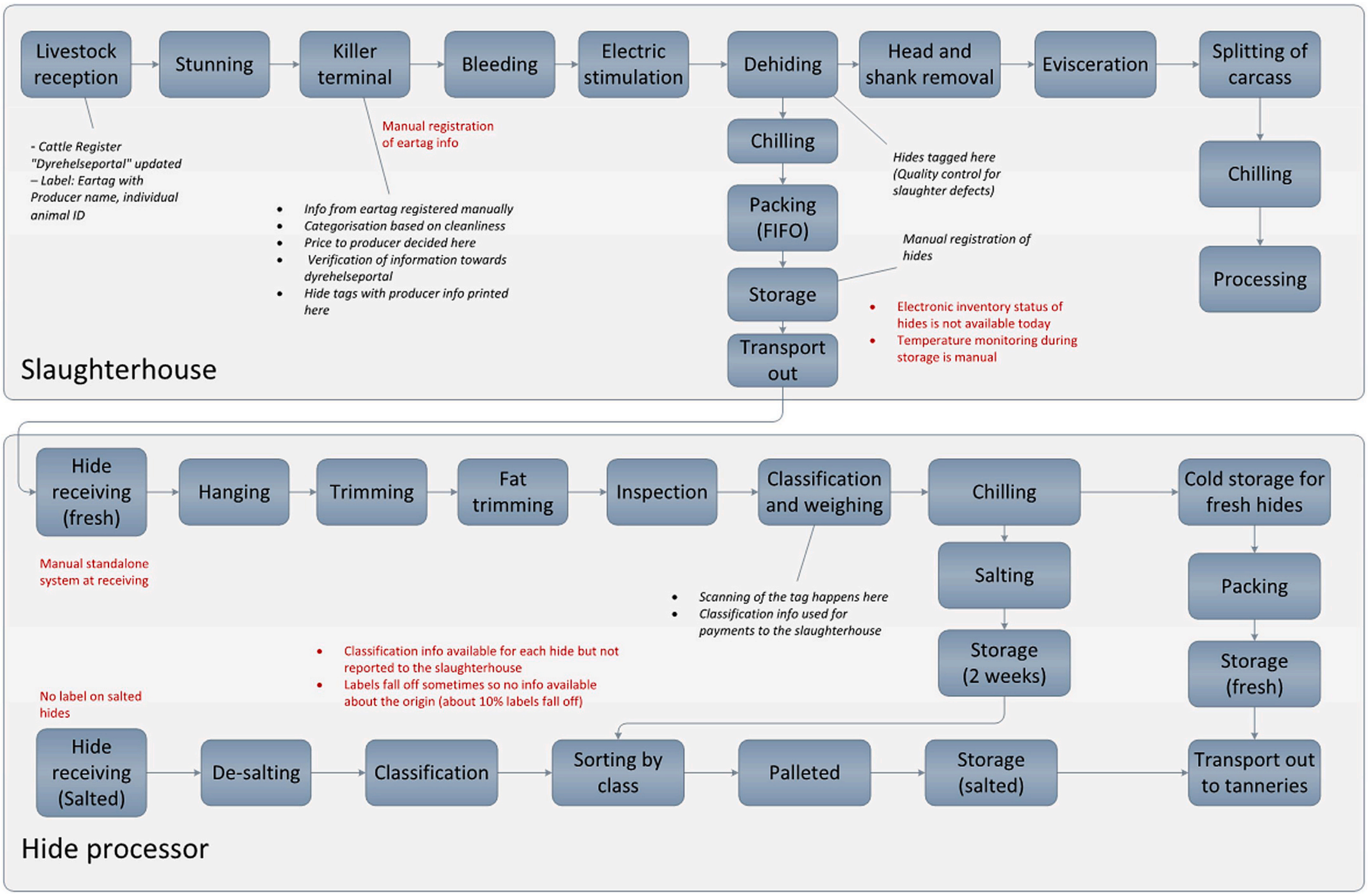

Fig. 11. Hide process map in the slaughtering and tanning stages. Source: Thakur et al. (2020).

developments hold promise for the research community. Potential future lines of enquiry are manifold. We highlight three. First is the development of maps to focus on the stability of supply systems and their vulnerabilities that can be used in mathematical network analysis (Demirel et al., 2019). Second is the integration of supply chain mapping with GIS, which is a strongly burgeoning science with principles and practices that may enrich supply chain mapping (Bearman, 2020). Third is the use of mapping to support digital transformation of supply systems, particularly incorporating emerging digital technologies (Ivanov, 2021).

Data availability

Data will be made available on request.

Appendix 1

Table 2
Cotton Export Data in 2007. Data Source: UN Comtrade (2022).

2007							
Combed or Carded Cotton		Cotton Yarn		Cotton Fabric		Overall	
Top 10 Countries	Export Volume Tons	Top 10 Countries	Export Volume Tons	Top 10 Countries	Export Volume Tons	Top 10 Countries	Export Volume Tons
USA	48,821	China, Hong Kong SAR	1,924,242	China, Hong Kong SAR	500,941	China, Hong Kong SAR	3,427,589
Turkey	8846	China	1,754,009	Turkey	124,808	China	1,754,280
Italy	3704	USA	1,081,534	USA	120,213	USA	1,588,634
Spain	2502	Turkey	346,231	Germany	86,648	Turkey	747,192
Greece	2380	Italy	204,394	Dominican Rep.	79,711	Germany	380,200
Singapore	2229	Thailand	178,218	Thailand	65,028	Thailand	373,658
France	1162	Spain	164,898	Japan	63,645	Rep. of Korea	268,643
Canada	1111	Germany	119,821	Rep. of Korea	58,462	Dominican Rep.	239,308
Colombia	462	Rep. of Korea	92,249	Russian Federation	28,022	Italy	215,507
Japan	369	Belgium	91,800	Czechia	22,078	Japan	207,071

Table 3
Cotton Export Data in 2017. Data Source: UN Comtrade (2022).

2017							
Combed or Carded Cotton		Cotton Yarn		Cotton Fabric		Overall	
Top 10 Countries	Export Volume Tons	Top 10 Countries	Export Volume Tons	Top 10 Countries	Export Volume Tons	Top 10 Countries	Export Volume Tons
Mali	90,887	India	1,120,104	China	1,894,152	China	2,287,995
Uganda	26,286	Pakistan	483,871	Slovenia	144,116	India	1,243,448
United Rep. of Tanzania	12,796	USA	454,658	India	120,888	Pakistan	484,021
USA	10,237	China	393,761	Turkey	115,765	USA	464,895
Rep. of Korea	8359	Indonesia	208,014	China, Hong Kong SAR	107,714	Turkey	282,061
Turkey	7785	China, Hong Kong SAR	171,993	Germany	61,820	China, Hong Kong SAR	279,772
Indonesia	5221	Turkey	158,511	Italy	61,779	Slovenia	276,449
Netherlands	3330	Slovenia	132,325	Spain	45,333	Indonesia	236,380
India	2456	Rep. of Korea	55,552	Belgium	31,972	Italy	91,466
Mexico	1573	Malaysia	45,570	Japan	27,489	Mali	91,229

References

Accenture, 2021. Technology Vision 2021 [WWW Document]. https://www.accenture.com/us-en/insights/technology/_acnmedia/Thought-Leadership-Assets/PDF-3/Accenture-Tech-Vision-2021-Full-Report.pdf. accessed 7.31.22.

Adewuyi, A., Babatunde, M., Bankole, A., 2014. A global value chain analysis of Cocoa and garment in Nigeria. J. Sustain. Dev. Afr. 16, 1–20.

Ahmed, W.A., MacCarthy, B.L., 2021. Blockchain-enabled supply chain traceability in the textile and apparel supply chain: a case study of the fiber producer, lenzing. Sustainability 13, 10496.

Ahmed, W.A.H., MacCarthy, B.L., 2022. Blockchain technology in the supply chain: learning from emerging ecosystems and industry consortia. In: Bauman, S. (Ed.), Handbook of Digital Business Ecosystems: Strategies, Platforms, Technologies, Governance and Societal Challenges. Edward Elgar Publishing, p. 800.

Ahmed, W.A.H., Rios, A., 2022. Digitalization of the International shipping and maritime logistics: a case study of TradeLens. In: MacCarthy, B.L., Ivanov, D. (Eds.), The Digital Supply Chain. Elsevier, pp. 309–323.

Alves, L.G.A., Mangioni, G., Rodrigues, F.A., Panzarasa, P., Moreno, Y., 2022. The rise and fall of countries in the global value chains. Sci. Rep. 12, 9086. https://doi.org/10.1038/s41598-022-12067-x.

Anastasiadis, F., Apostolidou, I., Michailidis, A., 2020. Mapping sustainable tomato supply chain in Greece: a framework for research. Foods 9, 539. https://doi.org/10.3390/foods9050539.

Aung, M.M., Chang, Y.S., 2014. Traceability in a food supply chain: safety and quality perspectives. Food Control 39, 172–184. https://doi.org/10.1016/j.foodcont.2013.11.007.

Bearman, N., 2020. GIS: Research Methods. Bloomsbury Publishing.

Bellamy, M.A., Dhanorkar, S., Subramanian, R., 2020. Administrative environmental innovations, supply network structure, and environmental disclosure. J. Oper. Manag. 66, 895–932. https://doi.org/10.1002/joom.1114.

Birkel, H.S., Hartmann, E., 2019. Impact of IoT challenges and risks for SCM. Supply Chain Manag.: Int. J. 24, 39–61. https://doi.org/10.1108/SCM-03-2018-0142.

Bremer, 2019. H&M Distribution Centre Hamburg [WWW Document]. https://www.bremerbau.com/en/references/logistics-buildings/hm-distribution-centre-hamburg.html. https://www.bremerbau.com/en/references/logistics-buildings/hm-distribution-centre-hamburg.html?call=lightbox%20-%20H&M_distribution_centre=. accessed 7.31.22.

Brintrup, A., Ledwoch, A., Barros, J., 2015. Topological robustness of the global automotive industry. Logist. Res. 9, 1. https://doi.org/10.1007/s12159-015-0128-1.

Brintrup, A., Wang, Y., Tiwari, A., 2017. Supply networks as complex systems: a network-science-based characterization. IEEE Syst. J. 11, 2170–2181. https://doi.org/10.1109/JSYST.2015.2425137.

Brintrup, A., Kosasih, E.E., MacCarthy, B.L., Demirel, G., 2022. Chapter 22 - digital supply chain surveillance: concepts, challenges, and frameworks. In: MacCarthy, B. L., Ivanov, D. (Eds.), The Digital Supply Chain. Elsevier, pp. 379–396. https://doi.org/10.1016/B978-0-323-91614-1.00022-8.

Brunt, D., 2000. From current state to future state: mapping the steel to component supply chain. Int. J. Logist. Res. Appl. 3, 259–271. https://doi.org/10.1080/713682765.

Carvalho, V.M., Tahbaz-Salehi, A., 2019. Production networks: a primer. Ann. Rev. Econ. 11, 635–663. https://doi.org/10.1146/annurev-economics-080218-030212.

Cha, S.Y., 2022. The art of cyber security in the age of the digital supply chain: detecting and defending against vulnerabilities in your supply chain. In: The Digital Supply Chain. Elsevier, pp. 215–233.

Chae, B., Kevin, 2009. Developing key performance indicators for supply chain: an industry perspective. Supply Chain Manag.: Int. J. 14, 422–428. https://doi.org/10.1108/13598540910995192.

Choi, T.-M., 2019. Blockchain-technology-supported platforms for diamond authentication and certification in luxury supply chains. Transport. Res. E Logist. Transport. Rev. 128, 17–29.

Choi, T.Y., Hong, Y., 2002. Unveiling the structure of supply networks: case studies in Honda, Acura, and DaimlerChrysler. J. Oper. Manag. 20, 469–493.

Choi, T.Y., Rogers, D., Vakil, B., 2020. Coronavirus is a wake-up call for supply chain management. Harv. Bus. Rev. 27, 364–398, 2020.

Comtrade, U.N., 2022. UN Comtrade | International Trade Statistics Database [WWW Document]. https://comtrade.un.org/. accessed 7.31.22.

Culot, G., Nassimbeni, G., Orzes, G., Sartor, M., 2020. Behind the definition of Industry 4.0: analysis and open questions. Int. J. Prod. Econ. 226, 107617.

Damelio, R., 2011. The Basics of Process Mapping, second ed. CRC Press.

de Backer, K., Miroudot, S., 2014. Mapping Global Value Chains. https://doi.org/10.2139/ssrn.2436411.

De Marchi, V., Di Maria, E., 2019. Environmental upgrading and suppliers' agency in the leather global value chain. Sustainability 11, 6530.

Demirel, G., 2022. Chapter 20 - network science for the supply chain: theory, methods, and empirical results. In: MacCarthy, B.L., Ivanov, D. (Eds.), The Digital Supply Chain. Elsevier, pp. 343–359. https://doi.org/10.1016/B978-0-323-91614-1.00020-4.

Demirel, G., MacCarthy, B.L., Ritterskamp, D., Champneys, A.R., Gross, T., 2019. Identifying dynamical instabilities in supply networks using generalized modeling. J. Oper. Manag. 65, 136–159.

Donaldson, A., Brice, J., Midgley, J., 2020. Navigating futures: anticipation and food supply chain mapping. Trans. Inst. Br. Geogr. 45, 606–618. https://doi.org/10.1111/tran.12363.

Euromonitor, 2022. Euromonitor [WWW Document]. Euromonitor. https://www.euromonitor.com/. accessed 7.31.22.

Fabbe-Costes, N., Lechaptois, L., Spring, M., 2020. The map is not the territory": a boundary objects perspective on supply chain mapping. Int. J. Oper. Prod. Manag. 40, 1475–1497. https://doi.org/10.1108/IJOPM-12-2019-0828.

Farris, T.M., 2010. Solutions to strategic supply chain mapping issues. Int. J. Phys. Distrib. Logist. Manag. 40, 164–180. https://doi.org/10.1108/09600031011035074.

Fernandez-Stark, K., Bamber, P., Gereffi, G., 2011a. The Fruit and Vegetables Global Value Chain: Economic Upgrading and Workforce Development, Duke Center on Globalization, Governance and Competitveness. Duke Center on Globalization, Governance and Competitveness, Durham, North Caroline, US.

Fernandez-Stark, K., Frederick, S., Gereffi, G., 2011b. The Apparel Global Value Chain. Duke Center on Globalization, Governance & Competitiveness.

Francis, T., Hoefel, F., 2018. 'True Gen': Generation Z and its Implications for Companies. McKinsey & Company.

Frandson, A., Berghede, K., Tommelein, I.D., 2013. Takt time planning for construction of exterior cladding. In: 21st Annual Conference of the International Group for Lean Construction. Fortaleza, Brazil. Citeseer, pp. 21–22.

Fraser, I.J., Mueller, M., Schwarzkopf, J., 2020. Transparency for multi-tier sustainable supply chain management: a case study of a multi-tier transparency approach for SSCM in the automotive industry. Sustainability 12, 1814.

Frederick, S., 2019. Global value chain mapping. In: Handbook on Global Value Chains. Edward Elgar Publishing, Cheltenham, UK, pp. 29–53.

Gardner, J.T., Cooper, M.C., 2003. Strategic supply chain mapping approaches. J. Bus. Logist. 24, 37–64.

Gereffi, G., Fernandez-Stark, K., 2016. Global Value Chain Analysis: A Primer [WWW Document]. https://dukespace.lib.duke.edu/dspace/bitstream/handle/10161/12488/2016-07-28_GVC%20Primer%202016_2nd%20edition.pdf. accessed 7.15.22.

Gereffi, G., Frederick, S., 2010. The Global Apparel Value Chain, Trade and the Crisis: Challenges and Opportunities for Developing Countries (Policy Research Working Paper Series No. 5281). The World Bank.

Ghadge, A., Wurtmann, H., Seuring, S., 2020. Managing climate change risks in global supply chains: a review and research agenda. Int. J. Prod. Res. 58, 44–64.
H&M Suppliers List, 2019. H&M Group Supply Chain. H&M Group. https://hmgroup-prd-app.azurewebsites.net/sustainability/leading-the-change/transparency/supply-chain/. accessed 4.1.19.
Haefner, B., Kraemer, A., Stauss, T., Lanza, G., 2014. Quality value stream mapping. Proc. CIRP 17, 254–259. https://doi.org/10.1016/j.procir.2014.01.093.
Hanai, K., 2021. Conflict minerals regulation and mechanism changes in the DR Congo. Resour. Pol. 74, 102394 https://doi.org/10.1016/j.resourpol.2021.102394.
Handfield, R.B., Graham, G., Burns, L., 2020. Corona virus, tariffs, trade wars and supply chain evolutionary design. Int. J. Oper. Prod. Manag. 40, 1649–1660.
Harland, C., Brenchley, R., Walker, H., 2003. Risk in supply networks. J. Purch. Supply Manag. 9, 51–62.
Hernández, V., Pedersen, T., 2017. Global value chain configuration: a review and research agenda. BRQ Bus. Res. Quarter. 20, 137–150. https://doi.org/10.1016/j.brq.2016.11.001.
Hines, P., Rich, N., 1997. The seven value stream mapping tools. Int. J. Oper. Prod. Manag. 17, 46–64. https://doi.org/10.1108/01443579710157989.
Hines, P., Rich, N., Esain, A., 1999. Value stream mapping: a distribution industry application. Benchmark Int. J. 6, 60–77. https://doi.org/10.1108/14635779910258157.
hmcareer, 2019. Explore Careers in Fashion at H&M | H&M Careers Myanmar [WWW Document]. https://career.hm.com/mm-en/. accessed 4.10.19.
Ho, W., Zheng, T., Yildiz, H., Talluri, S., 2015. Supply chain risk management: a literature review. Int. J. Prod. Res. 53, 5031–5069.
Huan, S.H., Sheoran, S.K., Wang, G., 2004. A review and analysis of supply chain operations reference (SCOR) model. Supply Chain Manag.: Int. J. 9, 23–29. https://doi.org/10.1108/13598540410517557.
Hunt, V.D., 1996. Process Mapping: How to Reengineer Your Business Processes. John Wiley & Sons.
Hutton, G., Powell, A., 2021. UK Supply Chain Problems [WWW Document]. House of commons Research Briefing. https://researchbriefings.files.parliament.uk/documents/CBP-9350/CBP-9350.pdf. accessed 7.31.22.
Ioannou, I., Demirel, G., 2022. Blockchain and supply chain finance: a critical literature review at the intersection of operations, finance and law. J. Bank. Financ. Technol. 1–25.
Ivanov, D., 2021. Digital supply chain management and technology to enhance resilience by building and using end-to-end visibility during the COVID-19 pandemic. IEEE Trans. Eng. Manag. 1–11. https://doi.org/10.1109/TEM.2021.3095193.
Ivanov, D., Dolgui, A., 2020. A digital supply chain twin for managing the disruption risks and resilience in the era of Industry 4.0. Prod. Plann. Control 1–14.
Jüttner, U., Maklan, S., 2011. Supply chain resilience in the global financial crisis: an empirical study. Supply Chain Manag.: Int. J. 16, 246–259.
Kays, H.M., Prodhan, S., Karia, N., Karim, A., Sharif, S., 2019. Improvement of operational performance through value stream mapping and yamazumi chart: a case of Bangladeshi rmg industry. Int. J. Recent Technol. Eng. 8, 11977–11986. https://doi.org/10.35940/ijrte.D9926.118419.
Kim, Y., Choi, T.Y., Yan, T., Dooley, K., 2011. Structural investigation of supply networks: a social network analysis approach. J. Oper. Manag. 29, 194–211. https://doi.org/10.1016/j.jom.2010.11.001.
Kito, T., Brintrup, A., New, S., Reed-Tsochas, F., 2014. The Structure of the Toyota Supply Network: an Empirical Analysis. https://doi.org/10.2139/ssrn.2412512.
Klotz, L., Horman, M., Bi, H.H., Bechtel, J., 2008. The impact of process mapping on transparency. Int. J. Prod. Perform. Manag. 57, 623–636. https://doi.org/10.1108/17410400810916053.
Kosmol, T., Reimann, F., Kaufmann, L., 2019. You'll never walk alone: Why we need a supply chain practice view on digital procurement. J. Purch. Supply Manag. 25, 100553.
Kumar, S., 2016. Value stream mapping-A lean manufacturing approach to reduce the process. Wastages Cloth. Ind. 5, 1–15.
Kusiak, A., 2018. Smart manufacturing. Int. J. Prod. Res. 56, 508–517.
Lambert, D.M., Cooper, M.C., Pagh, J.D., 1998. Supply chain management: implementation issues and research opportunities. Int. J. Logist. Manag. 9, 1–20. https://doi.org/10.1108/09574099810805807.
Lee, Q., Snyder, B., 2007. The Strategos Guide to Value Stream & Process Mapping. Enna Products Corporation, USA.
Lee, H.L., Tang, C.S., 2018. Socially and environmentally responsible value chain innovations: new operations management research opportunities. Manag. Sci. 64, 983–996.
Lomi, A., Pattison, P., 2006. Manufacturing relations: an empirical study of the organization of production across multiple networks. Organ. Sci. 17, 313–332. https://doi.org/10.1287/orsc.1060.0190.
MacCarthy, B.L., Ivanov, D., 2022. The Digital Supply Chain—emergence, concepts, definitions, and technologies. In: The Digital Supply Chain. Elsevier, pp. 3–24.
MacCarthy, B.L., Jayarathne, P., 2012. Sustainable collaborative supply networks in the international clothing industry: a comparative analysis of two retailers. Prod. Plann. Control 23, 252–268.
MacCarthy, B.L., Jayarathne, P., 2013. Supply network structures in the international clothing industry: differences across retailer types. Int. J. Oper. Prod. Manag. 33, 858–886.
MacCarthy, B.L., Blome, C., Olhager, J., Srai, J.S., Zhao, X., 2016. Supply chain evolution–theory, concepts and science. Int. J. Oper. Prod. Manag. 36, 1696–1718. https://doi.org/10.1108/IJOPM-02-2016-0080.
Mao, H., Görg, H., 2020. Friends like this: the impact of the US–China trade war on global value chains. World Econ. 43, 1776–1791. https://doi.org/10.1111/twec.12967.
Miyake, D.I., Junior, A.S.T., Favaro, C., 2010. Supply chain mapping initiatives in the Brazilian automotive industry: challenges and opportunities. J. Oper. Suppl. Chain Manag. 3, 78–97. https://doi.org/10.12660/joscmv3n1p78-97.
Mubarik, M.S., Kusi-Sarpong, S., Govindan, K., Khan, S.A., Oyedijo, A., 2021a. Supply chain mapping: a proposed construct. Int. J. Prod. Res. 1–17. https://doi.org/10.1080/00207543.2021.1944390, 0.
Mubarik, M.S., Naghavi, N., Mubarik, M., Kusi-Sarpong, S., Khan, S.A., Zaman, S.I., Kazmi, S.H.A., 2021b. Resilience and cleaner production in industry 4.0: role of supply chain mapping and visibility. J. Clean. Prod. 292, 126058 https://doi.org/10.1016/j.jclepro.2021.126058.
Nuss, P., Graedel, T.E., Alonso, E., Carroll, A., 2016. Mapping supply chain risk by network analysis of product platforms. Sustain. Mater. Technol. 10, 14–22. https://doi.org/10.1016/j.susmat.2016.10.002.
Oxford Learner Dictionary, 2022. map_1 Noun - Definition, Pictures, Pronunciation and Usage Notes | Oxford Advanced Learner's Dictionary. OxfordLearnersDictionaries.com [WWW Document]. https://www.oxfordlearnersdictionaries.com/definition/english/map_1?q=map. accessed 7.31.22.
Pathak, S.D., Day, J.M., Nair, A., Sawaya, W.J., Kristal, M.M., 2007. Complexity and adaptivity in supply networks: building supply network theory using a complex adaptive systems perspective. Decis. Sci. J. 38, 547–580. https://doi.org/10.1111/j.1540-5915.2007.00170.x.
Peng, S., Jia, F., Doherty, B., 2021. The role of NGOs in sustainable supply chain management: a social movement perspective. Supply Chain Manag.: Int. J. 27, 383–408. https://doi.org/10.1108/SCM-05-2020-0191.
Pfohl, H.-C., Gomm, M., 2009. Supply chain finance: optimizing financial flows in supply chains. Logist. Res. 1, 149–161.
Phuong, N.A., Guidat, T., 2018. Sustainable value stream mapping and technologies of Industry 4.0 in manufacturing process reconfiguration: a case study in an apparel company. In: 2018 IEEE International Conference on Service Operations and Logistics, and Informatics (SOLI). Presented at the 2018 IEEE International Conference on Service Operations and Logistics, and Informatics (SOLI), pp. 85–90. https://doi.org/10.1109/SOLI.2018.8476750.
Porcari, J.D., Fazili, S., Reynolds, L., 2021. Improving and Tracking Supply Chains Link by Link [WWW Document]. The White House. https://www.whitehouse.gov/briefing-room/blog/2021/11/03/improving-and-tracking-supply-chains-link-by-link/. accessed 7.31.22.
Rother, M., Shook, J., 2003. Learning to See: Value Stream Mapping to Add Value and Eliminate Muda. Taylor & Francis, Germany.
Roy, R.N., 2011. Enhancing visibility through supply chain mapping: some cases from the hawke's bay region of New Zealand. In: 2011 International Conference on Management and Service Science. Presented at the 2011 International Conference on Management and Service Science, pp. 1–6. https://doi.org/10.1109/ICMSS.2011.5998257.
Serrano, I., Ochoa, C., Castro, R.D., 2008. Evaluation of value stream mapping in manufacturing system redesign. Int. J. Prod. Res. 46, 4409–4430. https://doi.org/10.1080/00207540601182302.
Serrano Lasa, I., Ochoa Laburu, C., de Castro Vila, R., 2008. An evaluation of the value stream mapping tool. Bus. Process Manag. J. 14, 39–52. https://doi.org/10.1108/14637150810849391.
Stevens, G.C., 1989. Integrating the supply chain. Int. J. Phys. Distrib. Mater. Manag. 19, 3–8. https://doi.org/10.1108/EUM0000000000329.
Suarez-Barraza, M.F., Miguel-Davila, J.-Á., Vasquez-García, C.F., 2016. Supply chain value stream mapping: a new tool of operation management. Int. J. Qual. Reliab. Manag. 33, 518–534. https://doi.org/10.1108/IJQRM-11-2014-0171.
Surana, A., Kumara *, S., Greaves, M., Raghavan, U.N., 2005. Supply-chain networks: a complex adaptive systems perspective. Int. J. Prod. Res. 43, 4235–4265. https://doi.org/10.1080/00207540500142274.
Tang, O., Musa, S.N., 2011. Identifying risk issues and research advancements in supply chain risk management. Int. J. Prod. Econ. 133, 25–34.
Taylor, D.H., 2005. Value chain analysis: an approach to supply chain improvement in agri-food chains. Int. J. Phys. Distrib. Logist. Manag. 35, 744–761. https://doi.org/10.1108/09600030510634599.
Thakur, M., Møen Tveit, G., Vevle, G., Yurt, T., 2020. A framework for traceability of hides for improved supply chain coordination. Comput. Electron. Agric. 174, 105478 https://doi.org/10.1016/j.compag.2020.105478.
The EU, 2020. EU Policy Action Plan on Critical Raw Materials. European Raw Materials Alliance (ERMA). https://erma.eu/eu-policy/. accessed 7.31.22.
The Economist, 2022a. Supply-chain Resilience Day | Global Trade Week. Global Trade Week | The Economist [WWW Document]. https://events.economist.com/global-trade-week/in-person-experience/. accessed 7.31.22.
The Economist, 2022b. Why the Structure of the World's Supply Chains Is Changing. The Economist [WWW Document]. https://www.economist.com/supplychains-pod. accessed 7.31.22.
The Economist, 2022c. A Flotilla of Startups Wants to Streamline Global Supply Chains. The Economist [WWW Document]. https://www.economist.com/business/2022/05/07/a-flotilla-of-startups-wants-to-streamline-global-supply-chains. accessed 7.31.22.
Treiblmaier, H., Rejeb, A., Ahmed, W.A.H., 2022. Blockchain technologies in the digital supply chain. In: MacCarthy, B.L., Ivanov, D. (Eds.), The Digital Supply Chain. Elsevier, pp. 127–144.
Tufte, E., 1983. The Visual Display of Quantitative Information, second ed. Graphic Press, Cheshire, Connecticut USA.
UNECE, 2021. Recommendation No. 46: Enhancing Traceability and Transparency of Sustainable Value Chains in the Garment and Footwear Sector. United Nations Economic Commission for Europe. https://doi.org/10.1787/9789264290587-en.

van den Brink, S., Kleijn, R., Sprecher, B., Tukker, A., 2020. Identifying supply risks by mapping the cobalt supply chain. Resour. Conserv. Recycl. 156, 104743 https://doi.org/10.1016/j.resconrec.2020.104743.

Wang, Y., Li, J., Wu, D., Anupindi, R., 2021. When ignorance is not bliss: an empirical analysis of subtier supply network structure on firm risk. Manag. Sci. 67, 2029–2048.

WEF, 2022. WEF_Supply_Chain_Sustainability_Policies_2022.pdf [WWW Document]. https://www3.weforum.org/docs/WEF_Supply_Chain_Sustainability_Policies_2022.pdf. accessed 7.31.22.

Wichmann, P., Brintrup, A., Baker, S., Woodall, P., McFarlane, D., 2020. Extracting supply chain maps from news articles using deep neural networks. Int. J. Prod. Res. 58, 5320–5336. https://doi.org/10.1080/00207543.2020.1720925.

Yan, T., Choi, T.Y., Kim, Y., Yang, Y., 2015. A theory of the nexus supplier: a critical supplier from A network perspective. J. Supply Chain Manag. 51, 52–66. https://doi.org/10.1111/jscm.12070.

Zhang, F., Wu, X., Tang, C.S., Feng, T., Dai, Y., 2020. Evolution of operations management research: from managing flows to building capabilities. Prod. Oper. Manag. 29, 2219–2229. https://doi.org/10.1111/poms.13231.

Zhang, L., Wu, L., Huang, L., Zhang, Y., 2021. Wield the power of omni-channel retailing strategy: a capability and supply chain resilience perspective. J. Strat. Market. 1–25.

Zhang, G., MacCarthy, B.L., Ivanov, D., 2022. The cloud, platforms, and digital twins—enablers of the digital supply chain. In: The Digital Supply Chain. Elsevier, pp. 77–91.

Zhao, K., Zuo, Z., Blackhurst, J.V., 2019. Modelling supply chain adaptation for disruptions: an empirically grounded complex adaptive systems approach. J. Oper. Manag. 65, 190–212.

Bart. L. MacCarthy is Professor of Operations Management at Nottingham University Business School. His research interests include digitalization, cloud technologies, blockchain technology, and the use of platforms in operations and supply chain management. He is a Fellow of the Institute of Mathematics, the Institution of Engineering and Technology, and the Chartered Institute of Logistics and Transport. He is European Vice-President for the Decision Sciences Institute.

Wafaa A.H. Ahmed is Assistant Professor in Information Systems in the Department of Operations Management and Information Systems, Nottingham University Business School, United Kingdom. She has a PhD in Supply Chain Management, a Master's degree in Industrial Engineering and Operations Management and Bachelor's degree in Electrical and Electronics Engineering. Prior to her academic career she worked as a manufacturing project manager in the Food sector. Her research interests include Blockchain technology, Business Analytics, and Digital transformation.

Guven Demirel is a Senior Lecturer in Supply chain Management at Queen Mary University of London. He holds a PhD in Physics from the Technical University of Dresden, Germany (research conducted at the Max Planck Institute for the Physics of Complex Systems, Dresden, Germany). He conducts interdisciplinary research on complex networks, investigating the stability and resilience of supply networks, supplier management and development programs, sustainability of agri-food supply chains, and adaptive networks of contact processes.